Repealing the Preferential Treatment of Government Bonds in Liquidity Regulation - Implications for Bank Behaviour and Financial Stability

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Abstract

This paper analyses the impact of different treatments of government bonds in bank liquidity regulation on financial stability. Using a theoretical model, we show that a sudden increase in sovereign default risk (government bond shock) may lead to liquidity issues in the banking sector implying the insolvency of a significant number of banks. Liquidity requirements do not increase the government-bond-shock-absorbing capacity of the banking sector. In this sense they do not increase financial stability. The shock-absorbing capacity will increase if a central bank as a lender of last resort exists. However, then the introduction of liquidity requirements in general and the repealing of the preferential treatment of government bonds in liquidity regulation in particular actually reduce the government-bond-shock-absorbing capacity. The driving force is a regulation-induced change in bank investment behaviour.

JEL classification: G28, G21, G01.

Keywords:.

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1 Introduction

The financial crisis of 2007/2008 was characterised by severe liquidity issues in many markets and illustrated the importance of liquidity with respect to a proper functioning of the financial system. The European Central Bank (ECB) provided massive liquidity to banks aiming to avoid the breakdown of the financial sector and to ensure financial stability. As a response to the crisis, the Basel Committee on Banking Supervision (BCBS) published for the first time global minimum liquidity standards for banks within the Basel III regulation framework. The main elements of this new liquidity regulation are the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR). The objective of the LCR is "to promote short-term resilience of a bank's liquidity risk profile by ensuring that it has sufficient HQLA [High Quality Liquid Assets] to survive a significant stress scenario lasting for one month" (BCBS, 2013). Considering government bonds within the LCR framework, they receive a favorable treatment with respect to other asset classes in the sense that they are classified as highly-liquid irrespective of their (credit) risks.[1] Accordingly, no haircuts or limits are applied to government bonds and they do not have to be diversified within the HQLA-classes. However, the European sovereign debt crisis of 2009 onwards highlighted that the credit risk of some EU member states is significantly higher than zero. Therefore, sovereign bonds from these countries could not be easily and quickly converted into cash without any losses during periods of distress. Against his background, there is an ongoing debate about whether the abolishment of the favorable treatment of sovereign bonds in EU banking regulation can strengthen financial stability. This paper adds to this debate by investigating within a theoretical model whether the contagion channel from sovereigns to banks can be weakened through the abolishment of the preferential treatment of government bonds within the LCR framework.

In our model, there are three agents: depositors, banks and investors.[2] The banks' objective is to maximise their depositors' expected utility. The depositors have the usual Diamond-Dybvig preferences. In the banking sector, there is no aggregate liquidity risk,

[1] Besides the privileged treatment of government bonds in liquidity regulation, sovereign bonds are also given privileged treatment in EU banking regulation with respect to capital requirements and to large exposure regimes.

[2] Except for the bank regulation part, the model setup corresponds to the setup presented in Neyer and Sterzel (2017).

though banks do face idiosyncratic liquidity risks. Banks can invest in a risk-free short-term asset, which does not earn any return, and in two risky long-term assets (government bonds and loans) with an expected positive return. However, whereas loans are totally illiquid, government bonds are liquid as there exists an interbank market for this asset. Investing in government bonds thus allows banks to hedge their idiosyncratic liquidity risks.[3] Besides deposits, banks can raise equity capital from risk-neutral investors to finance their investments. Raising costly equity capital allows banks to transfer liquidity risks associated with highly profitable but totally illiquid loans from risk-averse depositors to risk-neutral investors, thus increasing their depositors' expected utility. Banks may be subject to liquidity regulation requiring them to hold more liquid assets (the short-term asset and the government bond) than they would choose to hold.

Within this model framework we analyse in a first step the banks' investment and financing behaviour in different regulation scenarios. As a starting point, we determine their optimal behaviour when they are not subject to liquidity regulation. Then, we consider two possible scenarios with respect to the regulatory treatment of government bonds. In the first scenario, there is a preferential treatment of government bonds. Government bonds and the short-term asset are classified as equally liquid although government bonds have to be sold on a market for government bonds to obtain liquidity. However, in response to the introduction of such a liquidity regulation, banks increase their liquid asset holdings at the expense of a disproportionately high decrease of their loan investment and a reduction in their equity capital. Accordingly, the liquidity regulation implies an inefficiently low use of the possibility to transfer liquidity risks associated with high profitable loan investment from risk-averse depositors to risk-neutral investors. In the second scenario, the preferential treatment of government bonds in liquidity regulation is repealed as they are classified as less liquid than the short-term asset. Our model reveals that then, the observed bank behaviour in the first scenario is reinforced. This regulation requires banks to hold even more liquid assets. In response to this regulation banks thus increase their holdings of short-term assets and their loan investment as well as their equity capital de-

[3] As pointed out by Gennaioli et al. (2014), for example, banks may hold government bonds for many different reasons. So government bonds do play an important role in managing a banks' daily activities. In our model banks hold government bonds to manage their liquidity.

crease further. Therefore, the beneficial liquidity risk-transfer from risk-averse depositors to risk-neutral investors is further restricted.

In a second step, we investigate the banks' shock-absorbing capacity in the absence of liquidity regulation and in the two different scenarios with respect to government bond treatment in liquidity regulation. The triggering event in our model is a shock in the form of an increase in the default probability of sovereign bonds (government bond shock). The increased doubts about sovereign solvency may lead to a sovereign bond price drop and hence to liquidity issues in the banking sector, implying illiquid but per se solvent banks going bankrupt. We show that liquidity requirements do not increase the government-bond-shock-absorbing capacity of the banking sector. In this sense they do not increase financial stability. The shock-absorbing capacity will increase if a central bank as a lender of last resort exists, providing additional liquidity against adequate collateral. However, then the introduction of liquidity requirements in general and the repealing of the preferential treatment of government bonds in liquidity regulation in particular actually reduce the government-bond-shock-absorbing capacity. The driving force is that regulation-induced changes in bank investment behaviour (more government bonds and less loans) implies banks facing higher government bond losses and having less collateral to obtain additional liquidity from the LOLR.

The rest of the paper is structured as follows. In Section 2 we provide an overview of the related literature. In Section 3 we explain the institutional background of liquidity requirements within EU banking regulation. Section 4 describes the model setup. Section 5 analyses both sides of the interbank market for government bonds and derives the market equilibrium. Section 6 explains the banks' optimal investment and financing behaviour when banks face liquidity regulation and government bonds are treated differently regarding their liquidity property. Building on these analyses, Section 7 discusses the consequences of liquidity requirements for the government-bond-shock-absorbing capacity of the banking sector and the importance of the central bank acting as a LOLR in this context. The final section summarises the paper.

2 Related Literature

Our paper contributes to three strands of literature. The first strand deals with financial contagion, the second with different institutions aiming to weaken financial contagion between sovereigns and banks and the third with liquidity requirements in general. As there is no single definition of financial contagion we will refer to financial contagion if financial linkages imply that a shock, which initially affects only one or a few firms (financial or non-financial), one region or one sector of an economy, spreads to other firms, regions or sectors. In a seminal paper, Allen and Gale (2000) show that banks balance their different liquidity needs via an interbank deposit market. Due to the interconnection, a small liquidity preference shock initially affecting only one bank may spread to other banks, leading to the breakdown of the whole banking sector. Since the sovereign debt crisis of 2009 onwards, there has been a growing literature on financial contagion between sovereigns and banks. For a survey of the main channels through which sovereign risk influences the banking sector, see BCBS (2017, chap. 2).

According to the literature on the sovereign-bank nexus, the second strand of related literature deals with different newly implemented or proposed institutions aiming to weaken the financial contagion channel between sovereigns and banks. The European banking union is the most well-known recent reform to weaken the close sovereign-bank nexus. Against this background, Covi and Eydam (2016) argue that the *new recovery and resolution framework* actually weakens this contagion channel as, due to a "bail-in" rule, bank insolvencies no longer strain public finances. Farhi and Tirole (2016) argue that a *shared supranational banking supervision* can diminish contagion effects between internationally operating banks and sovereigns as banks' adverse risk-shifting incentives are impeded. Acharya and Steffen (2017) stresses the need for a complemented Banking Union and a *Fiscal Union*, which are both necessary to build a functioning capital market union that ensures financial stability. Brunnermeier et al. (2016) develop a model which illustrates how to isolate banks from sovereign risk via the introduction of *European Safe Bonds* ("ESBies"). These bonds are issued by a European debt agency, backed by a well-diversified portfolio of euro-area government bonds and are additionally senior on repayments. Neyer and Sterzel (2017) show that the introduction of *capital requirements for* *government bonds* can weaken the sovereign-bank nexus in combination with the central bank acting as LOLR. In the same context, Matthes and Jörg (2017) also suggest to back sovereign bonds with equity capital. However, there should be an exception for sovereign bonds which are needed for central bank interventions to avoid abrupt regulatory changes.

