The Preferential Sovereign Bond Treatment in Bank Regulation

DISSERTATION

zur Erlangung des akademischen Grades
doctor rerum politicarum (Dr. rer. pol.)
im Fach Volkswirtschaftslehre

eingereicht an der Wirtschaftswissenschaftlichen Fakultät der
Heinrich-Heine-Universität Düsseldorf

HEINRICH HEINE
UNIVERSITÄT DÜSSELDORF

von:	André Sterzel, M. Sc. geboren am 13.01.1989 in Mechernich
Erstgutachter:	Prof. Dr. Ulrike Neyer
Zweitgutachter:	Prof. Dr. Christoph J. Börner
Abgabedatum:	17. Juni 2019

Acknowledgements

This thesis was written during my time as a research assistant at the chair of monetary economics at the Heinrich Heine University in Duesseldorf. It was a period of intense learning for me, not only in the scientific area but also on a personal level. Many different people accompanied me during this time and I am very grateful to everyone.

First, I would like to thank my supervisor Ulrike Neyer for her patience, her support and for the countless constructive discussions. During the writing process she gave me the opportunity to attend national and international summer schools, conferences and workshops, which I greatly appreciated. It was a pleasure working for Ulrike. Her door was always open and, aside from work, she was a great personal confidant. Furthermore, I want to thank Christoph Börner for agreeing to be my co-supervisor and for writing the survey.

The opportunity to start a thesis came during my time as a master's student at the Heinrich Heine University. I am indebted to Dagmar Neumann who guided me in the early days at the chair with respect to organisational tasks and always encouraged me to write this thesis. Dagmar also read several parts of the thesis and I am very grateful for her helpful comments. Furthermore, a hearty thank you goes to Monika Bucher. During the first few months working at the chair, we shared an office and Monika gave me valuable advice with respect to the process of writing a thesis from an academic as well as a personal perspective. Many thanks go to my colleagues Maximilian Horst, Daniel Stempel, Thomas Link and Jana Magin for the discussions about my research and the many helpful comments and suggestions. I would also like to express my gratitude to my colleagues at DICE for giving me the opportunity to present my work in their research seminars; I really enjoyed our shared time during the winter schools. For proofreading all three papers I would like to thank Jennifer Rontanger. I would also like to acknowledge financial support from the Land Nordrhein-Westfalen and the Konrad-Henkel-Stiftung.

Finally, I would like to thank my family and friends. I spent many evenings in Duesseldorf with Anne Spies during the work on this thesis. Thank you very much for welcoming me week after week and for all the delicious dinners. A hearty thank you goes to Mats Hörmeyer for his patience and emotional support, especially during the last few months of the thesis. Last but certainly not least, I am grateful to my parents Petra and Detlef Sterzel for all their love and for always believing in me.

Contents

General Introduction

During the global financial crisis of 2008/2009 and the subsequent European sovereign debt crisis, significant contagion effects between sovereigns and banks could be observed. In some Member States of the European Union (EU) it was a serious banking crisis which forced governments to bail out troubled systemically important banks in order to avoid a collapse of the financial system. High bank bailouts thus strained public finances and, for example, in Ireland it caused a severe sovereign debt crisis (Frisell, 2016). In other EU countries serious doubts about the sovereign solvency put pressure on banks' balance sheets as domestic banks are one of the largest creditors of their national sovereigns. Risk transmission in this direction was shown in Greece where the sovereign debt crisis caused instability in the domestic banking sector (Navaretti et al., 2016, p. 9). The contagion effects from sovereigns to banks and vice versa can reinforce each other, also referred to as the "sovereign-bank nexus". This vicious circle became a threat to financial and macroeconomic stability in the EU.

In the aftermath of the crisis several reforms have been discussed in order to mitigate the sovereign-bank nexus. One of the most well-known reforms is the European Banking Union, consisting of three pillars: The Single Supervisory Mechanism (SSM), the Single Resolution Mechanism (SRM) and the European Deposit Insurance (EDIS). So far, two of the three pillars, namely the SSM and the SRM have been legally implemented in the EU. However, the European Banking Union covers only one side of the sovereign-bank doom loop, it hence aims to avoid risk transmission from banks to sovereigns. Against this background, other reforms have also been introduced which should work to reduce the probability of sovereign distress and thus the potential contagion of risks from sovereigns to banks. These reforms include, for example, the European fiscal pact with the aim to strengthen the budgetary discipline, or the European Stability Mechanism (ESM) which acts as a backstop lender for EMU countries facing financial difficulty (Frisell, 2016, p. 109 f.).

With respect to banking regulation, in the Basel Accords and in the EU legislative framework the risk of a potential sovereign default is still not considered. In particular, there are several areas in which sovereign bonds receive favourable treatment compared to other asset classes, most notably in three fields of bank regulation (Basel Committee on Banking Supervision, 2017): (i) for government bonds funded and denominated in the domestic currency a preferential risk weight is applied under the risk-based capital framework, (ii) sovereign exposures are exempted from the large exposure requirement, and (iii) government bonds are categorised as highly liquid assets within the liquidity regulation framework. To mitigate risk transmission from sovereigns to banks, some economists advocate in favour of abolishing the preferential sovereign bond treatment in bank regulation (see, for example, Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung (2018, p. 246 ff.)). Weidmann (2016), the President of the Deutsche Bundesbank, emphasises that:

> “There is one field of regulation, however, where too little has been done so far – the treatment of sovereign exposures in banks' balance sheets. A banking system can only truly be stable if the fate of banks does not hinge on the solvency of their national sovereigns. Thus, I have been advocating, for quite some time now, a phasing-out of the preferential treatment of sovereign borrowers over private debtors”.

Against this background, all three papers of this thesis deal with the preferential sovereign bond treatment in banking regulation. In the first paper, facts concerning the preferential sovereign bond treatment are outlined, whereas in the second and third paper the effects of repealing the sovereign carve-out in bank regulation are theoretically investigated. In what follows the content of the papers are briefly described.

The **first paper**, Reforming the Regulatory Treatment of Sovereign Exposure in Banking Regulation, adds to the existing literature in two ways. First, it gives an overview of facts which highlight the systemic risk associated with the existing preferential sovereign bond treatment in bank regulation. Second, it describes and discusses problems of three regulatory reforms dealing with the abolishment of the favourable sovereign bond treatment. The paper starts with a description of the sovereign bond regulatory treatment under the existing Basel Accords. The term “sovereign risk” is then defined and there is an assessment of whether the categorisation of sovereign bonds of the European Monetary Union (EMU) as being risk-free and highly liquid is justified. It is shown in the paper that sovereign bonds from the EMU are not per se risk-free. Hence, neglecting sovereign risk in bank regulation can be an issue for the stability of the banking sector (systemic risk). Since the start of the economic crisis in 2008, it could be observed that in particular in stressed euro area countries banks have significantly increased their sovereign holdings, and their home bias in sovereign bond holdings is the highest (with the exception of Ireland) compared to banks in non-stressed euro area countries. In order to explain this bank behaviour, it is analysed why banks hold sovereign bonds in normal times and which incentives banks might have to increase their domestic sovereign exposures when the risk of a sovereign default increases. Furthermore, the main contagion channels through which sovereign distress can affect the banking sector are summarised. Finally, the following three regulatory reforms addressing the recognised systemic risk associated with the regulatory treatment of sovereign exposures are discussed: (i) capital requirements for government bonds, (ii) large exposure limits for sovereign debt, and (iii) haircuts for sovereign bonds in liquidity regulation. The discussion focusses on the potential impacts of the reforms for the banking sector and financial stability. One of the main results is that all reforms would lead to large adjustments in banks' balance sheets, however, only two of the three reforms, namely capital requirements for government bonds and sovereign exposure limits, would be able to make banks more resilient to sovereign risk.

The **second paper**, Capital Requirements for Government Bonds – Implications for Bank Behaviour and Financial Stability (co-authored by Ulrike Neyer), analyses the effects of backing government bonds with equity capital for banks and financial stability within a theoretical model. The model is based on Allen and Carletti (2006). In the centre of the model is a banking sector that is raising deposits from risk-averse consumers (depositors). The aim of the banking sector is to maximise their depositors' expected utility. As the depositors have the usual Diamond-Dybvig preferences, banks face idiosyncratic liquidity risk. In order to maximise the depositors' utility, banks can invest in three types of assets: in two liquid assets, a short-term asset and a risky government bond, and in one illiquid but highly profitable asset: a loan portfolio. Investing in the short-term asset and in government bonds allows banks to deal with the idiosyncratic liquidity risk. Besides deposits, banks can also finance their investments with equity capital from risk-neutral investors. Raising costly equity capital allows banks to transfer the liquidity risk associated with an investment in highly profitable loans from the risk-averse depositors to the risk-neutral investors, which increases the depositors' expected utility. Within this model setup we then analyse how banks change their investment and financing behaviour under two different capital regulation scenarios. We introduce capital requirements in the form of a risk-weighted capital ratio, requiring banks to back risky assets with equity capital. In the first regulation scenario, government bonds receive preferential treatment in the sense that banks do not have to set aside equity for their sovereign holdings. In the second regulation scenario, the preferential sovereign bond treatment is repealed, so that banks also have to back sovereign exposure with some equity capital. Comparing the two regulation scenarios shows that if not only loans but government bonds also have to be backed with equity capital, i.e. if the preferential treatment of sovereign exposures is repealed, banks will increase their loan-to-liquid asset ratio and they will increase their amount of equity capital. In a second step, we then investigate the banking sector's shock-absorbing capacity and hence its stability when sovereign risk increases under the two capital regulation scenarios. It is shown that a sudden increase in sovereign default risk may lead to severe liquidity issues in the banking sector. The reason is that banks hold sovereign bonds to deal with the liquidity risk. An increase in sovereign risk can lead to a price drop for sovereign bonds, inducing liquidity issues for banks. Our model reveals that capital requirements for government bonds are not able to prevent liquidity issues in the banking sector and thus do not contribute to a more resilient banking sector in times of sovereign distress. However, in combination with a central bank acting as a lender of last resort (LOLR), this regulatory change can increase the shock-absorbing capacity of the banking sector. The central bank then provides liquidity to illiquid but per se solvent banks against adequate collateral – in our model loans. The regulation-induced change in bank investment behaviour, i.e. the increase in the loan-to-liquid asset ratio of banks, yields that banks have more adequate collateral to obtain additional liquidity from the central bank relative to the additional liquidity needs caused by the sovereign bond price drop. As a result, with a LOLR, capital requirements for government bonds make the banking sector more resilient to sovereign risk.

The **third paper**, Preferential Treatment of Government Bonds in Liquidity Regulation – Implications for Bank Behaviour and Financial Stability (co-authored by Ulrike Neyer), analyses the impact of different treatments of government bonds in bank liquidity regulation on bank behaviour and financial stability. In the same model setup as in the second paper, we explain in a first step how banks make their investment and financing decisions in two different liquidity regulation scenarios. The design of the liquidity ratio in our model captures the Liquidity Coverage Ratio (LCR) as it requires banks to back potential short-term liquidity withdrawals with a specific amount of liquid assets. In a first regulation scenario, there is a preferential sovereign bond treatment, meaning that sovereign bonds and the short-term asset are considered to be equally liquid although there exists a potential market liquidity risk for government bonds. In response to this required liquidity ratio, banks increase their amount of liquid assets (government bonds and the short-term asset) at the expense of loan investment and a reduction in equity capital. In a second regulation scenario, the preferential sovereign bond treatment in liquidity regulation is repealed, meaning that the potential market liquidity risk of sovereign exposures is taken into account by the regulator. Under this liquidity regulation framework sovereign bonds are considered to be less liquid than the short-term asset. In response to this changed required liquidity ratio, the observed bank behaviour as under the first regulation scenario is reinforced, i.e. banks increase their amount of liquid assets at the expense of loan investment and they reduce their amount of equity capital. The reason is that when sovereign bonds are assigned as being less liquid than the short-term asset, banks need even more liquid assets to fulfil the required liquidity ratio. However, the regulation has no effect on the banks' optimal composition of liquid assets, i.e. the ratio of the investment in the short-term asset relative to the investment in government bonds. Note that this optimal composition of liquid assets allows banks to fully hedge their idiosyncratic liquidity risk. Hence, in order to maintain the optimal ratio between the short-term asset and government bonds, banks have to increase their investments in both asset classes. In a second step, we then investigate the banking sector's shock-absorbing capacity under the two different liquidity regulation scenarios. As in the second paper, we show that a sudden increase in sovereign default risk may lead to liquidity issues in the banking sector, implying the insolvency of a significant number of banks. Liquidity requirements do not increase the resilience of the banking sector in the case of sovereign distress. To prevent banks from going bankrupt due to liquidity issues, a central bank acting as a LOLR is necessary. Then, introducing liquidity requirements in general and repealing the preferential treatment of government bonds in liquidity regulation in particular actually undermines financial stability. The reason is that the increase in government bond holdings increase the additional liquidity needs of banks after the shock and the decrease in loan investment leads to a decrease in the additional liquidity provision by the central bank. This regulation-induced change in bank investment behaviour makes banks more vulnerable to sovereign risk.