In the recent years, there has been a rapidly growing literature which addresses liquidity requirements.[4] Within this strand of literature, the majority of empirical literature deals with liquidity requirements and their impact on bank behaviour, see for example: Baker et al. (2017), Banerjee and Mio (2017), Bonner (2014), DeYoung and Jang (2016), Duijm and Wierts (2014), Gobat et al. (2014), King (2013) and Scalia et al. (2013). Furthermore, there is research analysing the effects from liquidity regulation on monetary policy implementation, as from Bech and Keister (2017), Bonner and Eijffinger (2016), Schmitz (2011) or Bindseil and Lamoot (2011). Our paper contributes to literature dealing with liquidity regulation and its impact on financial stability. Diamond and Kashyap (2016) modify the Diamond and Dybvig (1983) model and show that liquidity regulation, in particular the LCR and the NSFR incentivise banks to increase their liquid asset holdings. Accordingly, quantitative liquidity regulation reduces the bank-run probability and increases financial stability. Farhi and Tirole (2012) examine that banks are engaged in excessive maturity transformation and stress the need for liquidity requirements or limiting the banks' short-term debt to strengthens financial stability. Calomiris et al. (2015) develop a theoretical model which analyses the effectiveness of a liquidity requirement that takes the form of a narrow cash reserve. They show that introducing cash requirements make financial crises less likely as banks' default risks are limited. The reason for this is that the cash reserves encourage good banks' risk management i.e. when banks hold more cash they gain market confidence and in times of distress they are able to retain deposits, reducing the probability of liquidity issues. In the model developed by Ratnovski (2013), it is shown initially that banks become insolvent if they are unable to refinance their short-term liabilities. He argues that a liquidity buffer can prevent bank insolvencies but only in the event of a small liquidity shock, as the size of the liquidity buffer is limited. However,

[4]For a broad overview on the role of liquidity in financial institutions see Allen and Gale (2014). They also explain the role of central banks in this context and discuss the liquidity requirements within the Basel III framework. Bouwman (2013)) gives an overview over the theoretical and empirical literature on bank liquidity creation and she explains the recent regulatory development of capital and liquidity reforms.

the ability to communicate solvency information to outsider (transparency) contributes that banks can also withstand a large liquidity shock, as the communication provides access to external refinancing. Lallour and Mio (2016) address several structural funding metrics and investigate whether the NSFR is an adequate regulatory tool to strengthen banks' resilience. They find that the recent financial crisis was mainly a funding crisis. As the NSFR requires banks to finance their investments with more stable funding sources, it contributes to make the financial system more resilient. However, they also empirically show that retail deposits provided a stable funding source during the recent financial crisis. Therefore, a deposit-to-asset ratio would have outperform the NSFR to prevent this crisis. Hong et al. (2014) examine the effectiveness of the LCR and the NSFR in reducing bank failures. They empirically show that idiosyncratic liquidity risk measures as the LCR and the NSFR have only a limited effect to prevent bank failures. However, the recent financial crisis highlighted that the systemic liquidity risk was the major issue. Therefore, the authors suggest that liquidity risk management should not take only individual liquidity risk into account, rather systemic liquidity risk. Perotti and Suarez (2011) theoretically analyse how liquidity should be regulated, via a simple pigovian tax or quantitative regulation. They assume that banks are heterogeneous in their risk-taking incentives and in their ability to extent credits. If banks are heterogeneous in their ability to extent credits, a pigovian tax on short-term liabilities is more efficient than quantitative regulation itself. The reason is that binding liquidity requirements as LCR or a NSFR induce negative systemic risk externalities, as banks with better credit opportunities are constrained and banks with a low credit ability are encouraged to increase lending. However, if banks varying in their risk-taking incentives, quantitative liquidity regulation is more effective, as banks' adverse risk-shifting incentives can be prevented. König et al. (2015) develop a theoretical model and also shows that bank liquidity regulation may endanger financial stability. Introducing liquidity requirements has two effects, a liquidity effect and a solvency effect. The liquidity effect arises as banks are forced to hold more liquid assets and thereby the probability of becoming illiquid decreases. However, as liquid assets have lower returns than illiquid assets, a liquidity buffer induces lower bank returns and therefore increases the banks' insolvency risk. Hence, liquidity regulation is only effective as long as the liquidity effect exceeds the solvency effect. Hartlage (2012) assesses that banks' maturity transformation processes yield benefits for the economy, but on the other side expose banks to liquidity risk. After describing the liquidity regulation in the US and the EU, he evaluates the LCR within a simple model of bank liquidity. The main result is that a binding LCR may undermine financial stability and rather increases systemic risk, as the LCR incentivises banks to engage in regulatory arbitrage[5] and leads to excessive lending. Ratnovski (2009) shows that banks hold insufficient liquidity if they assume that the central bank acts as a LOLR and provides liquidity in a systemic crisis. Against this background, quantitative liquidity regulation contributes to a resilient financial system as banks are forced to hold a liquidity buffer, however, this regulation is costly. In addition to quantitative liquidity regulation Ratnovski (2009) argues that a LOLR policy based on bank's capital information allows for a more efficient regulation i.e. lower regulatory costs, and can mitigate adverse banks' behaviour. Buschmann and Schmaltz (2016) pointed out that the LCR requires banks to hold sufficient liquid assets, inter alia sovereign bonds. However, the design of the LCR neglects sovereign credit risk. Regarding this, it is shown that unaddressed sovereign risk can lead to a system wide liquidity crisis as sovereign bonds a widely used in banks' funding operations. The authors propose a LCR framework which takes sovereign risk into account. Chiaramonte and Casu (2017) investigate whether the combination of liquidity and capital requirements, as defined in Basel III, reduces the probability of banks' default and hence financial distress. They empirically show that the NSFR reduces the default probability of all banks considered in their sample, whereas capital regulation only reduces the default probability of large banks. With respect to capital regulation, Cifuentes et al. (2005) illustrate that capital requirements should be supplemented by liquidity regulation in order to make the financial system more resilient. In particular, they examine that minimum capital requirements themselves in combination with mark-to-market accounting might induce a downward spiral in asset prices and endanger financial stability.

[5]Regulatory arbitrage in the sense that banks replace wholesale funding with retail deposits to fulfil the liquidity ratio. Hartlage (2012) argues that this might undermine financial stability, as retail deposits especially from large-volume-depositors which are not secured by the deposit insurance are a less stable funding source.

Our paper contributes to all three strands of literature: In our model, banks hold liquid government bonds to hedge the idiosyncratic liquidity risk. Hence, government bond holdings generate a potential contagion channel from sovereigns to banks (first strand). Regarding the institutions aiming to weaken financial contagion from sovereign to banks, we investigate the effects of repealing the preferential treatment of government bonds within the LCR-framework (second strand). As we analyse if this regulatory reform improves financial stability, our research also contributes to the literature which deals with liquidity requirements in general and their impact on financial stability (third strand). Within the last strand our paper links to the work from Buschmann and Schmaltz (2016) as they also address sovereign risk in the current Basel III liquidity regulation framework.

3 Institutional Background

Before the global financial crisis of 2007/2008, bank regulation relied mainly on capital regulation. However, the crisis underlined the importance of sufficient bank liquidity to the proper functioning of the financial system. In response to the financial crisis, the BCBS (2008) published *"Principles for Sound Liquidity Risk Management and Supervision"*. This proposal should help to promote better risk management and contains a detailed guidance on supervision and risk management of funding liquidity risk for banks. To complement these principles, the BCBS (2010) presented two minimum standards for funding liquidity within the Basel III framework: the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR)[6]. We address in this paper the LCR based on two reasons: (i) there is a clear preferential government bond treatment with respect to

[6]The NSFR is designed to supplement the LCR and shell improve the resilience of the banking sector over a one-year time horizon. In particular, the requirement incentivise banks to provide a sustainable maturity structure of their assets and liabilities. The BCBS published the final version of the NSFR-framework in 2014 (BCBS (2014)).It was initially proposed in 2010 and after a consultant period re-proposed in January 2014. The BCBS suggests the implementation of a binding NSFR by January 2018. The CRR already introduces a reporting obligation, however, a binding ratio for the NSFR has not been implemented in European law yet. Formally the liquidity requirement is defined as: $NSFR = \frac{\text{Available amount of stable funding}}{\text{Required amount of stable funding}} \geq 100\%$. The NSFR consists of two components: the available amount of stable funding in the numerator and the required amount of stable funding in the denominator. The available amount of stable funding is calculated by the total value of a bank's capital and liabilities expected to be reliable over the time horizon of one year. In particular, the equity and liability instruments are categorised in one of five categories regarding their expected availability within a one-year stress scenario and weighted with a corresponding available stable funding (ASF) factor. The amount of stable funding which is required is defined as the value of bank's assets and off balance sheet exposures categorised in one required stable funding (RSF) category weighted with a corresponding RSF factor. The positions are clustered regarding their liquidly risk profiles and their maturity.

other asset classes, (ii) the required liquidity ratio in our model equals the LCR as it also requires that the maximum potential short-term liquidity withdrawals have to be backed with sufficient liquid assets.