Bibliography

Allen, F. and E. Carletti (2006). Credit risk transfer and contagion. *Journal of Monetary Economics 53*(1), 89–111.

Basel Committee on Banking Supervision (2017). The regulatory treatment of sovereign exposures. Discussion Paper, Bank for International Settlements.

Frisell, L. (2016). Europe's regulatory treatment of banks' sovereign exposures – How a flawed framework was put to use in the Irish financial crisis. *European Economy* (1), 105–117.

Navaretti, G. B., G. Calzolari, and A. F. Pozzolo (2016). Diabolic loop or incomplete union? Sovereign and banking risk. *European Economy* (1), 9–28.

Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung (2018). Banken- und Kapitalmarktunion entschiedener vorantreiben. Jahresgutachten 2018/19.

Weidmann, J. (2016). Dinner speech at the 6th Frankfurt Finance Summit, Frankfurt Main, May 11th. Available at `https://www.bundesbank.de/en/press/speeches/dinner-speech-667106`. Accessed: 2018-09-03.

Paper I:

Reforming the Regulatory Treatment of Sovereign Exposures in Banking Regulation*

André Sterzel

Abstract

The European sovereign debt crisis has shown the tight linkage between sovereign and bank balance sheets. In the aftermath of the crisis, several reforms have been discussed in order to mitigate the sovereign-bank nexus. These reforms include the abolishment of preferential government bond treatment in banking regulation. This paper gives a detailed overview of facts which are closely related to the existing preferential sovereign bond treatment in bank regulation and highlights the need for reforms especially in the euro area. Against this background, the following three regulatory reforms are described and discussed: (i) positive risk weights for government bonds in bank capital regulation, (ii) sovereign exposure limits, and (iii) haircuts for government bonds in bank liquidity regulation. The discussion focusses on the effects of these reforms for bank behaviour and financial stability.

JEL classification: H63, H12, G11, G18.

Keywords: Sovereign bonds, preferential treatment, bank regulation, sovereign risk, financial contagion, regulatory reforms.

*I would like to thank Ulrike Neyer, Maximilian Horst and Jennifer Rontanger for many helpful comments and suggestions.

Contents

List of Tables

List of Figures

1 Introduction

The European sovereign debt crisis has demonstrated the tight linkage between sovereign and bank balance sheets. In response to the crisis, several reforms have been discussed in order to break the sovereign-bank nexus. One of the most well-known recent reforms is the European Banking Union which is based on three pillars: the Single Supervisory Mechanism (SSM), the Single Resolution Mechanism (SRM) and the European Deposit Insurance Scheme (EDIS). Two of the three pillars, namely the SSM and the SRM, have already been implemented in the European Union (EU). However, the Banking Union only covers one side of the sovereign-bank loop, preventing the transfer of risks from the banking sector to the sovereign. Owing to a mitigation of contagion effects also from sovereigns to banks, some economists advocate in favour of repealing the preferential treatment of government bonds in banking regulation, see for example Weidmann (2016), ESRB (2015, p. 111). This paper adds to this policy discussion in two ways. First, it gives a broad overview of facts which underline the potential systemic risk related to the current preferential treatment of government bonds in bank regulation. Second, it describes and discusses three regulatory reforms dealing with the abolishment of the preferential government bond treatment in banking regulation.

As a starting point, the paper presents the regulatory treatment of sovereign exposure under the Basel Accords. Most notably, sovereign bonds receive a zero risk weight in capital regulation, they are exempted from the large exposure requirements, and they are classified as highly liquid in the liquidity regulation framework. Furthermore, the term "sovereign risk" is defined and an overview of potential forms of sovereign defaults is given. Against this background, the paper discusses whether the treatment of sovereign bonds in banking regulation as *risk-free* and *highly liquid* is justified. Based on (i) a depiction of yields from sovereign bonds in the European Monetary Union (EMU), (ii) a short description of the sovereign default in Greece, and (iii) an assessment of the possibilities for an overindebted EMU country to reduce its debt, it is concluded that sovereign debt from EMU countries is not per se default risk-free. Consequently, neglecting sovereign risk in banking regulation could be an issue for the stability of the banking sector. In order to assess the extent of this issue, stylised facts regarding the sovereign bond portfolios held by banks in the euro area are presented. It is shown that banks in stressed countries (Greece, Ireland, Italy, Portugal and Spain) have more than doubled their sovereign exposures from the year 2008 until the beginning of 2019. Furthermore, the banks' home bias in sovereign bond holdings in stressed countries (except Ireland) is significantly higher in 2019 than that of banks in non-stressed countries. In order to emphasise the crucial role sovereign bonds play for banks, the paper outlines reasons for banks holding sovereign debt in normal times, and incentives banks may have to increase their (domestic) government holdings in times of sovereign distress. Furthermore, the paper briefly describes the main channels through which sovereign risk can affect the banking sector. Finally, three regulatory reforms addressing a potential regulatory gap are discussed: applying positive risk weights for sovereign bonds in bank capital regulation, considering sovereign exposures under the large exposure requirement, and applying haircuts for sovereign bonds in bank liquidity regulation. The discussion focusses on the potential implications of the regulatory reforms for bank behaviour and financial stability. Concerning the banks' reaction in response to the reforms, the discussion concludes that all reforms would lead to large adjustments in banks' balance sheets which would reduce banks' profitability. With respect to financial stability, the discussion shows that two of the three reforms, positive risk weights for government bonds and sovereign exposure limits, would make banks more resilient to sovereign risk. However, haircuts for sovereign bonds in the liquidity regulation could make banks more vulnerable to sovereign risk.

The rest of the paper is structured as follows. Section 2 presents the regulatory treatment of sovereign exposure under the Basel Accords. Section 3 defines the term "sovereign risk" and explains forms of sovereign defaults. In this context it is investigated whether sovereign debt from EMU countries is risk-free. Moreover, the section presents stylised facts regarding the sovereign bond holdings of banks in the EMU and explains motives for banks holding sovereign bonds. Section 4 describes the main contagion channels between sovereigns and banks. Section 5 discusses reforms dealing with the abolishment of the preferential sovereign bond treatment. The final section concludes the paper.

2 Regulatory Treatment of Sovereign Exposures under the Basel Accords

This section captures the existing regulatory treatment of sovereign exposures under the existing Basel framework. The Basel Accords (Basel I, II and III) aim to strengthen the resilience of the banking sector worldwide. Note that the Basel Accords are not legally binding per se, however, the Basel recommendations form the starting point for the EU directives, which apply to all banks in the EU.

2.1 From Basel I to Basel III

The first Basel Accord was issued by the Basel Committee on Banking Supervision (BCBS) in 1988 with the goal of minimising bank credit risk (BCBS, 1988). The framework contains a risk-weighted capital ratio, so that banks were required to maintain a minimum of equity capital based on a percentage of risk-weighted assets. The second Basel Accord was issued in 2004 and replaced the first Basel Accord (BCBS, 2004). Basel II introduced the "three pillar" concept, which does not only incorporate requirements regarding bank capital. In fact, the "three pillar" concept contains: minimum capital requirements (Pillar 1), a supervisory review process (Pillar 2), and disclosure requirements to ensure market discipline (Pillar 3), see Figure 1. As the first version of Basel II focussed primarily on the banking book, the BCBS published in July 2005 a consensus document dealing with banks' trading book positions. A comprehensive version of the documents from 2004 and 2005 was released in 2006 (BCBS, 2006). In response to the global financial crisis of 2007/08, in 2010 the BCBS published the first version of the third Basel Accord (BCBS, 2010a,b). Basel III should strengthen the three pillars established in Basel II and extend it in several areas. These extensions include: stricter requirements for the quantity and quality of regulatory capital, capital buffers, a leverage ratio, and liquidity requirements. Since 2011 the BCBS has turned its attention to improvements in the calculation of capital requirements.[1] In the following, the paper focusses on the treatment of sovereign exposures under Pillar 1 (Minimum capital requirements), as well as under the leverage ratio, the large exposure framework, and the liquidity requirements.

[1] For an overview of reforms, see Bank for International Settlements (2018).

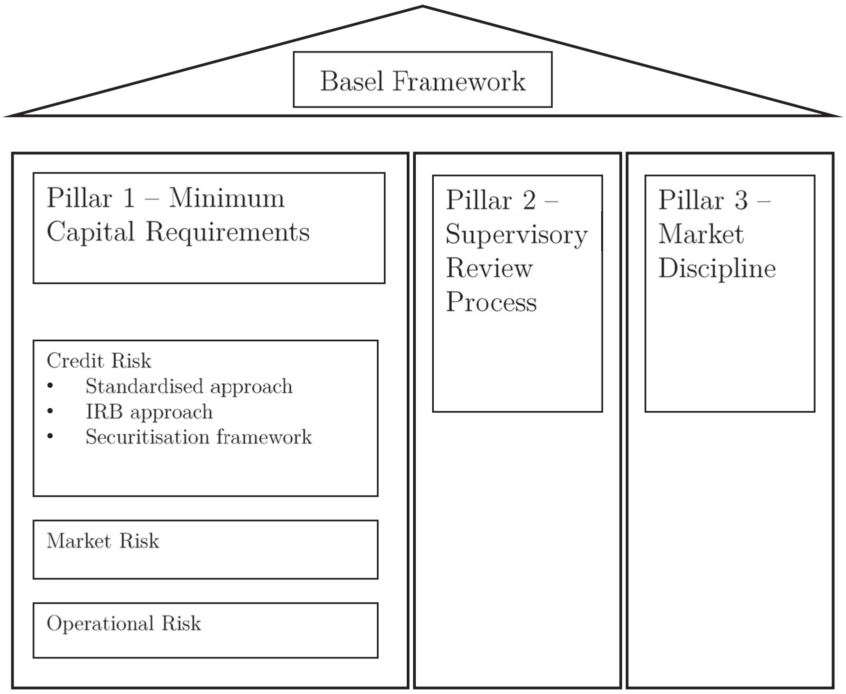

Figure 1: Three Pillars of the Basel II Accord, *Source: BCBS (2004)*

2.2 Risk-Weighted Capital Requirements

This section deals with the determination of risk weights and thus minimum capital requirements for government bonds under the risk-weighted capital framework in Pillar 1, focussing on credit and market risk.

2.2.1 Credit Risk

"Credit risk is [...] defined as the potential that a bank borrower or counterparty will fail to meet its obligations in accordance with agreed terms", (BCBS, 2000, paragraph 2). To quantify (sovereign) credit risk in the banking book, banks can choose between two approaches: (i) the standardised approach and (ii) the internal ratings-based (IRB) approach (BCBS, 2006).

Standardised Approach

The standardised approach allows banks to determine risk weights for (sovereign) exposure in a standardised manner based on external ratings from credit rating agencies (CRAs).[2] If sovereign credit ratings are available, a weighting range from 0% to 150% exists, which is illustrated in Table 1 (BCBS, 2006, paragraph 53). If sovereign ratings are not available, a risk weight of 100% is applied to sovereign exposures. However, the BCBS (2006, paragraph 54) stipulates that at national discretion a lower risk weight can be applied to banks' sovereign exposures, or exposures to their central bank, if they are denominated and funded in domestic currency. This implies that if national regulation is formulated accordingly banks are allowed to classify specific sovereign exposures as risk-free, meaning that sovereign bonds receive a zero risk weight in capital regulation.

Credit Assessment	AAA to AA–	A+ to A–	BBB+ to BBB–	BB+ to B–	Below B–	Unrated
Risk Weight	0%	20%	50%	100%	150%	100%

Table 1: Sovereign Risk Weights under the Basel II Standardised Approach

Internal Ratings-Based Approach

The IRB approach allows banks to calculate risk weights for given (sovereign) exposures on their *own* internal rating systems. This approach should be used by large and sophisticated banks and allows for a more nuanced differentiation of credit risk. For calculating credit risk, the following risk parameters are necessary: the probability of default (PD), the loss given default (LGD), the exposure at default (EAD), and the effective maturity (M). Two broad approaches exist to determine these risk parameters: a foundation and an advanced approach (BCBS, 2006, paragraph 245). Under the foundation approach, banks provide their own PD estimations and rely on estimations provided by the supervisor for the other risk parameters. Under the advanced approach, in addition to the PD, banks determine the values for the LGD, the EAD and the M on their own estimations.[3]

[2] The methodology used in the Basel document is based on ratings from Standard & Poor's (BCBS, 2006, p. 19).