Following a consultant period from 2011 onwards, the BCBS published in January 2013 the final version of the LCR-framework. In July 2013, the European Commission transported the Basel LCR framework into European law by way of the forth Capital Requirement Directive (CRD IV) and the Capital Requirement Regulation (CRR). After an observation period, the LCR had been phased in gradually since October 2015 and reached 100% in January 2018.[7] The aim of the LCR is to promote the short-term resilience of banks' liquidity profiles by ensuring that they have sufficient unencumbered high-quality liquid assets (HQLA) to withstand a significant stress scenario lasting for at least one month. It is expressed as:

$$LCR = \frac{\text{Stock of HQLA}}{\text{Total net cash outflows over the next 30 calendar days}} \geq 100\%. \quad (1)$$

The LCR consists of two components: the stock of HQLA in the numerator and the total net cash outflows over the next 30 calendar days in the denominator. HQLA are assets with a hight potential to be easily and quickly converted into cash at little or no loss of value even in times of stress. There are three categories of HQLA: level 1 assets, level 2A assets and level 2B assets. Level 1 assets consists of coins and banknotes, central bank reserves and a range of sovereigns securities (see BCBS, 2013, paragraph 50). Level 2A assets also include some sovereign bonds, corporate debt securities and covered bonds (see BCBS, 2013, paragraph 52). The asset class 2B contains mortgage backed securities, corporate debt securities and common equity shares (see BCBS, 2013, paragraph 54). Whereas the there is no limit for level 1 assets, the quantity of level 2 assets is restricted. Level 2A assets can only comprise up to 40% of the stock of HQLA and the amount of 2B assets is limited up to 15%. In addition to the unlimited quantity of level 1 assets, these assets are also not subject to a haircut. However, a haircut of 15% is applied to level 2A assets and level 2B assets are subject to haircuts of 25%-50%. The denominator

[7] However, CRD IV requires that the implementation period was shorter than proposed by the BCBS.

represents the total net cash outflows over the next 30 calender days and is defined as the total expected cash outflows minus the minimum of total expected cash inflows and 75% of the total expected cash outflows.

Government bonds receive a preferential treatment with respect to other asset classes within the LCR framework. In principal, sovereign bonds are eligible to classified as level 1 assets and thereby are not subject to haircuts and quantification limits if they satisfy the following three conditions (see BCBS, 2013, paragraph 50): (i) sovereign bonds assign a 0% risk-weight under the Basel II Standardised Approach, (ii) sovereign debt issued in domestic currencies by the sovereigns in the countries in which the liquidity risk is being taken or the bank's home country, (iii) sovereign bonds holdings denominated in foreign currency up the amount banks need that foreign currency for operations in that country. Moreover the LCR framework reveals that the HQLA should be well diversified within each asset class. However, there is an exception for sovereign bonds of the bank's jurisdiction in which the bank operates, or of its home justification, inducing that these bonds do not need to be diversified (see BCBS, 2013, paragraph 44).

4 Model

The model framework, the modelling of the interbank market (Section 5) and the theoretical approach to measure the resilience of the banking sector in Section 7 are exactly the same as in Neyer and Sterzel (2017).

4.1 Technology

We consider three dates, $t = 0, 1, 2$ and a single all-purpose good that can be used for consumption or investment. At date 0, the all-purpose good can be invested in three types of assets: one short-term and two long-term assets. The short-term asset represents a simple storage technology.[8] The two long-term assets are government bonds and loans. Government bonds are not completely safe but yield a random return S. With probability $1-\beta$ the investment fails and one unit invested at date 0 produces only $l < 1$ units of this good at date 2. With probability β, the investment succeeds and produces $h > 1$ units

[8] Investing one unit at date 0 returns one unit at date 1

at date 2. The government bond is a liquid asset i.e. it can be traded at price p on an interbank market at date 1. The loan portfolio yields a random return K. If the loan investment succeeds, one unit invested at date 0 will generate a return of $H > h > 1$ units at date 2 with probability $\alpha < \beta$. If the investment fails, it produces only $L < l < 1$ units of the single good at date 2 with probability $(1 - \alpha)$. The main properties of the loan portfolio are that it is the asset with the highest expected return ($E(K) > E(S) > 1$), the highest risk ($Var(K) > Var(S)$), and that it is totally illiquid at date 1. At date 2 banks discover whether the long-term assets succeed or fail. The return on the different types of assets are summarised in Appendix A Table A1.

4.2 Agents and Preferences

In our model, there are three types of agents: a continuum of risk-averse consumers normalised to one, a large number of banks and a large number of risk-neutral investors. Each consumer is endowed with one unit of the single all-purpose good at date 0 and non at date 1 and 2.

Like in Diamond and Dybvig (1983) consumers can be categorised into two groups. One group values consumption only at date 1 (early consumers), the other group only at date 2 (late consumers). We assume both groups are the same size. The proportion of early consumers is $\gamma = 0.5$ and the proportion of late consumers is $(1-\gamma) = 0.5$. Denoting a consumer's consumption by c, his utility of consumption is described by

$$U(c) = ln(c). \tag{2}$$

However, at date 0 each consumer is unsure of their liquidity preference i.e. he does not know whether he is an early or late consumer. Therefore, he has an incentive to conclude a deposit contract with a bank. According to this contract, he will deposit his one unit of the all-purpose good with the bank at date 0 and can withdraw c_1^* units of the all-purpose good at date 1 or c_2^* units of this good at date 2. As we have a competitive banking sector, each bank invests in the short-term asset and the two long-term assets in a way that maximises its depositors' expected utility.

Banks are subject to idiosyncratic liquidity risk but there is no aggregate liquidity risk (the fraction of early consumers is $\gamma = 0.5$ for sure). Accordingly, they do not know their individual proportion of early consumers. A bank has a fraction γ_1 of early consumers with probability ω and a bank faces a fraction γ_2 ($\gamma_2 > \gamma_1$) of early consumers with probability $(1 - \omega)$, so that $\gamma = 0.5 = \omega\gamma_1 + (1 - \omega)\gamma_2$. As in Allen and Carletti (2006), we assume the extreme case in which $\gamma_1 = 0$ and $\gamma_2 = 1$, so that $\omega = 0.5$.[9] Because of this strong assumption, we have two types of banks; banks with only early consumers (*early banks*) and banks with only late consumers (*late banks*) and the probability of becoming an early or a late bank is 0.5 each. Banks can hedge their idiosyncratic liquidity risk by using an interbank market for government bonds.[10]

In addition to the deposits from consumers, banks have the opportunity to raise funds (equity capital) from risk-neutral investors. These investors are endowed with an unbounded amount of capital W_0 at date 0. The contract concluded between a bank and an investor defines the units of the all-purpose good (equity capital) which are provided at date 0 ($e_0^* \geq 0$) and the units which are repaid and consumed by the investor at date 1 and date 2 ($e_1^* \geq 0$ and $e_2^* \geq 0$). As in Allen and Carletti (2006) the utility function of a risk-neutral investor is given by

$$U(e_0, e_1, e_2) = \rho(W_0 - e_0) + e_1 + e_2, \tag{3}$$

where ρ presents the investor's opportunity costs of investing in the banking sector.

4.3 Optimisation Problem

At date 0, all banks are identical, so we can consider a representative bank when analysing the banks' optimal investment and financing behaviour at date 0. Deposits are exogenous and equal to one. The bank has to decide on units x to be invested in the short-term asset, on units y to be invested in government bonds, on units u to be invested in loans and on

[9]The reason for this strong assumption is to keep the optimisation problem as simple as possible. Without this assumption the expected utility function given by (4) would be: $E(U) = \omega\gamma_1 ln(c_1) + (1 - \omega)\gamma_2 ln(c_1) + \omega(1 - \gamma_1)[\alpha\beta ln(c_{2Hh}) + \alpha(1 - \beta)ln(c_{2Hl}) + (1 - \alpha)\beta ln(c_{2Lh}) + (1 - \alpha)(1 - \beta)ln(c_{2Ll})] + (1 - \omega)(1 - \gamma_2)[\alpha\beta ln(c_{2Hh}) + \alpha(1 - \beta)ln(c_{2Hl}) + (1 - \alpha)\beta ln(c_{2Lh}) + (1 - \alpha)(1 - \beta)ln(c_{2Ll})]$. Given $\gamma_1 = 0$ and $\gamma_2 = 1$ the first and the last term of the equation can be eliminated.

[10]For a detailed explanation see Section 5.

units e_0 to be raised from the risk-neutral investors. A bank's optimal behaviour requires the maximisation of the expected utility of its risk-averse depositors. Consequently, a bank's optimisation problem reads

$$\begin{aligned}\max E(U) = {} & 0.5ln(c_1) + 0.5[\alpha\beta ln(c_{2Hh}) + \alpha(1-\beta)ln(c_{2Hl}) \\ & + (1-\alpha)\beta ln(c_{2Lh}) + (1-\alpha)(1-\beta)ln(c_{2Ll})] \end{aligned} \tag{4}$$

$$\text{with} \quad c_1 = x + yp, \tag{5}$$

$$c_{2Hh} = uH + \left(\frac{x}{p} + y\right) h - e_{2Hh}, \tag{6}$$

$$c_{2Hl} = uH + \left(\frac{x}{p} + y\right) l - e_{2Hl}, \tag{7}$$

$$c_{2Lh} = uL + \left(\frac{x}{p} + y\right) h - e_{2Lh}, \tag{8}$$

$$c_{2Ll} = uL + \left(\frac{x}{p} + y\right) l - e_{2Ll}, \tag{9}$$

$$\begin{aligned}\text{s.t.} \quad \rho e_0 = {} & 0.5(\alpha e_{2H} + (1-\alpha)e_{2L}) + 0.5(\alpha\beta e_{2Hh} \\ & + \alpha(1-\beta)e_{2Hl} + (1-\alpha)\beta e_{2Lh} + (1-\alpha)(1-\beta)e_{2Ll}), \end{aligned} \tag{10}$$

$$LR^{min} = \frac{\kappa_x x + \kappa_y y}{1}, \tag{11}$$

$$e_0 + 1 = x + y + u, \tag{12}$$

$$x, y, u, e_0, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll} \geq 0. \tag{13}$$

Equation (4) describes the expected utility of the bank's depositors. With probability 0.5 the bank is an early bank and all of its depositors thus withdraw their deposits at date 1. In this case, the bank will use the proceeds of the short-term asset ($x \cdot 1$) and of selling all its government bonds on the interbank market ($y \cdot p$) to satisfy its depositors, as formally revealed by (5). With probability 0.5, the bank is a late bank, thus all of its depositors are late consumers and withdraw their deposits at date 2. The consumption level of a late consumer depends on the returns on the bank's investments in government bonds and loans. As the probabilities of the success of these investments, α and β, are independent, we can identify four possible states: both investments succeed (Hh), only the investment in the loan portfolio succeeds (Hl,), only the investment in the government bonds succeeds

(Lh), or both investments fail (Ll). Equations (6) to (9) represent the consumption levels of late depositors in these possible states. The first term on the right-hand side in each of these equations shows the proceeds from the investment in loans, the second from the investment in government bonds. Note that the quantity of government bonds a late bank holds at date 2 consists of the units y it invested itself in government bonds at date 0, and of those it has bought on the interbank market in exchange for its units of the short-term asset x at date 1. The last term depicts the amount a bank has to pay to the risk-neutral investors at date 2. Due to their risk-neutrality, they are indifferent between whether to consume at date 1 or at date 2. Consequently, optimal (risk-averse) consumer contracts require $e_1^* = 0$.

Equation (10) represents the investors' incentive-compatibility constraint. Investors are only willing to provide equity capital e_0 to the banking sector if at least their opportunity costs ρ are covered. With probability 0.5 the bank is an early bank. Then, it will use its total amount of x including those units obtained in exchange for its total amount of government bonds on the interbank market to satisfy all its depositors at date 1, while investors will receive the total proceeds from loans $e_{2H} = uH$ or $e_{2L} = uL$ at date 2. With probability 0.5, the bank is a late bank. Then, the bank will buy government bonds on the interbank market in exchange for its short-term assets at date 1. At date 2, it will repay its depositors and investors. The investors will receive a residual payment from the proceeds of the bank's total loan and government bond investment, i.e. those returns not being used to satisfy the bank's depositors. Constraint (11) captures the potentially required minimum liquidity ratio LR^{min} by the regulator. It is expressed as a ratio of banks liquid assets (short-term asset and government bonds) weighted with a corresponding liquidity factor (κ_x and κ_y) to the maximum possible deposit withdrawals at date 1, which are equal to one. If $\kappa_x = \kappa_y$, there will be a privileged treatment of government bonds as the LR^{min} omits sovereign risk. This privileged treatment will be repealed if $\kappa_y < \kappa_x$. Then, government bonds are accounted less liquid as the short asset. The budget constraint is represented in equation (12), and the last constraint (13) represents the non-negativity constraint.

5 Interbank Market for Government Bonds

Before solving the banks' optimisation problem in the next section, we will have a closer look at the interbank market for government bonds. Banks use government bonds to balance their idiosyncratic liquidity needs: At date 0 all banks invest in government bonds and at date 1 the early banks sell their government bonds to the late banks in exchange for the short-term asset. We assume that the late consumers' expected utility of an investment in risky government bonds is higher than that of an investment in the safe short-term asset i.e.

$$\beta ln(h) + (1 - \beta)ln(l) \geq ln(1) = 0. \tag{14}$$

This means that the expected return on government bonds is sufficiently higher than on the short-term asset to compensate the risk-averse depositors for the higher risk. If it were not for this assumption, an interbank market for government bonds would not exist as no bank would invest in government bonds.

At date 1, each bank has learnt whether it is an early bank or a late bank. However, late banks will only buy government bonds in exchange for their short-term asset if

$$\beta ln(h) + (1 - \beta)ln(l) - ln(p) \geq ln(1), \tag{15}$$

i.e. if the expected utility of their depositors is than at least as high as that from the alternative of storing the short-term asset until date 2. Consequently, there is a maximum price

$$p^{max} = h^{\beta} l^{(1-\beta)} \tag{16}$$

late banks are willing to pay for a government bond. If $p \leq p^{max}$, a late bank wants to sell the total amount of its short-term asset in exchange for government bonds as government bonds yield a (weakly) higher expected utility for their depositors. If $p > p^{max}$, a late bank does not want to sell any unit of its short-term assets in exchange for government bonds.

Note that at date 0, all banks are identical and solve the same optimisation problem. Accordingly, for all banks the optimal quantities invested in the short-term asset and the long-term assets are identical. We denote these optimal quantities by x^*, y^*, and u^*. Considering the number of depositors is normalised to one, the optimal quantities of each individual bank correspond to the respective aggregate quantities invested in each asset type. As half of the banks are late banks, aggregate demand for government bonds at date 1 is

$$y^D = \begin{cases} 0.5\frac{x^*}{p} & \text{if} \quad p \leq p^{max}, \\ 0 & \text{if} \quad p > p^{max}. \end{cases} \tag{17}$$

Figure 1 illustrates this demand function. The jump discontinuity at p^{max} results from the fact that for $p \leq p^{max}$ late banks want to sell their total amount of the short-term asset $0.5x^*$ in exchange for government bonds. The demand curve is downward sloping because the amount of liquidity in the banking sector which can be used for buying government bonds is limited to $0.5x^*$. Consequently, a higher price p implies that fewer government bonds can be bought. Independently of the price, early banks want to sell all their government bonds at date 1 as early consumers only value consumption at this time. Therefore, the aggregate supply of government bonds is perfectly price inelastic. The respective aggregate supply curve is given by

$$y^S = 0.5y^* \tag{18}$$

as illustrated graphically in Figure 1.

Considering (17) and (18) and denoting the equilibrium price for government bonds p^{**},[11] the market clearing condition becomes

$$\frac{x^*}{p^{**}} = y^*. \tag{19}$$

[11] To be able to distinguish between those quantities optimally invested in the different assets and those quantities exchanged in equilibrium on the interbank market, we index optimal variables with * and equilibrium variables with **.

As there is no aggregate liquidity uncertainty and as all banks solve the same optimisation problem at date 0, aggregate supply and demand and thus the equilibrium variables are known at date 0. In addition, the following considerations reveal that $p^{**} = 1$. If $p^{**} < 1$, the return on government bonds at date 1 would be negative and thus smaller than on the short-term asset. Consequently, at date 0 banks would invest only in the short-term asset and not in government bonds. However, if no bank buys government bonds at date 0, there will be no supply of government bonds and thus no interbank market for government bonds with a positive price at date 1.

If $p^{**} > 1$, a government bond would be worth more than the short-term asset at date 1. Therefore, no bank would invest in the short-term asset at date 0 but only in government bonds. However, if at date 0 no bank invests in the short-term asset but only in government bonds, there will be no demand for government bonds at date 1, and thus no interbank market for this asset with a positive price. Consequently, the only possible equilibrium price at date 1 is $p^{**} = 1$. Note that due to (14) and (16), $p^{max} \geq 1$, which implies that the interbank market is always cleared.

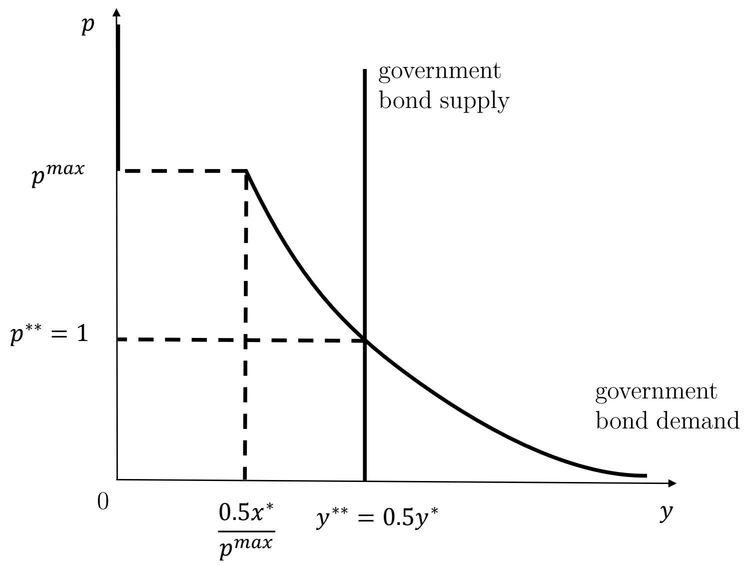

Figure 1: Interbank Market for Government Bonds at Date 1

6 Optimal Bank Investment and Financing Behaviour

This section analyses the impact of different treatments of government bonds in bank liquidity regulation on bank investment and financing behaviour. We start our analysis by determining how banks invest and finance these investments without any binding liquidity requirements. Then, we analyze how their behaviour will change if a binding required minimum liquidity ratio LR^{min} is introduced. The required liquidity ratio defines the necessary liquid assets a bank must hold (short-term asset and government bonds, each weighted with a liquidity factor κ_x and κ_y) in relation to the maximum possible deposit withdrawals at date 1 (see constraint (11)). First, we assume that the regulator classifies a short-term asset and a government bond as equally liquid, i.e. they are assigned the same liquidity factor in the required minimum liquidity ratio. Our analysis shows that compared to the case without any liquidity regulation bank investment in liquid assets increases at the expense of a decrease in their loan investment. However, the decrease in loans is disproportionately higher than the increase in liquid assets, i.e. the regulation also implies that banks raise less equity capital. Second, we assume the liquidity factor assigned to government bonds to be lower than to the short term asset, i.e. the regulator regards government bonds as less liquid than the short-term asset. It turns out that then the effects observed when a binding minimum liquidity ratio with equal liquidity factors is introduced are reinforced.