[3] In the following, the paper does not distinguish between the foundation and the advanced approach. The acronym IRB refers to both approaches.

Regarding the treatment of sovereign exposures, the two approaches do not differ. Table 2 shows risk weights and capital charges under the IRB approach for sovereign exposures with an LGD of 45% and an M of 2.5 years, for several default probabilities. Once a bank decides to use the IRB approach for certain asset classes, it is expected

Asset class: LGD: 45% M: 2.5 years	Sovereign exposure	
PD (in %)	Risk weight (in %)	Capital charge (in %)
0.00	0.00	0.00
0.01	7.53	0.06
0.02	11.32	0.91
0.03	14.44	1.16
0.05	19.65	1.57
0.10	29.65	2.37
0.05	69.61	5.57
1.00	92.32	7.39
5.00	149.86	11.99
10.00	193.09	15.45
20.00	238.23	19.06

Table 2: Illustrative Sovereign Risk Weights and Capital Charges under the Basel II IRB Approach

that the bank will extend this approach across all material asset classes (BCBS, 2006, paragraph 256). However, there is an exception for asset classes if they fulfil the following two conditions (BCBS, 2006, paragraph 259): First, they are immaterial in nature, and second, for assets that are classified as non-significant business units. For these assets it is permitted to compute credit risk with the standardised approach. With regard to banks' sovereign holdings, the exception implies that sovereign bonds with a default probability which deviates significantly from zero can receive a zero risk weight if they fulfil the conditions mentioned in paragraph 259 (BCBS, 2006).

2.2.2 Market Risk

Banks are also opposed to market risks if they hold sovereign bonds in their trading or available-for-sale books. Market risk is defined as the risk of losses arising from movements in market prices (BCBS, 2006, paragraph 683(i)). Key determinants of market risk are: default risk, interest rate risk, credit spread risk and equity risk. To calculate capital charges for market risk, banks can choose between two approaches: a standardised and an internal model approach. Banks using the standardised approach (IRB approach) for calculating credit risk in the banking book are supposed to use the standardised approach (internal model approach) to calculate market risk in the trading and available-for-sale book.

Regarding the sovereign bond treatment under the standardised approach, at national discretion, sovereign bonds can be subject to a zero risk weight when they are denominated and funded in domestic currency (BCBS, 2016, paragraph 137). Under the internal model approach, banks must measure the default risk of sovereign bonds in the trading book. This requirement also applies to government bonds which are denominated in the sovereign's domestic currency (BCBS, 2016, paragraph 186 (c)). Accordingly, when banks use the internal model approach for their trading book positions, government bonds do not receive a preferential treatment.

2.3 Leverage Ratio

Within the Basel III framework, a non-risk-based leverage ratio was introduced. The aim of this instrument is to restrict the build-up of excessive leverage in the banking sector, and to minimise the costs of any model-risk in the system of risk-weighted assets (ESRB, 2015, p. 21). The leverage ratio is defined as (BCBS, 2014a):

$$\frac{\text{Tier 1 capital}}{\text{Total exposures}} \geq 3\%.$$

It consists of two components: The Tier 1 capital (numerator), and the total exposures (denominator). Tier 1 capital – also referred to as the core capital – consists primarily of equity capital and disclosed reserves. The total exposures are the sum of: on-balance sheet exposures, derivative exposures, securities financing transactions exposures and off-balance sheet (OBS) items (BCBS, 2014a, paragraph 14). Sovereign exposures are fully included in the leverage ratio, meaning that they do not receive preferential treatment compared to other asset classes.

2.4 Large Exposure Framework

The large exposure framework supplements the risk-based capital standards in the Basel II and III Accord (BCBS, 2014c). The framework was introduced by the BCBS in April 2014 and should protect internationally active banks from large losses, resulting from the sudden default of a single counterparty. A large exposure is defined as the sum of all exposure values of a bank to a counterparty if it is equal to or above 10% of the bank's eligible capital base (BCBS, 2014c, paragraph 14). The minimum large exposure requirement stipulates that a bank's large exposure is not allowed to be higher than 25% of the bank's Tier 1 capital.[4] A more stringent limit of 15% applies for exposures of global systemically important banks (G-SIB) to other G-SIB. Regarding the sovereign bond treatment under the large exposure framework, banks' exposures to sovereigns and their central banks are exempted from this regulation (BCBS, 2014c, paragraph 61).

2.5 Liquidity Requirements

The BCBS introduced two minimum standards for funding liquidity within the Basel III Accord, the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR). The following description of the LCR and the NSRF are quite similar to the description in Neyer and Sterzel (2018).

2.5.1 Liquidity Coverage Ratio

The aim of the LCR is to promote the short-term resilience of banks' liquidity profiles by ensuring that banks have sufficient unencumbered high-quality liquid assets (HQLA) to withstand a significant stress scenario of a duration of at least one month. The LCR is defined as (BCBS, 2013):

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

It consists of two components: the stock of HQLA (numerator) and the total expected net cash outflows over the next 30 calendar days (denominator). HQLA are assets with a high potential to be quickly and easily liquidated at little or no loss of value even in

[4] A detailed Tier 1 capital definition is given in paragraphs 49 to 96 in BCBS (2010a).

times of stress. There are two categories of HQLA: level 1 assets and level 2 (A and B) assets. Level 1 assets consist of coins and banknotes, central bank reserves and a range of sovereign securities (BCBS, 2013, paragraph 50). Level 2 assets include lower rated sovereign securities, corporate debt securities, covered bonds, mortgage-backed securities and common equity shares (BCBS, 2013, paragraph 52 and 54). No quantitative limits and haircuts apply to level 1 assets, whereas level 2 assets can only comprise up to 40% of the stock of HQLA and they are subject to haircuts of at least 15%. The denominator represents the total expected net cash outflows over the next 30 calendar days. This amount is defined as the total expected cash outflows minus the minimum of total expected cash inflows. However, to ensure a minimum level of HQLA holdings, total expected cash inflows are subject to a cap of 75% of the total expected cash outflows.

Sovereign bonds are eligible to be classified as level 1 assets when they satisfy at least one of the following three conditions (BCBS, 2013, paragraph 50): (i) they are assigned a 0% risk weight under the Basel II standardised approach, (ii) they are 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 bond holdings which are denominated in foreign currencies are eligible up the amount of the bank's net cash outflows in that foreign currencies in times of distress. Moreover, the LCR framework requires 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 jurisdiction (BCBS, 2013, paragraph 44).

2.5.2 Net Stable Funding Ratio

The NSFR is designed to supplement the LCR. It requires banks to have a sustainable maturity structure of their assets and liabilities over a one-year time horizon. Formally, the liquidity ratio is defined as (BCBS, 2014b):

$$NSFR = \frac{\text{Available amount of stable funding}}{\text{Required amount of stable funding}} \geq 100\%.$$

It consists of two components: the available amount of stable funding (numerator) and the required amount of stable funding (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 stress scenario (BCBS, 2014b, paragraph 26). The total value of the instruments in each category is then weighted with an available stable funding (ASF) factor and finally summed up. Note that funding instruments which are regarded as stable funding sources receive a high ASF factor and vice versa. The required amount of stable funding is based on the liquidity characteristics of banks' assets and OBS exposures. Accordingly, the banks' assets and OBS exposures are assigned to one of eight required stable funding (RSF) categories (BCBS, 2014b, paragraph 44). The amount of each category is weighted with an RSF factor and then summed up. Note that the higher the liquidity value of an asset or an OBS exposure, the lower the RSF factor and vice versa.

Sovereign securities are assigned an RSF factor of 5% within the NSFR if they are classified as level 1 assets in the LCR. Only coins, banknotes and central bank reserves are assigned a lower RSF factor of 0%, whereas level 2 assets are assigned RSF factors of between 15% and 50%.

3 Sovereign Risk

For decades sovereign risk was mainly an issue for emerging markets and no OECD country defaulted on its domestic debt between 1950 and 2010 (Reinhart and Rogoff, 2010). However, the European sovereign debt crisis and especially the Greek sovereign debt crisis, with its peak in 2010–2012, highlighted that sovereign risk is not only an issue for emerging economies.

3.1 Sovereign Risk and Sovereign Defaults

There is no single definition of the term "sovereign risk" in the existing literature and it contains various risk factors, depending on the context and the user (Pepino, 2015, p. 9). The ESRB (2015, p. 44) defines sovereign risk as:

> "Sovereign risk arises from the fact that a sovereign may, for a significant time, have higher expenditures than tax revenues and go so much into debt

that, eventually, it finds it impossible or undesirable to pay its debts as they fall due or, more generally, may not comply with its contractual debt obligations."

This definition assigns "sovereign risk" to the category of "sovereign credit/default risk" which also incorporates risks like migration or spread risk (ESRB, 2015, p. 45).[5]

The definition from the ESRB refers to an outright sovereign default, i.e. the failure of a sovereign to meet the principal or interest payment on the due date. In the case of an outright default, the sovereign rarely defaults on its entire amount of outstanding debt. Commonly, the sovereign negotiates a debt restructuring or exchange programme with its creditors. Such programmes are mostly accompanied by losses for creditors as the maturity dates on the newly exchanged sovereign bonds will be extended and/or the bonds' face value and the coupon rates will be reduced. Due to the "reduced" debt obligations, the sovereign will be able continuing its debt payments – at least for a given period.

Note, that a sovereign default decision, in general, does not necessarily depend on the sovereign's ability to pay its debt. It is also possible that a sovereign is not willing to serve its debt although it has the ability. In this case a sovereign default is driven by strategic reasons ("strategic default"). A strategic default may be beneficial for a sovereign as it can increase the total financial resources in the domestic economy. This can be realised through a selective sovereign default, meaning that a sovereign only defaults on debt which is held by foreign investors (Gennaioli et al., 2014, p. 820). Losses then mostly emerge abroad, whereas the domestic costs of the default are low.[6]

Whether a sovereign defaults on its debt obligation also depends on the currency in which the debt is denominated (domestic currency or foreign currency). If the sovereign debt is denominated in the domestic currency, an over-indebted country has the possibility to serve its debt by printing money. This is not possible if the debt is denominated in foreign currency. Furthermore, printing money to pay the debt is only feasible if the country has monetary sovereignty, meaning that the sovereign has legal control over its currency. From this perspective, government debt denominated in the domestic currency

[5] Migration risk arises due to rating downgrades. Spread risk arises when the spread between bond-yields listed on the secondary market and corresponding risk-free rates starts to increase (ESRB, 2015, p. 45).

[6] Note that such a perfect discrimination is hard to exercise for the sovereign as sovereign bonds are traded in secondary markets. Hence, the sovereign does not exactly now where the bonds are being held.

can be seen as "default-risk free" as "[governments], when issuing debt in local currency, have the unique power, to print money to pay their obligations and thus can avoid default" (Damodaran, 2010, p. 14).

A side effect of printing money to finance domestic debt obligations is inflation, which reduces the real value of outstanding sovereign debt. Inflating sovereign debt away can be seen as a sovereign "real default", as creditors' claims lose value driven by internal currency devaluation. Another form of a sovereign "real default" exists when there is a change in the currency in which the sovereign debt is denominated, i.e. in the case of a currency redenomination (ESRB, 2015, p. 85).[7] If, for example, a country in a monetary union leaves the union, it is likely that it will reintroduce the old national currency. This will be followed by a redenomination of debt contracts that fall under the country's own law. The value of existing sovereign bonds which will be redenominated is thus dependent on the valuation of the reintroduced national currency. In the case of an external currency devaluation (relative to the currency in the monetary union) creditors will face losses as the real value of their sovereign bonds decreases.

3.2 Sovereign Risk and Sovereign Defaults in the Euro Area

The European sovereign debt crisis underlined that the risk of a sovereign outright default, and also of a real default de facto exists in the EMU. Figure 2 shows the yields of 10-year euro area sovereign debt from January 2001 to January 2019. Before 2008 the yields were about the same. However, after the Lehman collapse in autumn 2008 the yields started to diverge. The sovereign yields mainly in the GIIPS countries (Greece, Ireland, Italy, Portugal and Spain; later in the paper also referred to as "stressed countries") increased significantly from around 2008 until 2014, whereas the sovereign yields from bonds in Austria, Belgium, Germany, Finland, France and the Netherlands (later in the paper also referred to as "non-stressed countries") decreased. These yield spreads resulted from several reasons. Barrios et al. (2009) show that at the beginning of the crisis, the government bond yield spreads within the euro area were mainly driven by three factors: (i) the different sovereign default risks, (ii) the different market liquidity of sovereign bonds,

[7] Reasons for a currency redenomination can be: (i) high inflation and currency devaluation, (ii) when a currency union is formed, (iii) when one country, or more countries in a currency union leave the union ,(iv) when the total currency union breaks up.