To demonstrate a bank's optimal investment and financing behaviour in the different scenarios, we make use of the same numerical example as in Neyer and Sterzel (2017) which is similar to the one used by Allen and Carletti (2006). The government bond returns $h = 1.3$ with probability $\beta = 0.98$ and $l = 0.3$ with probability $(1 - \beta) = 0.02$. Consequently, the investment in government bonds of one unit of the consumption good at date 0 yields the expected return $E(S) = 1.2746$ at date 2. Loans are also state-dependent and return at date 2. They return $H = 1.54$ with probability $\alpha = 0.93$, and they fail and yield $L = 0.25$ with probability $(1 - \alpha) = 0.07$. Hence, the expected loan return at date 2 is $E(K) = 1.4497$. Investors' opportunity costs are $\rho = 1.5$.

6.1 No Liquidity Requirements

If there is no binding required liquidity ratio ($LR^{min} = 0$), we will get the solutions given in Table 1 for optimal bank behaviour. With respect to these results, we will comment

Balance Sheet

A					L
x^*	0.4544	41.87%	e_0^*	0.0853	7.86%
y^*	0.4544	41.87%	D	1	92.14%
u^*	0.1765	16.26%			
$\sum$	1.0853	100%	$\sum$	1.0853	100%

Contracts with Investors:

early banks:	e_{2H}^*=0.2718	e_{2L}^*= 0.0441		
late banks:	e_{2Hh}^*=0	e_{2Hl}^*=0	e_{2Lh}^*=0	e_{2Ll}^*=0

Deposit Contracts:

c_1^*= 0.9088 c_{2Hh}^*=1.4532 c_{2Hl}^*= 0.5444 c_{2Lh}^*= 1.2256 c_{2Ll}^*=0.3168

$E(U)$=0.1230

Proof. See Proof II in Appendix B

Table 1: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors when there Is No Liquidity Regulation

on two aspects in more detail, first, the equal investment in the short-term asset and government bonds ($x^* = y^*$) and second, that banks raise equity capital ($e_0 > 0$) although it is costly.

Table 1 shows that banks equally divide their liquid-asset investment into the short-term asset and government bonds, $x^* = y^*$. With respect to this result two aspects are important. First, one half of the banks are early banks whereas the other half are late banks. Second, there is idiosyncratic but no aggregate liquidity uncertainty, so that at date 0 banks are certain of the aggregate supply and demand in the government bond market and therefore know the equilibrium price $p^{**} = 1$ (see Section 5 for details). Accordingly, all banks invest the identical amount in government bonds and in the short-term asset, to be able to hedge their idiosyncratic liquidity risks completely by trading government bonds on the interbank market at date 1 when consumption uncertainty is resolved. This allows us to set $x^* = y^* = 0.5z^*$ in our subsequent analyses. The variable z^* thus donates a bank's optimal investment in liquid assets (short-term asset and government bonds).

Furthermore, the results reveal that although equity capital is costly for banks in the sense that investors' opportunity costs, and thus the amount banks expect to repay to investors, exceed the expected return even of the banks' most profitable asset, in our case loans ($\rho > E(K)$), it is optimal for banks to raise equity capital. The reason is that equity capital allows the liquidity risk involved with an investment in relatively high profitable loans to be transferred at least partially from risk-averse depositors to risk-neutral investors, leading to an increase in depositors' expected utility: An investment in highly profitable loans leads to the highest expected consumption of a late consumer. However, as loans are totally illiquid, this investment involves a liquidity risk for a consumer. If it turns out that he is an early consumer, his consumption from this investment will be zero. If it were not for the possibility to raise equity capital, the consumers would bear the total liquidity risk themselves. An increase in loan investment leads to a decrease of investment in liquid assets and thus to a decline in date-1 consumption to the same amount, $\frac{\partial z}{\partial u}|_{no\ capital} = \frac{\partial c_1}{\partial u}|_{no\ capital} = -1$, If the bank invests 0.5 of its deposits in the short-term asset and the other 0.5 in government bonds, a depositor will consume $c_1 = 1$ if he becomes an early consumer and expects to consume $E(c_2) = E(S) = 1.2746$ if he becomes a late consumer. If the bank starts to invest in highly profitable but totally illiquid loans, $E(c_2)$ will increase, but due to the budget constraint the investment in liquid assets must be reduced, so that c_1 falls below one. An early consumer gets back less than he invested. The fall of c_1 below one reflects the liquidity risk involved with loan investment.

However, with the possibility of raising equity capital, an increase in loans leads to a lower necessary decrease in liquid assets, $\frac{\partial z}{\partial u}|_{with\ capital} > -1$. Consequently, an investment in loans, which increases expected date-2 consumption, only implies a relatively small decrease of consumption at date 1, so that there is an increase in depositors' expected utility. Crucial for this result is that a huge part of the additional loan investment is financed by raising equity capital from risk-neutral investors. Due to their risk-neutrality, they do not mind whether to get repaid at date 1 or 2, so that it is optimal that they bear the liquidity risk involved with the banks' loan investment. The risk-averse depositors' thus benefit from transferring their liquidity risk to the risk-neutral investors.

Optimal risk-sharing implies that if it turns out that a bank is an early bank, the investors of this bank will receive the total proceeds from the loan investment at date 2 ($e^*_{2H}, e^*_{2L} > 0$). If it turns out that a bank is a late bank, they will receive nothing ($e^*_{2Hh}, e^*_{2Hl}, e^*_{2Lh}, e^*_{2Ll} = 0$). Considering investors thus get repaid with the total proceeds from the bank loan investment but only with probability 0.5, and that their opportunity costs are higher than the expected return on loans ($\rho > E(K)$), the bank loan investment must exceed the amount of raised equity capital to be able to satisfy investors' claims. This means that it is not possible to finance an additional loan investment exclusively by raising more equity, i.e. an increase in loan investment is still associated with a decrease of investment in liquid assets ($-1 < \frac{\partial z}{\partial u}|_{with\ capital} < 0$). Formally, the investors' incentive-compatibility constraint given by (10) becomes $e^*_0\rho = 0.5u^*E(K)$, so that $\frac{2\rho}{E(K)} = \frac{u^*}{e^*_0}$. This means that the loan investment needs to be at least $\frac{2\rho}{E(K)}$ times higher than the amount of raised equity capital. In our numerical example loan investment thus needs to be 2.0692 times higher than the amount of raised equity.

6.2 With Liquidity Requirements: Preferential Treatment of Government Bonds

In this section, we analyse bank behaviour when banks face a required minimum liquidity ratio in which the short-term asset and government bonds are treated as equally liquid, i.e. in constraint (11) we have $\kappa_x = \kappa_y = 1$. Government bonds are preferentially treated in this liquidity ratio with respect to the short-term asset as government bonds have to be sold on an interbank market to obtain liquidity unlike the short asset. Hence, government bonds are exposed to a market liquidity risk that will be neglected in this regulation scenario. If banks do not face binding liquidity requirements (Section 6.1), they will choose an optimal liquidity ratio of $LR^{opt} = \frac{x^*+y^*}{1} = 0.9088$. In order to analyse the impact of a binding required liquidity ratio, $LR^{min} > LR^{opt}$ must hold, so that we set $LR^{min} = 0.92$. The results for optimal bank behaviour under this constraint are shown in Table 2. The comparison of the results for optimal bank behaviour given in Tables 1 and 2 reveals that

Balance Sheet

A					L
$x^* =$	0.46	42.8%	$e_0^* =$	0.0748	6.96%
$y^* =$	0.46	42.8%	$D =$	1	93.04%
$u^* =$	0.1548	14.4%			
$\sum$	1.0748	100%	$\sum$	1.0748	100%

Contracts with Investors:

early banks:	e_{2H}^*=0.2384	e_{2L}^*= 0.0387		
late banks:	e_{2Hh}^*=0	e_{2Hl}^*=0	e_{2Lh}^*=0	e_{2Ll}^*=0

Deposit Contracts:

c_1^*= 0.92 $\quad c_{2Hh}^*$=1.4344 $\quad c_{2Hl}^*$= 0.5144 $\quad c_{2Lh}^*$= 1.2347 $\quad c_{2Ll}^*$=0.3147

$E(U)$=0.1229

Proof. See Proof III in Appendix B

Table 2: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors when the Short-term Asset and Government Bonds Are Classified as Equally Liquid in Bank Liquidity Regulation

the binding liquidity requirement induces banks to increase their liquid asset investment at the expense of a decrease in their loan investment. However, the decrease in loans is disproportionately higher than the increase in liquid assets, i.e. the regulation also implies that banks raise less equity capital (z^* increases, e_0^* and u^* decrease). This regulation induced change in bank investment and financing behaviour can be explained as follows. The introduction of the binding minimum liquidity ratio requires banks to increase their liquid assets. One possibility to finance these increased investments could be to raise more equity capital. However, this strategy requires a disproportionately higher increase in loan investment to satisfy investors' claims (in our numerical example additional loan investment must be more than twice as high as additional equity capital, see Section 6.1). However, with regulation induced fixed holdings of liquid asset, the budget constraint prohibits such a strategy. Consequently, the higher liquid asset investment required by the regulator has to be carried out at the expense of a decrease in bank loan investment. However, this decrease implies that investors' claims can no longer be satisfied so that less equity capital is raised implying a further decrease in loan investment. Therefore, the budget constraint (12) in combination with the investors' incentive-compatibility constraint (10) are the driving forces behind the disproportionately high decrease in loan investment and the decrease in equity capital in response to the introduction of a binding liquidity ratio.[12] The decrease in equity capital and loan investment reveals that the introduction of a binding minimum liquidity ratio implies an inefficiently low use of the possibility to transfer liquidity risks involved with the investment in highly profitable loans from risk-averse depositors to risk-neutral investors which reduces the depositors' expected utility.