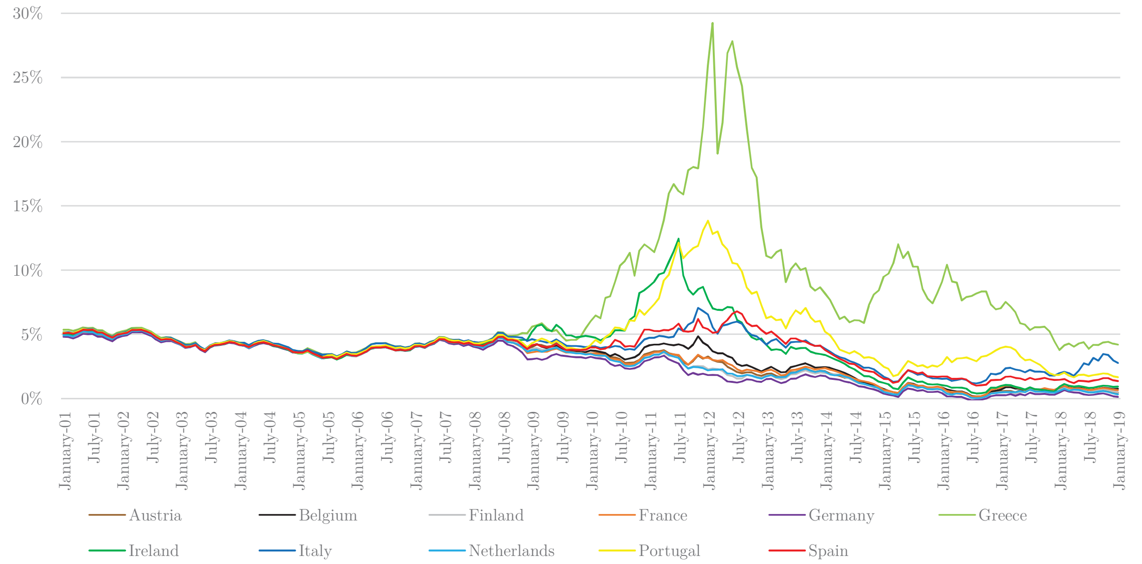

Figure 2: Yields of 10-Year Euro Area Sovereign Debt, *Data Source: European Central Bank (ECB)*

and (iii) changes in investors' preferences. What is crucial is that since the outbreak of the crisis, the expected default risks of sovereigns in the EMU have been differing significantly from each other. As higher sovereign bond risk premiums directly impact the sovereign refinancing conditions, CRAs have responded to these developments. Standard and Poor's, for example, announced credit rating downgrades for nine EU member states in the years 2010–2012 (Baum et al., 2016, p. 117).

The Greek sovereign debt crisis showed that it is possible that for an EMU Member State to default on its debt. The Greek sovereign default was one of the largest in history, besides the default in Argentina in 2005 (Das et al., 2012). After several reforms to rescue Greece, debt restructuring programmes were proposed in 2012 which related to all privately held sovereign bonds which had been issued prior to 2012. The programmes required bond holders to turn their Greek government bonds into new securities with lower face values, lower interest rates and longer maturities. As a result, the face value of Greece's debt decreased by €108 billion (or 52.5% of the eligible debt) (Zettelmeyer et al., 2013, p. 527).[8] The total "haircuts" suffered by the creditors from the debt restructuring programmes were estimated to be, on average, between 59% and 65%, depending on the methodology which was used (Zettelmeyer et al., 2013).

[8]For a detailed description of the Greek debt restructuring of 2012 see Zettelmeyer et al. (2013).

An outright sovereign default can be avoided when a sovereign has monetary sovereignty. Then a sovereign has the possibility to serve its debt by printing money. This is not the case in the EMU, where the Member States transferred the monetary policy to the Eurosystem[9]. Article 130 of the Treaty on the Functioning of the European Union (TFEU) declares that the Eurosystem is formally independent from political influence. The decision-making bodies of the Eurosystem are prohibited from taking instructions from any EU institution. The independence of the ECB helps to maintain price stability, the primary objective of the European System of Central Banks (ESCB[10]).

Nevertheless, transferring monetary policy to an independent central bank does not automatically prevent the monetisation of sovereign debt (ESRB, 2015, p. 46). To ensure this, Article 123 of the TFEU prohibits any form of the monetary financing of public debt or deficits, for all EU central banks. After the global financial crisis of 2007/2008 and in response to, from the ECB's perspective too low inflation rates in 2014/2015, the ECB launched purchase programmes for government bonds. It has been questioned whether these programmes violate the prohibition of monetary financing and exceed the monetary policy mandate of the ECB. Against this background, there have been initiated constitutional complaints against the Outright Monetary Transactions programme (OMT) and the Public Sector Purchase Programme (PSPP) with the German Federal Constitutional Court. However, both constitutional complaints were unsuccessful (Bundesverfassungsgericht, 2016; Court of Justice of the European Union, 2018). Hence, from a legal perspective, the risk of monetising sovereign debt in the euro area does not exist.

The previous analyses show that sovereign debt from EMU Member States are not per se default risk-free, implying that the current situation in the EMU represents a new reality (ESRB, 2015, p. 50). On the one hand, the euro is the domestic currency in the EMU. On the other hand, EMU Member States have transferred their monetary policy to the ECB, and the TFEU provides central bank independence and prohibits monetary financing. From this perspective, the situation in the EMU is similar to that of a government issuing debt in a foreign currency. From a theoretical point of view an outright sovereign default is the only possible form of debt reduction in the EMU (Alesina et al., 1992).

[9]The Eurosystem is composed of the ECB and the national central banks of the euro area Member States.

[10]The ESCB comprises the ECB and all national central banks of all EU Member States.

One could think that an over-indebted EMU country could leave the Monetary Union so that it would regain access to monetary policy tools. However, for Member States there does exist an exit option in the treaties. Although there is no legal right for a Member State to leave the EMU, the future of the euro was questionable during the sovereign debt crisis and there were fundamental doubts over the integrity of the EMU. As long as the euro remains the national currency in all EMU Member States, the exchange rate risk within the Union can be neglected. However, Klose and Weigert (2014) show that redenomination risk played a crucial role during the European sovereign debt crisis.[11] They find that euro area sovereign bond yields incorporated redenomination risk premiums/discounts in the crisis. In particular, Klose and Weigert (2014) show that there were redenomination risk premiums for sovereign bonds from the countries: Portugal, Ireland, Spain and Italy, as their currencies were expected to depreciate (vis-à-vis the euro) after exiting the EMU. In contrast, there were redenomination risk discounts for sovereign bonds from France, the Netherlands, Germany, Austria and Belgium, as their currencies were expected to appreciate.

3.3 Banks' Sovereign Bond Holdings in the Euro Area

Whether an increase of sovereign risk has systemic implications also depends on the level and the composition of banks' sovereign bond portfolios.

Banks' Total Sovereign Bond Holdings

Figure 3 shows the banks' total euro area sovereign debt holdings of selected EMU countries from January 2000 to January 2019. Comparing the banks' sovereign exposures at the beginning of 2000 with the exposures in January 2019, shows that most of them were significantly larger in 2000. Especially banks in Greece and Belgium reduced their sovereign holdings from over 20% of their total assets in 2000 to around 6% in 2019. However, Greek banks did not continuously reduce their sovereign exposures. Since the global financial crisis of 2007/2008, they sharply increased their euro area sovereign holdings by around 5% of their total assets (from 5% in 2008 to close to 10% in 2012). This trend stopped in 2012, as a result of the debt restructuring programmes (ESRB, 2015, p. 77),

[11] See also Di Cesare et al. (2012) and Bayer et al. (2018).

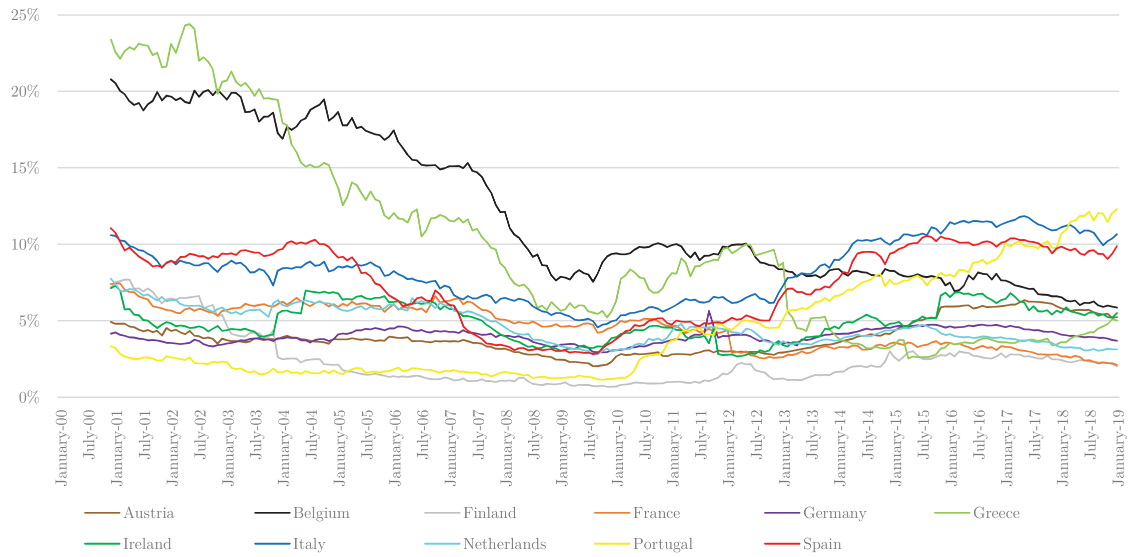

Figure 3: Banks' Total Euro Area Sovereign Debt Holdings as a Percentage of Their Total Assets in Selected Euro Area Countries, *Data Source: ECB*

and Greek banks again decreased their euro area exposures from around 10% to less than 6% in 2019. The decreasing trend over the whole period can also be observed for French and Dutch banks, but less strongly. They decreased their sovereign holdings from over 7% in 2000 to less than 3% in January 2019. Banks in Spain and Italy decreased their sovereign debt holdings from around 11% in 2000 to less than 5% in 2008. In the same period, Portuguese banks also reduced their share of sovereign bond holdings from 3% in 2000 to 1% in 2008. However, since 2008, banks in Spain, Italy and Portugal gradually increased their government bond exposures to more than 10% of their total assets in 2019. This trend can also be observed for banks in Ireland, but less strongly. In contrast to these developments, the sovereign debt exposures from banks in Austria, Germany and Finland remained quite stable over the period from 2000 until 2019. They hold at most times less than 5% of their total assets in sovereign bonds.

Banks' Sovereign Exposures in Stressed and Non-Stressed EMU Countries

It is noticeable that the development of banks' sovereign holdings in most stressed euro area countries and those in non-stressed euro area countries has diverged since the global financial crisis of 2008 until today (2019). The different evolution of sovereign bond exposures from banks in stressed and non-stressed euro area countries are displayed in

Figure 4. The figure shows the averaged total euro area sovereign debt holdings across the two country groups from January 2000 to January 2019. In 2000, the banks' euro

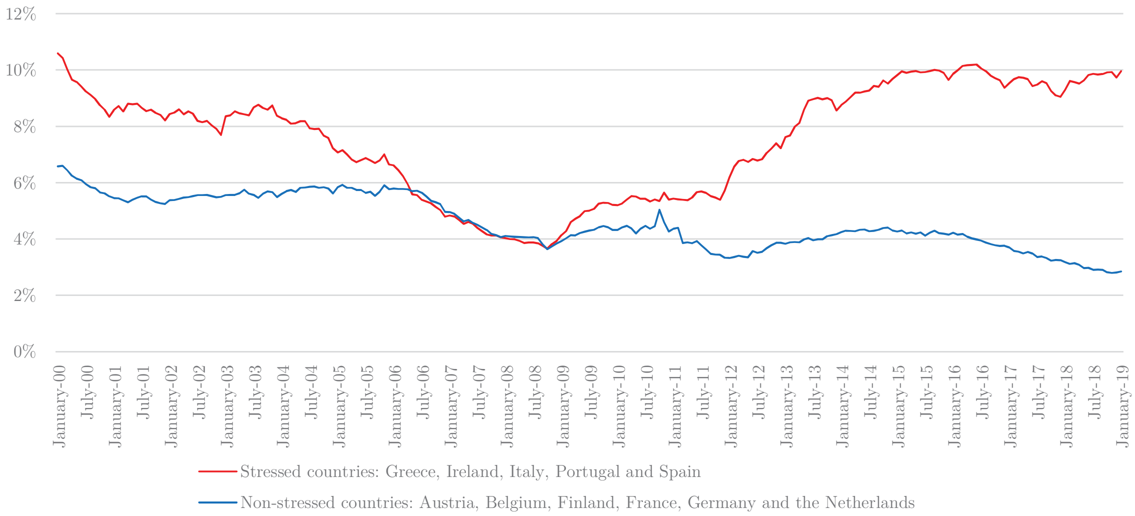

Figure 4: Banks' Total Euro Area Sovereign Debt Holdings as a Percentage of Their Total Assets in Certain Stressed and Non-Stressed Euro Area Countries, *Data Source: ECB*

area sovereign exposures in stressed countries were much higher (with more than 10% of their total assets) than the banks' sovereign exposures in non-stressed countries (with more than 6% of their total assets). Banks in both groups decreased the average euro area sovereign debt holdings from 2000 until 2008, but the reduction of banks in stressed countries was stronger. They reduced their sovereign exposures by more than 6% and banks in non-stressed countries decreased their sovereign holdings by more than 2%. This development started to diverge in 2008. The average sovereign debt from banks in non-stressed countries remained stable, at around 3% to 5% of total assets, whereas banks in stressed euro area countries have more than doubled their average euro area sovereign debt holdings in recent years (from less than 4% in 2008, to around 10% of their total balance sheet in January 2019).