6.3 With Liquidity Requirements: Repealing the Preferential Treatment of Government Bonds

This section analyses bank optimal investment and financing behaviour when in bank liquidity regulation government bonds are classified as less liquid than the short-term asset. Formally, government bonds are then assigned a lower liquidity factor κ than the short-term asset in the required minimum liquidity ratio, We assume that $\kappa_x = 1$ and $\kappa_y = 0.95$ so that the required minimum liquidity ratio becomes $LR^{min} = (\kappa_x x + \kappa_y y)/1 = x + 0.95y = 0.92$. The resulting optimal bank behaviour in this regulation scenario is illustrated in Table 3.

Comparing the results given in Tables 2 and 3 shows that classifying government bonds as less liquid than the short-term asset in bank liquidity regulation has qualitatively the same impact on bank behaviour as the introduction of a binding minimum liquidity ratio which we described in the previous section: Banks increase their liquid asset investment at the expense of a decrease in their loan investment. However, the decrease in loans is disproportionately higher than the increase in liquid assets, i.e. the regulation also implies that banks raise less equity capital (z^* increases, e_0^* and u^* decrease). The reason is as follows. A binding minimum liquidity ratio implies that banks are required to hold more liquid assets than they would do if it were not for the regulation. If government bonds are classified as less liquid than the short-term asset, *banks must hold in total even more*

[12] Formally: From the budget constraint (12) we have that $dz + du = de_0$. The investors' incentive-compatibility constraint (10) requires $du = 2.0692de_0$ (see also Section 6.1). The introduction of the binding liquidity ratio implies $dz = 0.0112$. Solving the equations for du and de_0, we obtain $du = -0.0217$ and $de = -0.0105$.

Balance Sheet

A					L
$x^* =$	0.4718	44.81%	$e_0^* =$	0.0528	5.02%
$y^* =$	0.4718	44.81%	$D =$	1	94.98%
$u^* =$	0.1092	10.37%			
$\sum$	1.0528	100%	$\sum$	1.0528	100%

Contracts with Investors:

early banks:	e_{2H}^*=0.1682	e_{2L}^*= 0.0273		
late banks:	e_{2Hh}^*=0	e_{2Hl}^*=0	e_{2Lh}^*=0	e_{2Ll}^*=0

Deposit Contracts:

c_1^*= 0.9436 c_{2Hh}^*=1.3948 c_{2Hl}^*= 0.4512 c_{2Lh}^*= 1.2540 c_{2Ll}^*=0.3104

$E(U)$=0.1221

Proof. See Proof IV in Appendix B

Table 3: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors when Government Bonds Are Classified as Less Liquid than the Short-term Asset in Bank Liquidity Regulation

liquid assets to fulfill the requirement compared to the regulation scenario in which both assets are treated as equally liquid.[13]

As in the regulation scenario in which both assets are treated as equally liquid, banks can only hold more liquid assets at the expense of lower loan investment and a reduction in equity capital because of the budget constraint (12) in combination with the investors' incentive-compatibility constraint (10). The impact of the introduction of a binding minimum liquidity ratio in which the short-term asset and government bonds are classified as equally liquid on bank behaviour described in the previous section will thus be reinforced if government bonds are classified as less liquid. Consequently, the beneficial liquidity risk transfer will be further restricted leading to a further reduction in the depositors' expected utility.

[13]Note that the different treatment of government bonds and the short-term asset in bank liquidity regulation has no influence on the optimal relative composition of banks' liquid assets. To be able to completely hedge their idiosyncratic liquidity risks, banks still equally divide their liquid-asset investment into the short-term asset and government bonds, i. e. x^* still equals y^* (see Section 6.1 for details).

7 Financial Stability

The aim of this paper is to analyse the resilience of the banking sector in case of a sovereign debt crisis when banks face liquidity regulation and government bonds are classified differently regarding their liquidity-property. We consider two liquidity ratios that differs in their valuation of (risky) government bonds. In the first required minimum liquidity ratio government bonds are assigned as liquid as the short-term asset, whereas in the second required minimum liquidity ratio a liquidity haircut are applied to government bonds. At the beginning, this section shows that increasing doubts about sovereign solvency may lead to liquidity issues in the banking sector driven by a respective price drop for sovereign bonds. Liquidity requirements can not prevent illiquid but solvent banks from going bankrupt caused by a sovereign bond price drop. However, a central bank acting as a LOLR can avoid bank insolvencies due to liquidity issues. Against this background, introducing liquidity requirements, and in particular repealing the preferential treatment of government bonds within the liquidity ratio, weakens the resilience of the banking sector in the case of a sovereign debt crisis.

7.1 Government Bond Shock

After the banks have made their financing and investment decisions at date 0, but before the start of interbank trading at date 1, the economy is hit by a shock in the form of an increase in the default probability of government bonds (we refer to this shock as a government bond shock). This implies a respective decrease of the expected return on government bonds. Denoting after-shock variables with a bar, we thus have $(1-\overline{\beta}) > (1-\beta)$ and $E(S) > \overline{E(S)}$. As the liquidity shock in Allen and Gale (2000), this government bond shock is assigned a zero probability at date 0, when investment decisions are made. The expected return on the loan portfolio and the return on the short-term asset are not affected by the shock.[14]

[14]To keep the model as simple as possible, we assume that the expected loan return is not affected by the government bond shock. However, there is empirical evidence that there are spillovers going from sovereigns to other sectors of an economy (see e.g. Corsetti et al. (2013)) as sovereigns' ratings normally apply as a "sovereign floor" for the ratings assigned to private borrowers. Nevertheless, if we take this correlation into account our results will not qualitatively change. See footnote 21 for details.

The shock influences the late banks' demand for sovereign bonds in the interbank market at date 1. The decline in the expected return on government bonds implies that the maximum price late banks are willing to pay for a bond decreases (equations (16) and (17)). The early banks' supply of government bonds is not affected by the shock. As their depositors only value consumption at date 1, they want to sell their total holdings of government bonds at the same time, independent of their default probability (see equation (18)).

To be able to satisfy their depositors according to the deposit contract, the price an early bank receives for a government bond must be at least one, i.e. we have a critical price

$$p^{crit} = 1. \tag{20}$$

Setting in equation (16) p^{max} equal to p^{crit} and then solving the equation for $(1-\beta)$ gives us the critical default probability

$$(1-\beta)^{crit} = \frac{ln(h) - ln(p^{crit})}{ln(h) - ln(l)} = \frac{ln(h)}{ln(h) - ln(l)}. \tag{21}$$

If the after-shock default probability of government bonds exceeds this critical probability, the expected return on government bonds will become so low that the maximum price late banks are willing to pay for a bond will fall below one, early banks will be illiquid and insolvent. Therefore, the threshold $(1-\beta)^{crit}$ allows us to distinguish between a small and a large government shock.

A small government shock implies that $(1-\overline{\beta^{small}}) \leq (1-\beta)^{crit}$. In particular, the increased sovereign default probability induces that the maximum price late banks are willing to pay for sovereign bonds decreases, $\overline{p^{max\ small}} < p^{max}$. However, the equilibrium price and the equilibrium transaction volume after a small shock do not change, $\overline{p^{**small}} = p^{**} = 1$, $\overline{y^{**small}} = y^{**} = 0.5y^{*}$.[15] As a result, a small government bond shock does not to liquidity issues in the banking sector.[16]

[15]Figure 4 in Appendix A illustrates the interbank market for a small government bond shock.

[16]For a broad discussion who actually bears the shock, in the case of small and a large government bond shock see Neyer and Sterzel (2017).