One may expect that the increased share of sovereign bonds from banks in stressed countries is because banks' balance sheets shrunk during and after the global financial crisis, rather than that of the banks' increase in sovereign holdings (ESRB, 2015, p. 79). To address this issue, Figure 5 shows the banks' average total euro area government bond portfolios in *millions of euro* in stressed and non-stressed euro area countries from January 2000 to January 2019. The figure highlights that the level of banks' sovereign debt holdings

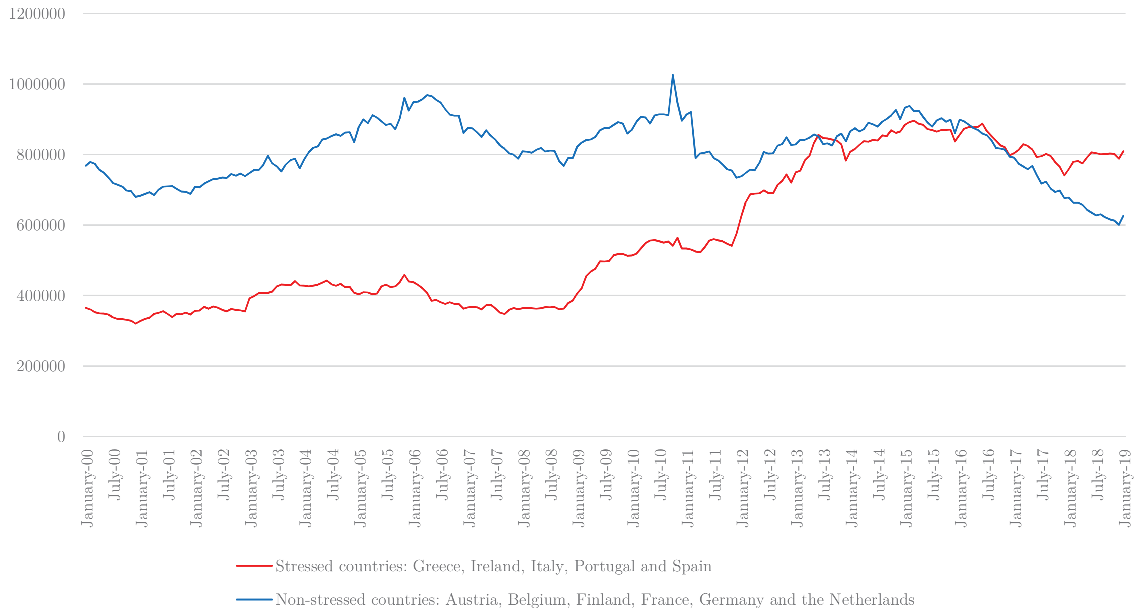

Figure 5: Banks' Total Euro Area Sovereign Debt Holdings in Certain Stressed and Non-Stressed Euro Area Countries (in € million), *Data Source: ECB*

in stressed countries – and not just their ratio to total assets – increased significantly post-2008. They increased their euro area sovereign holdings from €360 billion in September 2008 to €809 billion in January 2019, i.e. an increase of 125%. Accordingly, the increased share of sovereign bond exposures in the banks' balance sheets from banks in stressed countries is not driven by a reduction in total assets.

The Banks' Home-Bias in Sovereign Bond Holdings

With respect to the composition of the banks' sovereign exposures, Figure 6 displays the development of the share of banks' *domestic* sovereign bonds to total euro area sovereign bonds ("home bias") from January 2000 to January 2019. It is shown that the banks' home bias in sovereign bond holdings exceeds 50% for most of the countries in the considered period. Only the banks in Ireland and the Netherlands hold less than 50% domestic sovereign bonds of their total euro area sovereign exposures over the whole period from 2000 to January 2019. The sovereign debt home bias of banks in Finland decreased from 90% in 2000 to 32% in January 2019. Banks in Austria, Belgium, France and Germany reduced their home bias in sovereign bonds in the first decade, but they increased their share of domestic sovereign holdings over the time period from 2008 until 2012. Since

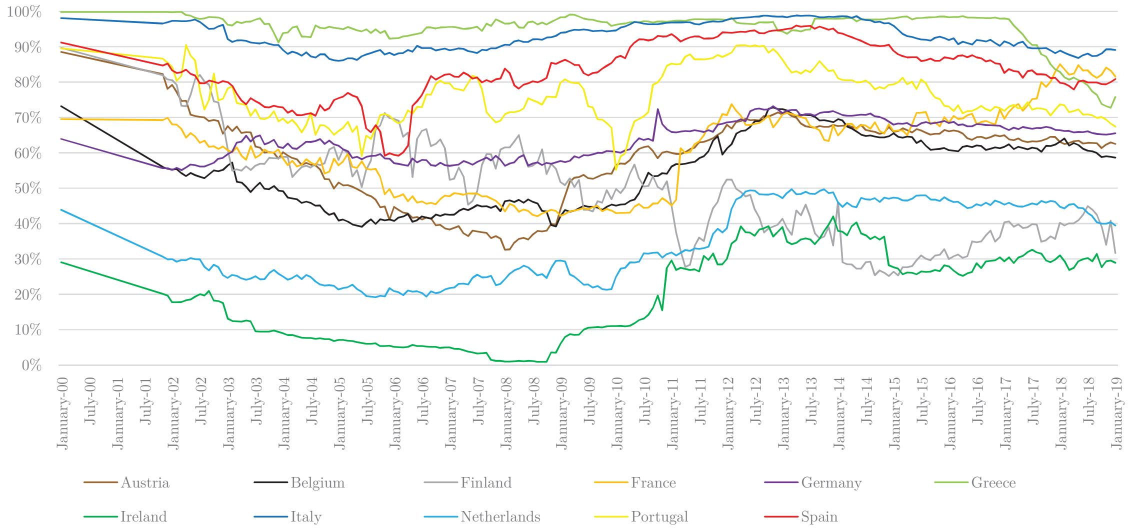

Figure 6: Banks' Domestic Sovereign Debt Holdings as a Percentage of Their Total Euro Area Sovereign Debt Holdings, *Data Source: ECB*

2012, the sovereign debt home bias has remained stable at around 60% to 70% for the banks in Austria, Belgium and Germany. Banks in France significantly increased their home bias in sovereign bond holdings from around 70% in 2016, to 82% in January 2019. Moreover, the share of domestic bonds is the highest for banks in Greece, Italy, Spain and Portugal, the home bias of banks in these countries is at most times over 70%.

3.4 Why Banks Hold Sovereign Bonds

There are a host of reasons for why banks hold sovereign bonds. Some of these reasons are structural and permanent in nature, while others are temporary, meaning that they arise, for example, in times of sovereign distress (Lenarčič et al., 2016, p. 10).

Motives for Banks Holding Sovereign Bonds in Normal Times

Usually, government bonds carry high credit ratings and are considered to be low-risk (in particular from developed economies). These characteristics of sovereign bonds make them attractive for banks to hold. One reason for banks to invest in sovereign bonds is to diversify and reduce their overall balance sheet risk, that in turn reduces their funding costs (Lenarcic et al., 2016, p. 11). Assets that are less risky tend to have higher market liquidity, so that some banks hold sovereign bonds as a way of storing liquidity (Gennaioli et al., 2014)). Note that banks can also store liquidity by holding cash or close substitutes to public debt, however, holding sovereign exposure is generally less costly (Lenarčič et al., 2016, p. 10). Due to the low credit risk and the high market liquidity, sovereign debt is an eligible asset class which is used as collateral. Banks use government bonds, inter alia, for interbank refinancing operations, for refinancing operations with the central bank and/or for repurchase agreements (Bolton and Jeanne, 2011, p. 162). Some banks hold large amounts of sovereign bonds as they operate as the primary dealer or market-makers for government bonds (BCBS, 2017, p. 12). In the former case, banks act as an underwriter and buy sovereign debt securities from the government in order to sell them for a profit. Another argument for holding sovereign bonds are regulatory reasons. The liquidity requirements (LCR and NSFR) stipulate that banks should hold sufficient HQLA – sovereign securities are classified as level 1 HQLA. It is beneficial for banks to fulfil the liquidity requirements with sovereign securities as holding sovereign debt is generally less costly than holding other liquid assets. Within the capital regulation framework, government exposures receive a zero risk weight, implying that banks do not have to set aside equity capital to protect potential losses (Bonner, 2016; Acharya and Steffen, 2015). This makes investing in sovereign bonds more attractive compared to other asset classes.

Motives for Banks Holding (Domestic) Sovereign Bonds in Times of Sovereign Distress

The motives for holding government debt can change when sovereign risk increases. In the previous Section 3.3 it was shown that especially banks in stressed euro area countries have increased their (domestic) sovereign bond holdings since 2008. There has been a growing literature in recent years investigating motives for this relationship.

The "carry trade" hypothesis states that banks borrow at relatively low interest rates in non-stressed countries and invest in high-yielding sovereign bonds in stressed countries (Acharya and Steffen, 2015). This can be rational for banks as they will benefit from the spreads as long as there is no materialisation of default risk. The carry-trade behaviour can be driven by risk-shifting (moral hazard) motives and regulatory reasons. The risk-shifting (moral hazard) motive reveals how especially troubled banks place a bet on their own survival, in the sense that they shift their investments into risky government bonds (Acharya and Steffen, 2015; Ari, 2016). In the event of a sovereign default, domestic banks' balance sheets will deteriorate and it is expected that troubled banks will go bankrupt anyway (independently of their level of sovereign bond holdings). However, they will benefit from sovereign holdings when the sovereign's situation improves, as then there will be an increase in sovereign bond prices. Regulatory reasons can also force troubles (undercapitalised) banks to engage in carry trades (Acharya and Steffen, 2015). They have an incentive to substitute high risk-weighted assets with zero-risk-weighted high-yielding sovereign bonds. Through this adjustment strategy undercapitalised banks are able to fulfil the risk-weighted capital ratio and it increases the short-term return on equity. However, this bank behaviour leads to a crowding-out effect as credit is reallocated from the private to the public sector (ESRB, 2015).

The deficit-absorption hypothesis argues that domestic banks act as residual buyers when sovereign risk increases and macroeconomic factors deteriorate (Lenarčič et al., 2016, p. 13). A deterioration in macroeconomic fundamentals is typically associated with larger fiscal deficits. To finance the deficits, sovereigns can issue public bonds. The resulting higher sovereign bond supply on the government bond market will lead to an increase in sovereign bond yields, which makes financing for sovereigns more expensive. This effect can be reinforced due to the retrenchment of foreign sovereign bond investors in times of sovereign distress. The national banking sector can prevent sovereign financing issues by absorbing the excess supply of government bonds. This behaviour can reduce the sovereign default probability and can be self-preserving for banks, as it might reduce negative spill-overs from sovereign risk to their own performance (ESRB, 2015, p. 99).

The increasing banks' domestic sovereign bond holdings during times of sovereign distress can also be a result of moral suasion by national sovereigns (Acharya and Rajan, 2013; Becker and Ivashina, 2017; Chari et al., 2014). In this case, sovereigns prompt domestic banks to purchase domestic sovereign bonds with the aim to stabilise sovereign bond yields and hence avoid sovereign financing issues. There is empirical evidence that, in particular, government-owned banks and banks with politicians on the board of directors increased their home bias in sovereign holdings during times of sovereign distress (De Marco and Macchiavelli, 2016).

Another reason why banks in stressed countries increasingly invest in domestic government bonds when sovereign risk increases, is to hedge redenomination risk (ESRB, 2015, p. 190). When a country changes its currency, large balance sheet positions of banks – such as, for example, deposits – will be redenominated and their values thus depend on the valuation of the new currency. Banks can hedge the redenomination/currency risk by investing in assets that will also be redenominated in the case of a currency change. These assets include, inter alia, sovereign bonds issued under domestic law (Bayer et al., 2018, p. 7). With respect to the EMU, redenomination/exchange rate risk within the Union can be neglected as long as the euro remains the national currency in all EMU Member States. However, if a EMU country would exit the currency union – and hence would introduce a new currency upon this event –, redenomination/exchange rate risk will also exist in the EMU. This is the case as it is expected that sovereign bonds issued under domestic law would be definitely redenominated into the new currency (Bayer et al., 2018).[12] Hence, if banks expect a currency change and therefore the redenomination of balance sheet positions on the liability side, they can increase their domestic government bond holdings to hedge the redomionation risk.

Discriminatory reasons can also be responsible for the increased banks' domestic sovereign bond investments in a sovereign debt crisis. The investment in risky domestic sovereign bonds can be more attractive for banks in comparison to the investment in foreign sovereign debt. The advantage exists due to the assumption that sovereigns may discriminate between domestic and foreign creditors in the case of a default (Broner et al., 2014). Such a selective default induces that domestic investors will benefit from the high bond yields, whereas they are less likely to be defaulted. Against this background, domestic sovereign debt becomes more attractive for domestic investors, leading to a re-nationalisation of sovereign bond markets.

[12] Sovereign bonds issued after January 1, 2013 include the Collective Action Clause (CAC) which allows for a majority of bondholders to enforce the restructuring terms on a minority of bondholders. However, this clause will not prevent the redenomination of sovereign bonds that fall under domestic law according to *lex monetae* (Bayer et al., 2018, p. 7 f.).

4 Contagion Channels Between Sovereigns and Banks

Sovereign exposures can generate several risks for banks as credit, refinancing, interest rate or market risk (BCBS, 2017, p. 4). This paper focusses on risks for banks induced by sovereign credit/default risk. Sovereign credit risk adversely affects the banking sector through various channels. Four main channels have been identified in the literature: (i) the direct exposure channel, (ii) the collateral channel, (iii) the sovereign credit ratings channel, and (iv) the government support channel (BCBS, 2017; CGFS, 2011; ESRB, 2015).[13]

4.1 Direct Exposure Channel (or Asset Holding Channel)

Sovereign risk affects banks through their direct holdings of sovereign bonds or their derivative positions with sovereigns. Increases in sovereign risk thus weaken banks' balance sheets and increase their riskiness. The extent of this effect depends on the purpose for which banks hold their sovereign securities. If these assets are held in the trading or available-for-sale book, they are carried at market value on the banks' balance sheets (CGFS, 2011, p. 13). In this case, falling government bond prices will lead to direct losses for banks and to an erosion of their capital base. If sovereign bonds are expected to be held to maturity, these bonds are put in the banking book and are carried at amortised cost (CGFS, 2011, p. 13). A drop in government bond prices will then not have direct effects for banks' balance sheets. Losses are only recorded when the bonds are impaired, i.e. when a sovereign default or restructuring becomes very likely or is realised. Nonetheless, banks are affected indirectly as their cost of funding increases. This is because banks' balance sheets become more risky and investors want to be compensated for this higher risk.

Due to the market-making role of banks, some banks are exposed to sovereigns through over-the-counter (OTC) derivatives (CGFS, 2011, p. 16).[14] Increasing sovereign risk

[13] In addition to these channels, the CGFS (2011) and the ESRB (2015) examine further channels: the international spillover channel, the risk-aversion channel, the non-interest income channel, the crowding-out channel, and the hedging strategy channel. However, the BCBS finds that these channels are less evident. In addition to the channels mentioned above, the BCBS (2017) identifies a further channel: the macroeconomic channel.

[14] Sovereigns are incentivised to use financial derivatives as they allow them to adjust their currency composition or the interest rate of their outstanding debt positions. Banks are key counterparties in these transactions.

affects banks in the same way as sovereign exposures in the trading or available-for-sale book as OTC derivatives are carried at market value. Hence, increasing sovereign risk will reduce the market value of banks' derivative positions, which leads to market-to-market losses on banks' income statement and thus to a reduction in the amount of equity capital.

4.2 Collateral Channel (or Liquidity Channel)

Sovereign risk affects banks as it reduces the collateral value of sovereign bonds and of other asset classes (ESRB, 2015; CGFS, 2011). Banks use sovereign bonds for a range of transactions, inter alia, to secure their wholesale funding with central banks, for private repo markets and covered bond issuance, and to back OTC derivative transactions. Increasing sovereign risk restricts the eligibility and the availability of collateral and deteriorates banks' funding conditions through the following mechanisms (CGFS, 2011, p. 17 f.): First, when sovereign debt is pledged as collateral, increasing sovereign risk could trigger a margin call, meaning banks will have to post more securities or they will have to sell some of their assets to fulfil the maintenance margin. Second, sovereign distress leads to higher haircuts for sovereign bonds and other asset classes that are used as collateral. The level of haircuts is determined by collateral valuation uncertainty, credit risk and market liquidity (CGFS, 2011, p. 18). Due to the low credit risk and the high market liquidity of government bonds in normal times, haircuts on government bonds are usually very low. This can change when sovereign risk increases. As domestic sovereign haircuts often serve as a "floor" for haircuts to many asset classes in the economy, higher sovereign risk not only affects haircuts which apply to sovereign securities, it rather affects haircuts of a broad range of assets which are used as collateral. Third, increasing sovereign risk – and especially sovereign downgrades – can lead to an exclusion of sovereign bonds accepted as collateral by investors in private markets, as well as from the pool of collateral eligible for specific transactions with the central bank. The latter was the case during the Greek sovereign debt crisis. The ECB "has decided to suspend the application of the minimum credit rating threshold in the collateral eligibility requirements for the purposes of the Eurosystem's credit operations in the case of marketable debt instruments issued or guaranteed by the Greek government", (ECB, 2010).

4.3 Government Support Channel

Increasing sovereign risk adversely affects the banking sector when banks benefit from explicit or implicit government guarantees (ESRB, 2015; CGFS, 2011). Explicit guarantees exist in the form of governments providing guarantees against the default on bank bonds, meaning that if a bank defaults, the interest and principal payments from the guaranteed bonds will be made by the government. Implicit guarantees stem from the expectations of the market participants that government authorities will provide financial support to a systemically important bank (SIB) when it gets into trouble. Such a bailout can be economically justified as the bankruptcy of an SIB can cause large shocks to the whole financial system and the real economy (systemic risk). These forms of public support (explicit and implicit guarantees) generally reduce the credit risks and the funding costs for those banks benefitting from the guarantees. However, if the public finances deteriorate in one country, the value of these guarantees will decrease and the funding costs of banks which rely on such guarantees will increase. The reason is that due to the deterioration of public finances, the banks' investors expect that the sovereign may no longer be able to bail out domestic banks.[15]

4.4 Sovereign Credit Rating Channel

Sovereign credit ratings are important for banks in many aspects. Increasing sovereign risk can lead to sovereign downgrades which have negative implications for banks in two respects (CGFS, 2011, p. 20). First, sovereign downgrades increase banks' equity and debt funding costs. Note that a sovereign downgrade reveals as a clear signal to investors that banks, which are affected by the higher sovereign risk have become riskier. To compensate the investors for this higher risk banks have to pay higher interest rates, and their funding costs increase (CGFS, 2011, p. 20). Second, sovereign downgrades often lead to a deterioration of domestic banks' credit ratings as sovereign ratings represent a ceiling for firms' (financial and non-financial) ratings in the economy. The CGFS (2011, p. 20) shows that the share of banks that were downgraded (between 2007 and 2011), following

[15] In recent years several regulatory reforms have been adopted to reduce government interventions in the case of a bank insolvency. One of the reforms is the European Banking Union. Especially the second pillar, the SSM, ensures the efficient resolution of failing banks with minimal costs for the taxpayers.

a sovereign downgrade in Greece, Ireland and Portugal, lies between 58% and 83%. The potential government support contributes to the strong link between sovereign and banks' ratings.[16] Moreover, the deterioration of banks' credit ratings can limit banks' access to external financing (CGFS, 2011, p. 20). The reason is that institutional investors might be restricted in their investment decisions, so that they have to sell bank bonds when their ratings fall below a ratings-based threshold.

4.5 Sovereign-Bank Nexus

All channels discussed above are illustrated in Figure 7. These channels in isolation as

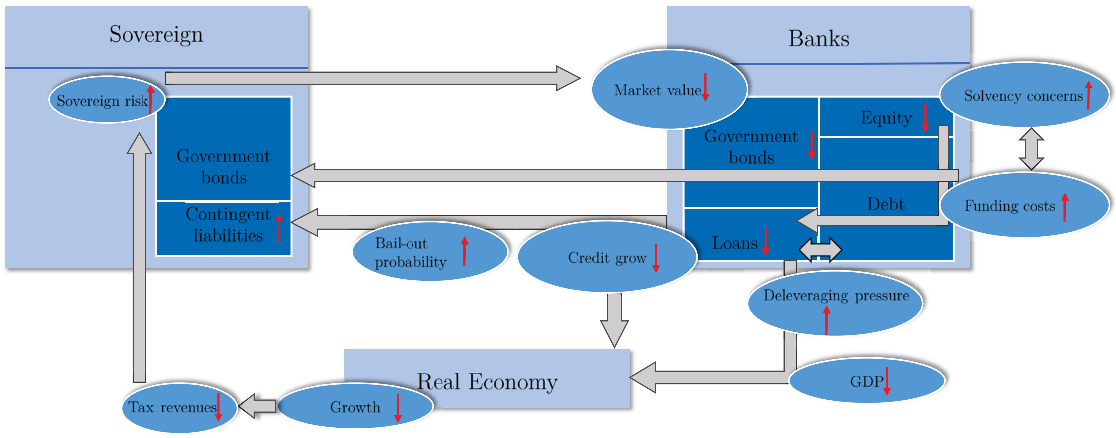

Figure 7: Contagion Channels Between Sovereign and Banks, *Source: Based on ESRB (2015)*

well as in combination make banks vulnerable to sovereign risk. The figure also shows that contagion can run in the opposite direction, i.e. from the banking sector to the sovereign. This is the case when a weak banking sector strains public finances. Contagion effects in this direction can have two triggers. First, troubled banks usually reduce their lending to the real economy, leading to lower economic growth and therefore to lower tax revenues for the sovereign. Second, a weak banking sector strains public finances when a sovereign provides financial support to troubled SIB (bank bailout) (BCBS, 2017, p. 4).

[16] Note that the sovereigns' creditworthiness influences the probability that domestic banks will receive financial support from their domestic sovereigns in times of distress (ESRB, 2015, p. 62). This is taken into account by the CRAs when they assess the banks' long-term ratings. Sovereign downgrades thus indicate that the sovereigns' ability to bail out troubled banks decreases, which will lead to a deterioration of banks' credit ratings.

The contagion channels from sovereign to banks and vice versa can reinforce each other. These reinforcing contagion effects are often referred to as “sovereign-bank nexus” or “diabolic loop” (BCBS, 2017, p. 4). However, banks can also absorb sovereign risk when they act as stable investors in a sovereign crisis (see Section 3.4). Then, domestic banks act as buyers of last resort. In doing so, banks can avoid an increase in bond yields and relax the sovereign’s financing conditions. Whether the buyer-of-last-resort strategy will dampen or amplify the sovereign-bond nexus depends on a number of factors such as, for example, the dimension of the existing dependence between sovereigns and banks and the magnitude of the crisis (BCBS, 2017, p. 5).