A large shock means that $(1 - \overline{\beta^{large}}) > (1-\beta)^{crit}$. The increase in the government bonds' default probability is so high that their expected return becomes low enough that the maximum price late banks are willing to pay for a bond falls below one, so that considering equation (16), the after-shock equilibrium price becomes

$$\overline{p^{**large}} = \overline{p^{max\ large}} < 1. \tag{22}$$

At the equilibrium price $\overline{p^{**large}}$, there is an excess demand for government bonds[17] but the equilibrium trading volume has not changed, $\overline{y^{**large}} = y^{**} = 0.5y^*$. Figure 2 illustrates the interbank market for a large government bond shock. The decrease of the equilibrium

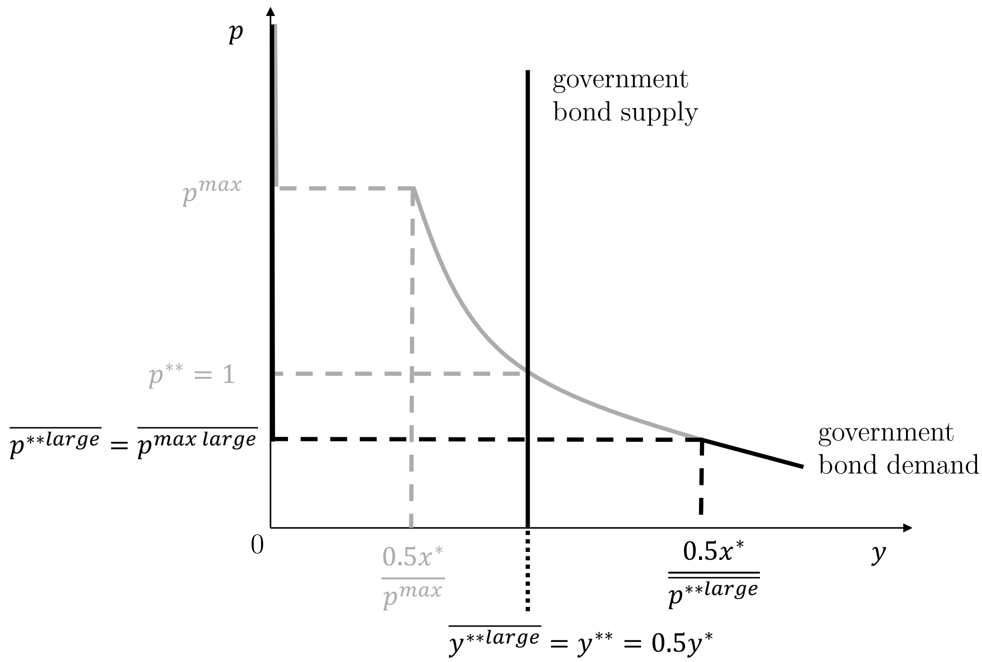

Figure 2: Interbank Market for Government Bonds at Date 1; $(1 - \overline{\beta^{large}}) > (1-\beta)^{crit}$

price below 1 means that early banks are no longer able to fulfil their deposit contracts:

$$\overline{c_1^{large}} = x^* + y^*\overline{p^{**large}} < x^* + y^*p^{**} = x^* + y^* = c_1^*. \tag{23}$$

Early banks are thus insolvent and are liquidated at date 1.

[17]The reason is that late banks want to sell their total holdings of the short-term asset ($0.5x^*$) in exchange for government bonds. However, the supply of government bonds is limited to the early banks' total holdings of this asset ($0.5y^*$), so that at prices below 1, there is an excess demand.

7.2 Central Bank as a Lender of Last Resort

As banks hold government bonds in order to hedge their idiosyncratic liquidity risks, a government bond price drop leads to liquidity issues for banks and thus to insolvencies. To avoid bankruptcies due to liquidity issues we introduce a central bank as a lender of last resort (LOLR) in the sense of Bagehot (1873).[18] The central bank provides liquidity to troubled banks against adequate collateral. In our model, banks' loan portfolios serve as collateral. In order to avoid any potential losses for the central bank, the maximum amount of liquidity ψ the central bank is willing to provide to an early bank against its loan portfolio as collateral is[19]

$$\psi = u^* L. \tag{24}$$

An early bank's additional liquidity needs after a large government bond shock τ are determined by the repayment agreed upon in the deposit contract c_1^* and the lower after-shock repayment $\overline{c_1^{large}}$ (without a LOLR):

$$\tau = c_1^* - \overline{c_1^{large}} = y^*(p^{**} - \overline{p^{**large}}) = y^*(1 - \overline{p^{**large}}). \tag{25}$$

Equation (25) reveals that the bank's additional liquidity needs increase in its holdings of government bonds y^* and in the extent of the shock which is reflected by the decrease of the government bond price $(p^{**} - \overline{p^{**large}})$. The promised repayment to early consumers c_1^* increases in a bank's holdings of government bonds $(c_1^* = x^* + y^* p^{**} = x^* + y^*)$. The shock-induced price drop for government bonds below one therefore implies the additional liquidity needs the larger the higher the bank's holdings of government bonds y^* are.

[18] Bagehot (1873): In a liquidity crisis, a central bank should lend freely, at a high rate of interest relative to the pre-crisis period, to any borrower with good collateral.

[19] Considering that potential interest payments for the additional central bank liquidity should also be covered by collateral, does not qualitatively change our results. In that case, the maximum amount of liquidity ψ the central bank is willing to provide against the loan portfolio as collateral decreases. This decrease implies that the shock-absorbing capacity of the banking sector in the presence of a LOLR (SAC^{LOLR}) becomes smaller in both regulation scenarios i.e. with and without a preferential regulatory treatment of government bonds. However, as the loan-to-liquid assets ratio $\frac{u^*}{z^*}$ is higher without a preferential treatment of sovereign debt in bank capital regulation, the SAC^{LOLR} will be higher in this case (see equation (29)).

The comparison of a bank's additional liquidity needs τ with the maximum amount of liquidity the central bank is willing to provide ψ gives us the critical government bond price

$$p^{critLOLR} = 1 - \frac{u^* L}{y^*} < 1. \tag{26}$$

Inserting $p^{critLOLR}$ for $\overline{p^{**large}}$ in equation (22) and then solving the equation for $(1 - \overline{\beta^{large}})$, gives us the critical default probability

$$(1-\beta)^{critLOLR} = \frac{ln(h) - ln(p^{critLOLR})}{ln(h) - ln(l)} = \frac{ln(h) + ln(\frac{u^* L}{y^*})}{ln(h) - ln(l)} = \frac{ln(h) + ln(\frac{u^*}{z^*} 2L)}{ln(h) - ln(l)}. \tag{27}$$

If the government bond shock is so large that $(1-\overline{\beta^{large}}) > (1-\beta)^{critLOLR}$, the equilibrium price $\overline{p^{**large}}$ will fall below $p^{critLOLR}$, and early banks will become insolvent, despite the existence of a LOLR. The reason is that the central bank is only willing to provide liquidity to illiquid but not to insolvent banks.[20] The liquidity issue leads to a solvency issue as the price drop, and thus the resulting early banks' liquidity problem, will be so huge that they will not have sufficient collateral to obtain enough liquidity from the LOLR.

Comparing the critical default probability with and without a central bank as a LOLR (see equations (21) and (27)) reveals the obvious result that with a LOLR the critical default probability is higher. However, the comparison also shows that with a LOLR the critical default probability not only depends on the possible government bond returns h and l, as is the case without a LOLR, but, in addition, on the loan portfolio return L and the bank's investment in government bonds y^* and loans u^*. An increase in y^* leads to a decrease of the critical default probability as then an early bank needs more additional liquidity after a government bond shock (see equation (25)). The critical default probability increases in u^* and L, as then an early bank's collateral increases in quantity and value, so that in case of a shock it can obtain more additional liquidity from the central

[20]Even if one assumes that the central bank cannot distinguish between illiquid and insolvent banks, the main results do not change. Providing liquidity to insolvent banks does not prevent their insolvency as the maximum liquidity the central bank is willing to provide will not be sufficient to cover the additional liquidity needs of insolvent early banks ($\tau > \psi$).

bank (see equation (24)).[21] This has important implications for the banking sector's shock-absorbing capacity under the different liquidity regulation approaches as we will see in Section 7.3.

7.3 The Shock Absorbing Capacity of the Banking Sector in Different Liquidity Regulation Scenarios

The above analysis allows us to discuss the (government bond) shock-absorbing capacity of the banking sector, and in this sense its stability,[22] when banks face liquidity requirements and government bonds are classified differently in their liquidity property. The difference between the critical and the initial default probability of government bonds serves as a measure of the banking sector's shock-absorbing capacity. The measure thus shows how large a government bond shock can be without implying the insolvency of early banks and thus of a huge part of the banking sector. Considering equations (21) and (27) and denoting the shock-absorbing capacity by SAC and SAC^{LOLR} respectively, we get

$$SAC = (1-\beta)^{crit} - (1-\beta) = \frac{ln(h)}{ln(h) - ln(l)} - (1-\beta) \tag{28}$$

for the banking sector's shock absorbing capacity without a LOLR and

$$SAC^{LOLR} = (1-\beta)^{critLOLR} - (1-\beta) = \frac{ln(h) + ln(\frac{u^*}{z^*}2L))}{ln(h) - ln(l)} - (1-\beta) \tag{29}$$

for the banking sector's shock absorbing capacity with a LOLR.

Equation (28) reveals that without a LOLR, the shock-absorbing capacity is not at all influenced by liquidity requirements. The reason is that without a LOLR early banks will become insolvent if the equilibrium price for government bonds, falls below one (large

[21] We argued at the beginning of this section that considering a possible spillover of the government bond shock to loans would not lead to a qualitative change of our results. In case the probability of loan success is negatively affected by the government bond shock, i.e. if $\alpha > \overline{\alpha}$, the expected consumers' consumption at date 2 will decrease. However, there are no liquidity issues for late banks as the contractually agreed repayments to the consumers are not influenced. The crucial point is that the potential increase in α neither induces a change in the liquidity provision by the central bank (ψ) nor does it lead to an additional liquidity demand (τ). As these variables determine the shock-absorbing capacity with a LOLR (see Section 7.3), spillover effects from sovereign to loans have no impact on our results.

[22] The ECB defines financial stability as a condition in which the financial system – intermediaries, markets and market infrastructures – can withstand shocks without major distribution in financial intermediation and the general supply of financial services.

government bond shock). Then, early banks will no longer be able to satisfy their customers according to the deposit contract. However, the government bond price drop is only determined by the expected return on a government bond (see equation (16)) which will not change if liquidity requirements are introduced. Hence, if there is no LOLR, the shock-induced liquidity problem cannot be solved by any kind of liquidity requirements, the difference $(1-\beta)^{crit} - (1-\beta) = SAC$ is always the same. This result is illustrated in Figure 3 by the solid line.

However, as shown by (29), with a LOLR liquidity requirements influence the banking sector's shock-absorbing capacity. The reason is that binding liquidity requirements influence bank investment behaviour. They imply an increase in government bond investments y^* and a decrease in loan investments u^*. The former implies an increase in the banks' additional liquidity needs τ after the shock (see equation (25)), and thus lowers the shock-absorbing capacity. The latter leads to a decrease in the additional liquidity ψ the central bank is willing to provide, and therefore also in the shock absorbing capacity. Overall, both effects induce a decrease in the SAC^{LOLR}. The main driver for this result is that the regulation-induced decrease in u^* implies that banks have less collateral to obtain additional liquidity from the central bank and the increase in y^* induces that banks face higher losses after a respective shock. As the decrease in $\frac{u^*}{z^*}$ will be higher if governments bonds are classified as less liquid within the LR ($\frac{u^*}{z^*}|_{LR^{min}|_{\kappa_x=1>\kappa_y}} < \frac{u^*}{z^*}|_{LR^{min}|_{\kappa_x=\kappa_y=1}} < \frac{u^*}{z^*}|_{LR^{min}=0}$), the (government bond) shock-absorbing capacity of the banking sector will be the lowest if there is a LOLR and if government bonds are classified as less liquid within liquidity regulation ($SAC^{LOLR}|_{LR^{min}|_{\kappa_x=1<\kappa_y}} < SAC^{LOLR}|_{LR^{min}|_{\kappa_x=\kappa_y=1}} < SAC^{LOLR}|_{LR^{min}=0}$). This result is illustrated in Figure 3 by the broken line.

8 Conclusion

Banks' sovereign exposures can act as a significant financial contagion channel between sovereigns and banks. The European sovereign debt crisis of 2009 onwards highlighted that some countries within the EU were having severe problems with repaying or refinancing their debt. The resulting price drops of sovereign bonds severely strained the banks'

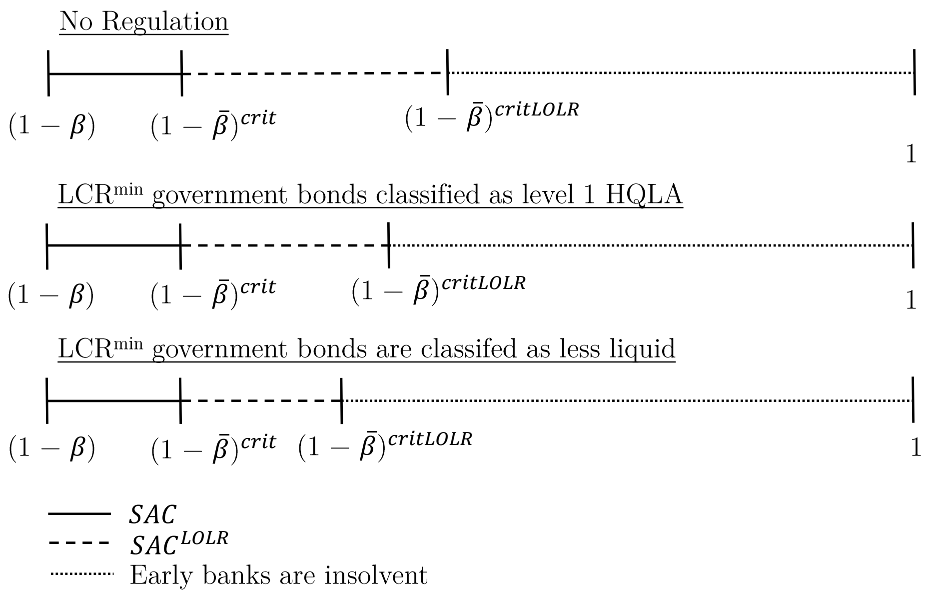

Figure 3: Government Bond Shock-Absorbing Capacity of the Banking Sector

balance sheets. Nevertheless, sovereign risk is not addressed in the LCR framework i.e. government bonds are classified as risk-free and therefore as highly-liquid, implying that there are no limits nor haircuts applied to this asset class. Hence, neglecting sovereign risk in liquidity regulation may endanger financial stability. Currently, there is an ongoing debate addressing the abolishment of the preferential treatment of sovereign borrowers in bank liquidity regulation. Our paper adds to this debate in two ways. First, by analysing the impact of different treatments of government bonds in bank liquidity regulation on bank investment and financing behaviour. Second, by investigating to which extent liquidity requirements, and in particular the different treatment of government bonds within liquidity regulation contribute to make the banking sector more resilient against sovereign debt crisis.

As pointed out, for example, by Gennaioli et al. (2014) an important reason for relatively large government bond holdings is that banks use them to manage their everyday business. Capturing this idea, in the model presented in this paper, banks hold government bonds and a short-liquid asset to balance their idiosyncratic liquidity needs by using an interbank market for government bonds. Increasing sovereign risk may induce a price drop for government bonds, implying liquidity issues in the banking sector leading to bank insolvencies as illiquid banks have no opportunity to obtain additional liquidity.

Government bond holdings thus create a financial contagion channel. Our model shows that liquidity requirements themselves, regardless of the government bond treatment, are not able to increase the banks' shock absorbing capacity in case of a sovereign debt crisis. The reason is that government bonds play an important role for banks dealing with the idiosyncratic liquidity risk and only a small government bond price decline implies liquidity issues for banks. This result is independent of the banks' investment structure. To overcome this liquidity issue, a central bank as LOLR is necessary. Then, banks can obtain additional liquidity from the LOLR against adequate collateral and may cover their government bond losses that increases the banks' shock-absorbing capacity with and without a required liquidity ratio. Crucial is that, if there is a LOLR, the banks' investment structure determines the banks' shock-absorbing capacity. As a required liquidity ratio, and in particular treating government bonds as less liquid, incentivise banks to hold more liquid assets (government bonds and the short-term asset) at the expense of a decrease in loan investment, banks face higher government bond losses and have less collateral to obtain additional liquidity from the central bank to cover their shock-induced losses i.e. the banks' shock-absorbing capacity decreases.

A Appendix A

	Return at date 1	Return at date 2		
Short-term asset	1			
Government bonds	p	h	β	$E(S) > 1$
		l	$(1-\beta)$	
Loan portfolio	0	H	α	$E(K) > E(S)$, $Var(K) > Var(S)$
		L	$(1-\alpha)$	

Table A1: Return on the Different Types of Assets (Investment at Date 0: 1 Unit)

B Appendix B

Appendix B is currently available only in hand written form.

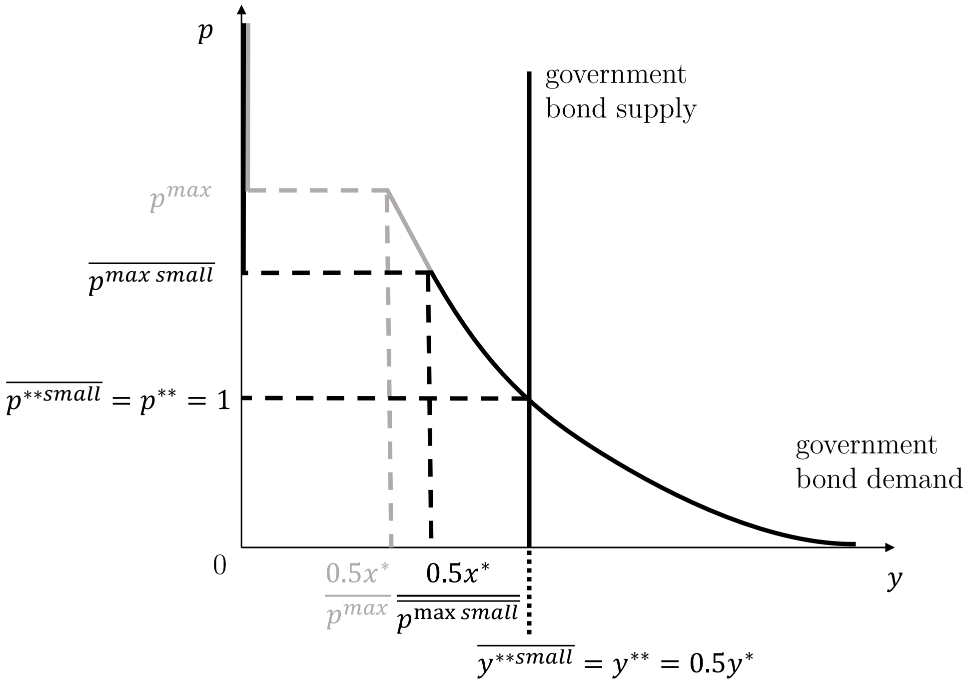

Figure 4: Interbank Market for Government Bonds at Date 1; $(1 - \overline{\beta^{small}}) \leq (1-\beta)^{crit}$

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