5 Discussion of Regulatory Reforms

Since the European sovereign debt crisis several reforms have been proposed to weaken financial contagion between sovereigns and banks. These reforms include the idea of revising the preferential sovereign bond treatment in banking regulation (see, for example, Weidmann (2016)). Sovereign bonds receive a preferential treatment in the existing Basel framework most notably in three areas (see Section 2): First, under the capital regulation framework sovereign bonds receive a zero risk weight. Second, sovereign debt exposures are not included in the large exposure framework. Third, under the liquidity regulation framework government bonds are classified as level 1 HQLA, and in addition they do not have to be diversified within asset classes. In the following, policy options regarding the abolishment of the preferential sovereign bond treatment are discussed.[17]

5.1 Positive Risk Weights for Government Bonds

There are several proposals discussed in the literature on how to address sovereign credit risk in bank capital regulation (Pillar 1 of the Basel framework). The ESRB (2015) investigates three policy options of how to reform the regulatory treatment of sovereign exposures in this field. These policy options include: (i) removing the domestic carve-out

[17]Note that there exists few literature dealing with the impact of these regulatory reforms on banks and financial stability. Therefore, large parts of the discussion are based on Lenarčič et al. (2016). In this paper the authors analyse the trade-offs in reforming the regulatory treatment of government bonds for banks and sovereigns. They focus on two regulatory reforms: positive risk weights for government bonds and sovereign exposure limits.

in the standardised approach, (ii) introducing a non-zero risk-weight floor for sovereign exposures in the standardised approach, and (iii) setting a minimum (regulatory) floor in the IRB approach.[18] Basically, the aim of positive risk weights for government bonds is to increase the banks' resilience to sovereign risk and thus weaken the sovereign-bank nexus.

Removing the carve-out for sovereign bonds in the standardised approach implies that sovereign exposures would not automatically receive a zero risk weight. Instead, the risk weights would be based on external ratings, going from 0% to 150% (see Table 1). With respect to the EMU, it should be noted that high sovereign ratings are the rule rather than the exception. Table 3 shows that eight (out of 19) countries within the EMU would retain a zero risk weight, seven would retain a low risk weight of 20%, and only four countries would retain a risk weight $\geq$ 50%. Accordingly, for bank exposures to highly

Standardised risk weights on euro area sovereign exposures, January 2019					
Germany	AAA	0%	Slovenia	A+	20%
Netherlands	AAA	0%	Latvia	A	20%
Luxembourg	AAA	0%	Lithuania	A	20%
Austria	AA+	0%	Spain	A–	20%
Finland	AA+	0%	Malta	A–	20%
Belgium	AA	0%	Italy	BBB	50%
France	AA	0%	Cyprus	BBB–	50%
Estonia	AA–	0%	Portugal	BBB–	50%
Ireland	A+	20%	Greece	B+	100%
Slovakia	A+	20%			

Table 3: Standardised Risk Weights on Euro Area Sovereign Exposures Based on Ratings from Standard & Poor's

rated sovereigns, the abolishment of the carve-out in the standardised approach would only have a low impact on risk weights, while for bank exposures of sovereigns with lower credit ratings, the effects would be quite large.

However, the dependence only on ratings from CRAs within the standardised approach could be inappropriate for sovereign bonds (Lenarčič et al., 2016; ESRB, 2015). This is because CRA ratings tend to be backward-looking, they might be too optimistic in upswings and too pessimistic in economic downturns, and in case of rating-adjustments they are often abrupt. It is also criticised that the standardised approach follows a bucket-

[18] For further ideas relating to the regulatory treatment of sovereign exposures in capital regulation see, for example, BCBS (2017).

ing approach. This implies that a sovereign downgrade from one credit-quality step to a lower one, could lead to a significant increase in risk weights for the respective sovereign bonds. Overall, these shortcomings could lead to "cliff effects" and would amplify the impact of procyclical-regulatory effects (Lenarčič et al., 2016; Lanotte et al., 2016). To reduce the reliance on external ratings and to mitigate their shortcomings, the BCBS (2017) discusses the role of additional non-rating indicators to assess the creditworthiness of sovereign exposures.

Introducing a non-zero risk-weight floor for sovereign exposures in the standardised approach implies that banks would have to back all of their sovereign exposures with some capital. This regulation would mainly affect the risk weights of highly rated sovereign exposures (with risk weights below the floor), and the risk weights of sovereign securities which benefit from the domestic carve-out (ESRB, 2015, p. 120). The resulting effects from the regulatory change would depend on the level of the risk-weight floor. An advantage of the risk-insensitive floor is that it could reduce the excessive build-up of banks' sovereign exposures, and that it could make banks more resilient to sovereign risk over the economic cycle. Furthermore, the floor system would align the favourable treatment of sovereign exposures with respect to other asset classes, as it would bring the risk weights of sovereign bonds and other asset classes closer together. In a way, the leverage ratio, introduced under Basel III (see Section 2.3), can be seen as a risk-weight floor for sovereign exposures. A leverage ratio of 3%, for example, implies a risk weight for sovereign bonds of approximately 37.5%, for a bank with a targeted capital ratio of 8%. However, note that the leverage ratio is only binding for banks with a risk-weighted capital ratio which is below the leverage ratio.

Within the IRB approach, banks are allowed to calculate the risk weights for given asset classes on their own internal rating systems. The ESRB (2015) discusses the effects of a hard floor rule for sovereign risk weights, and (regulatory) floors for the PDs and LGDs of sovereign exposures under the IRB approach. Sovereign bonds would assign positive risk weights under both proposals. A hard floor rule for risk weights in the IRB approach has similar advantages and disadvantages as under the standardised approach discussed in the previous paragraph. Regulatory floors for the PDs and LGDs of sovereign exposures would limit the freedom of banks to calculate sovereign credit risks with their own internal rating systems. The estimation of sovereign credit risk parameters are in general difficult for banks due to the poorness of data regarding sovereign defaults in the near past (ESRB, 2015, p. 124). The ESRB (2015) describes two experiments in which banks had to assign PDs and LGDs for sovereigns. The results show significant variations across banks in their estimations of the credit risk parameters for the same sovereigns. Owing to the estimation difficulties, the BCBS (2017) proposes the removal of the IRB approach for sovereign exposures. Nevertheless, regulatory floors for the PDs and LGDs would restrict banks from underestimating sovereign default risk. Moreover, in contrast to the standardised approach, which bundles credit risks in buckets, the IRB approach has the advantage of being based on a continuous function (depending on the estimations of credit risk parameters). Hence, "cliff effects" which could be an issue under the standardised approach, do not arise under the IRB approach.

Impact on Banks and Financial Stability

The introduction of positive risk weights for government bonds – either determined under the standardised approach or under the IRB approach – would induce an increase in the risk-weighted assets of banks which are affected by this regulation (Lenarčič et al., 2016, p. 18 f.). If due to the regulatory change their capital ratio becomes binding, banks will have four options to cope with this regulation: (i) they can substitute their sovereign holdings with zero-risk-weighted assets and keep their liability structure unchanged, (ii) they can sell excess sovereign bonds and reduce their outstanding debt, (iii) they can substitute their sovereign holdings with other positive risk-weighted assets and increase their amount of equity funding, (iv) they can keep their investments unchanged and raise more equity.

According to Lenarčič et al. (2016), banks would choose one of the first two options (or a combination of both) to deal with the regulatory change, i.e. they would substitute their sovereign holdings with zero-risk-weighted assets (in order to keep the original risk-weighted assets constant), or they would sell sovereign bonds with positive risk weights and reduce their outstanding debt simultaneously. The advantage of these two strategies would be that both are not accompanied by raising equity capital, which is costly and would be difficult for some banks to implement. In the short run or during the transition period, it would be likely that banks substitute high risk-weighted government bonds with zero-risk-weighted assets (for example, zero-risk-weighted sovereign bonds, central bank reserves or cash).[19] However, this strategy would reduce banks' profitability as high risk-weighted sovereign bonds usually yield higher returns than zero-risk-weighted assets. Therefore Lenarčič et al. (2016) expect that, in the longer run, more banks would shed high risk-weighted sovereign bonds and reduce their debt simultaneously. This strategy would be hard to implement in the short run, as the banks' funding structure could limit the ability to deleverage immediately. Banks which do not have issues over increasing their own funds could fulfil the capital ratio with the third and/or the fourth policy option, i.e. they could substitute their sovereign holdings with non-zero risk-weighted assets and increase their amount of equity capital, or they could keep their investments unchanged and only raise additional equity. Lenarčič et al. (2016) emphasise that these two options are only likely for banks which could increase their amount of equity capital via retained earnings. In all policy options (except the first one) the banks' equity ratio would increase. With respect to financial stability, higher banks' equity ratios can reduce systemic risk in the banking sector as the expansion of shocks can be mitigated (Adrian and Shin, 2010). However, on the other hand, higher equity ratios lead to an increase in banks' funding costs.

There are some studies for the euro area quantifying the consequences of capital requirements for government bonds. Based on data from the European Banking Authority (EBA) transparency exercise published in 2013, Lenarčič et al. (2016) show that by using standardised risk weights, banks in Italy and Spain have the largest sovereign bond holdings for which positive risk weights would apply (with €200 billion exposures and €170 billion exposures respectively). The third and the fourth highest amount of sovereign bond holdings that would have positive risk weights are held by banks in Germany and France (with amounts around €60 billion to €70 billion). In a similar way, Lanotte et al. (2016)

[19] Whether for all sovereign bonds positive risk weights would apply is dependent on the reform. The abolishment of the domestic carve-out in the standardised approach would induce that they were still sovereign bonds from the EMU countries with zero-risk weights. However, a regulatory floor for sovereign exposures would imply that all sovereign bonds have to be backed with some capital.

show that the strongest reduction in the banks' capital ratios would be for Portuguese, Italian and Spanish banks.[20] The reason is that banks in these countries are heavily exposed to their national sovereigns and the risk weights which would apply to the domestic sovereign bonds would be quite high (see Table 3).

To quantify the banks' reactions in response to an increase in risk-weighted assets, Lenarčič et al. (2016) simulate potential scenarios of banks' adjustment processes in the transition period. According to these simulations it is likely that banks in the euro area would meet the capital requirements with a combination of the options described before, depending on the level of the sovereign bonds' risk weights. In a simulation which is considered to be most realistic, Lenarčič et al. (2016) predict that banks would mainly sell sovereign bonds with the highest risk weights, i.e. Greek, Cypriot and Portuguese bonds, and they would increase their amount of equity capital (by €25 billion) to cover for lower risk-weighted sovereign bonds. In this scenario, 10% of the outstanding government debt in the affected countries would be sold (or reallocated) driven by the change in capital requirements for government bonds.

The overall quantitative impact of risk weights for government bonds on bank behaviour is difficult to predict. One of the main reasons is that there exists a range of motives for banks holding sovereign bonds (see Section 3.4). These motives would significantly determine bank behaviour if risk weights for government bonds were introduced (ESRB, 2015; Lenarčič et al., 2016). Note that sovereign risk weights would reduce the net yields of sovereign bonds. If banks hold sovereign bonds for investment reasons, only a small reduction in net yields would cause banks to make significant reallocations away from sovereign bonds. However, if banks hold sovereign bonds to fulfil the liquidity requirements, the reduction in sovereign bonds' net yields would only have a small impact on the banks' sovereign investments.

In a theoretical model, Neyer and Sterzel (2017) investigate the effects of positive risk weights for government bonds for bank investment and financing behaviour, and financial stability. They show that the introduction of positive risk weights for government bonds encourages banks to raise more equity capital and to adjust their investment structure. In particular, banks increase their investments in loans relative to their investments in

[20] Andritzky et al. 2016 come to similar results.

government bonds. In this model, banks hold government bonds to manage their liquidity needs. Higher sovereign default risk may induce a price drop for government bonds, implying liquidity issues in the banking sector. Capital requirements themselves cannot prevent illiquid but per se solvent banks from going bankrupt. However, in combination with a lender of last resort (LOLR) the introduction of positive risk weights for government bonds increases financial stability. The driving force is the regulation-induced change in bank investment behaviour.

Using a DSGE model, Abad (2018) shows that repealing the preferential treatment of government bonds in capital regulation has two effects for banks: First, it makes investing in government bonds less attractive. One, because equity funding is more costly than deposit funding, and two, due to the "skin-in-the-game" effect, meaning that the equity losses banks would suffer are higher in the case of a sovereign default. Second, it reduces banks' leverage and thus increases the resilience of the banking sector. Furthermore, Abad (2018) shows that capital requirements for government bonds are able to mitigate contagion effects from sovereigns to banks, hence making the banking sector more resilient to sovereign risk. Under the proposed calibration scheme of this model, a maximum social welfare exists at a government bond risk weight of 40%, for a given capital ratio of 8%.

With respect to financial stability, Abad (2018) as well as Neyer and Sterzel (2017) show that capital requirements for government bonds will make the banking sector more resilient to sovereign risk. However, Gros (2013) criticises that this kind of regulation will not be enough to disentangle the solvency of banks from the solvency of their national sovereigns. He argues that sovereign defaults are rare events, however, in the case of a sovereign default, the losses are quite large for bondholders (above 50%). Introducing a risk weight of 100% for government bonds (for a given capital ratio of 8%) would only cover losses of 8% in the case of a sovereign default. Thus, Gros (2013) highlights that diversification is much more important than backing sovereign bonds with equity capital.

5.2 Sovereign Exposure Limits

Both sovereign exposure limits and capital requirements for government bonds have the same objective, i.e. to increase the shock-absorbing capacity of the banking sector with respect to sovereign risk, and thus weaken the sovereign-bank nexus. Although the objective is the same, both regulation approaches differ from each other in the sense that large exposure limits address concentration risk, whereas positive risk weights address counterparty credit risk (Lenarčič et al., 2016, p. 3). There are proposals discussed in the literature which combine elements from sovereign exposure limits with elements from positive risk weights for government bonds (see, for example, BCBS (2017), ESRB (2015), Andritzky et al. (2016) or Matthes and Rocholl (2017)). In this paper, the regulation approaches are discussed in isolation.

Regarding the sovereign bond treatment under the large exposure framework, banks' exposures to sovereigns and their central banks are exempted from this regulation (see Section 2.4). The ESRB (2015) discusses a full and a partial removal of this exemption. A full removal implies that a bank's exposure to one sovereign is not allowed to be higher than 25% of its own funds. A partial removal implies that only a share of a bank's exposure to one sovereign is considered under the large exposure framework and the remaining share is still exempted. This is the case if, for example, sovereign exposures are considered for only 20% of their face value, implying that 80% of the sovereign exposures are exempted. Then, 20% of a bank's sovereign exposure is not allowed to be higher than 25% of its own funds.

Impact on Banks and Financial Stability

If sovereign exposure limits were introduced (either fully or partially) and became binding for banks, they would have four options to meet this requirement (Lenarčič et al., 2016, p. 30): (i) they could substitute their excess sovereign holdings with other zero-risk-weighted assets (for example, sovereign bonds from other countries, central bank reserves or cash) and keep the funding structure unchanged, (ii) they could sell excess sovereign bonds and reduce their outstanding debt simultaneously, (iii) they could substitute their sovereign holdings with non-zero-risk weighted assets and raise equity capital, or (iv) they could keep their investments unchanged and raise more equity.

As these policy options are similar to the options when sovereign bonds had to be backed with equity capital, the argumentation of Lenarčič et al. (2016) is also similar.

They argue that banks would fulfil the sovereign exposure limit either by the first or the second adjustment strategy, i.e. they would substitute their sovereign holdings with other zero-risk-weighted assets and keep their funding structure unchanged, or they would sell excess sovereign bonds and reduce their outstanding debt simultaneously. In the short run, it is expected that banks would try to diversify their sovereign bond holdings by replacing (domestic) sovereign bonds with sovereign bonds of other countries with similar risk profiles. However, it is questionable whether banks would find enough government bonds with similar risk profiles on the government bond market (Lenarčič et al., 2016, p. 30). If there were insufficient close substitutes on the government bond market, banks could deposit the liquidity generated by selling the excess sovereign bonds at the central bank or they could hold more cash. As both options usually yield a lower return than government bonds, this strategy would reduce banks' profitability. Banks could also fulfil the sovereign exposure limit by selling excess sovereign bonds and reducing their outstanding debt simultaneously (Lenarčič et al., 2016, p. 30). However, this could be problematic for some banks as, in the short run, the rigid banks' funding structure could limit the ability to deleverage immediately. Similar to the argumentation in the previous section, it is unlikely that banks would choose the third or fourth adjustment strategy, as these two strategies are accompanied by an increase in equity capital. In all adjustment strategies (except the first one) the banks' equity ratio increases, which would increase the banks' funding costs. However, in the long run, it is expected that banks' funding costs will decrease again as banks' balance sheets become more diversified and therefore less risky. With respect to financial stability, Lenarčič et al. (2016), ESRB (2015) and the European Political Strategy Centre (2015) predict that large exposure limits for sovereign bonds would make banks less vulnerable to sovereign risk due to their better diversified sovereign bond portfolios.[21]

To quantify the effects of a full removal, Lenarčič et al. (2016) simulate the rebalancing needs in EU banks based on data from the EBA transparency exercise 2013. It is shown that banks in high-rated small countries (between AAA and A-, for example, Austria and Belgium), would satisfy their government bond rebalancing needs with sovereign bonds

[21]The European Political Strategy Centre (2015, p. 4) concludes that:"A straightforward exposure regime would greatly limit systemic risk in the banking system, result in a well-diversified government debt portfolio and considerably weaken the doom loop between sovereigns and their banking systems."

from other high-rated small countries (for example, Luxembourg). Banks in Greece and Portugal would need to substitute their excess sovereign bonds with higher rated sovereign bonds, as their domestic sovereign bonds have the lowest ratings within the EMU. The highest rebalancing needs would arise for German and Italian banks (with €273.41 billion and €177.32 billion respectively).[22] Banks in these two countries would not find enough government bonds with similar risk levels in order to substitute their large domestic sovereign holdings. As a result, German and Italian banks would have to sell excess sovereign bonds, or they could keep their investments unchanged and raise more equity. The latter option is less likely, at least in the short run.

The ESRB (2015) emphasises that the implementation of sovereign exposure limits could significantly restrict important bank activities and that it could interfere with other forms of regulation. Considering that banks have an important role as primary dealers for issuing sovereign bonds, and also acting as market-makers, the large exposure limits for sovereign bonds could seriously restrict these functions. This regulation would restrict banks from holding large amounts of the same sovereign bonds, which is however necessary for these activities. Moreover, the introduction of sovereign exposure limits could interfere with other forms of regulation as liquidity requirements (ESRB, 2015, p. 162). Within the LCR and the NSFR government bonds are classified as level 1 HQLA and banks are strongly incentivised to hold sovereign bonds rather than other liquid assets. Hence, the close relationships between regulatory tools should be carefully considered when reforming the large exposure regulation in order to avoid adverse effects for the banking sector and the whole economy.

5.3 Haircuts for Government Bonds

Within the Basel III Accord, two minimum standards for funding liquidity were introduced, the LCR and the NSFR. The LCR gives sovereign bonds preferential treatment in the sense that they are assigned as level 1 HQLA and that they do not need to be diversified within asset classes (see Section 2.5). The classification as level 1 HQLA implies that sovereign bonds are not subject to either quantitative limits or haircuts. Since sovereign

[22]In a similar study, Lanotte et al. (2016) reach identical results. They also show that the application of large exposure limits for sovereign bonds would have the largest impact for banks in Germany and Italy.

bonds are considered to be level 1 HQLA under the LCR, they are also given preferential treatment under the NSFR. Repealing the preferential treatment in liquidity regulation would induce that sovereign bonds are not automatically classified as level 1 HQLA and that they have to be diversified within their asset class. This removes the assumption that sovereign bonds always entail less liquidity risk than private sector bonds (ESRB, 2015, p. 143). If sovereign bonds were classified as "less-liquid", and thus as level 2 HQLA, quantitative limits and haircuts would apply to respective sovereign bonds, they would also assign a higher RSF factor under the NSFR.

In order to define the market liquidity of eligible HQLA properly, the ESRB (2015) proposes that the HQLA should be assessed based on market indicators of liquidity. These market indicators should be independent of whether bonds are public or private, that would make the assessment approach more market-oriented than the current one. The European Commission tasked the EBA with developing appropriate uniform definitions of liquid assets (EBA, 2013). An empirical analysis in the report shows that there is "some degree of differentiation in the liquidity features of different sovereign bonds". From a regulatory perspective, the different market liquidity of sovereign bonds should be taken into account. However, the ESRB (2015, p. 143) stresses that sovereign bonds' liquidity issues should be analysed further before changing the rules in liquidity regulation. In particular, it should be investigated whether the illiquidity of sovereign bonds is driven by fundamental characteristics of the respective sovereign or rather by the general market situation.

Impact on Banks and Financial Stability

In this research area there is very little literature addressing regulatory changes in liquidity regulation with respect to sovereign risk. Bonner (2016) does not deal directly with regulatory reforms, but he emphasises that the preferential sovereign bond treatment in liquidity regulation encourages banks to overinvest in sovereign bonds. Buschmann and Schmaltz (2017) underline that this preferential treatment in liquidity regulation endangers financial stability in sovereign crises. They advocate in favour of abolishing the preferential sovereign bond treatment in liquidity regulation.

In the following, consequences of introducing haircuts for "less-liquid" sovereign bonds within the LCR are discussed. To keep the analysis simple, it is assumed that there are three categories of liquid assets after the regulation: liquid assets which are not subject to haircuts with zero risk weights in capital regulation (for example coins, banknotes, central bank reserves and "high-liquid" sovereign bonds),[23] "less-liquid" sovereign bonds with low haircuts and zero risk weights, and other liquid assets with high haircuts and positive risk weights (for example, corporate debt securities or covered bonds). Banks holding "less-liquid" sovereign bonds would be affected by this regulation in the sense that their eligible amount of liquid assets would decrease. If banks can then no longer fulfil the LCR, they have the following options to increase their amount of liquid assets: (i) they can increase their liquid-asset exposures with no haircuts or low haircuts ("less-liquid" sovereign bonds) but no capital charges, (ii) they can increase their exposures of other liquid assets with high haircuts and positive capital charges, or (iii) they can restructure their stock of liquid assets, meaning that they can sell liquid assets which are subject to haircuts and buy liquid assets which are not subject to haircuts. Note that the higher the haircuts, the more liquid assets are needed to fulfil the liquidity ratio.

As long as sovereign bonds receive a zero risk weight in capital regulation, it is likely that banks would choose the first and/or the third option to meet the liquidity ratio, i.e. they would increase their liquid-asset exposures with no haircuts or low haircuts but no capital charges, or they would restructure their stock of liquid assets. With respect to the first option, banks would prefer to increase their investments in sovereign bonds rather than to hold more cash or to deposit a higher amount at the central bank, as sovereign bonds yield a higher return. Note that in the first option, banks would finance the liquid-asset investments only with debt, so that the banks' leverage ratio would increase. However, if the leverage ratio restriction is binding for banks, they could not increase their amount of liquid assets only with debt financing. The only option for banks to fulfil the regulation by keeping the funding structure unchanged is to substitute "less-liquid" sovereign bonds with no-haircut liquid assets (option three). Also in this case, banks would prefer to increase their sovereign exposures rather than their cash or central bank reserves. Banks

[23] Whether for all sovereign bonds haircuts apply or not depends on the regulatory reform. In this paper it is assumed that there are two types of sovereign bonds: "high-liquid" sovereign bonds with no haircuts and "less-liquid" sovereign bonds with positive haircuts.

could also increase their investments in liquid assets with positive risk charges to fulfil the liquidity ratio (option two). However, in this case banks would have to increase their amount of equity, which is unlikely for banks in the short run and especially difficult for stressed banks. In each of the options described above, the banks' profitability decreases as banks would be forced to hold more liquid assets which, in general, yield a low return. It is crucial that as long as sovereign bonds receive a zero risk weight in capital regulation, banks would be strongly incentivised to fulfil the changed regulation with sovereign bonds. With respect to financial stability, banks' higher sovereign exposures (which would not be covered with equity capital) and an increase in the leverage ratio would make them more vulnerable to sovereign risk.

In a theoretical model, Neyer and Sterzel (2018) investigate the consequences for banks' investment and financing behaviour, and financial stability of haircuts for sovereign bonds within the liquidity regulation framework. Basically, a binding liquidity ratio forces banks to increase their liquid asset holdings. In their model, liquid assets consist of short-term assets and government bonds. Banks hold these liquid assets to manage their liquidity needs. Considering sovereign bonds to be less liquid than the short-term asset within the liquidity ratio, forces banks to hold even more liquid assets. The regulation does not change the optimal composition of banks' liquid assets (the ratio between sovereign bonds and the short-term asset), meaning banks also hold more sovereign bonds. With respect to financial stability, they find that introducing liquidity requirements and repealing the preferential treatment of government bonds in particular does not contribute to a more robust banking sector in times of sovereign distress. The reason is that due to this regulation banks hold more sovereign bonds and are hence more vulnerable to increasing sovereign default risk.

6 Conclusion

Under the existing Basel framework, sovereign bonds are considered to be risk-free and highly liquid. The European sovereign debt crisis has shown that this is actually not the case. Neglecting sovereign risk in banking regulation endangers financial and macroeconomic stability. In the paper, an overview of regulatory reforms regarding the abolishment of the preferential sovereign bond treatment is given. It is discussed which effects these reforms would have for bank behaviour and financial stability. Three reforms are considered: (i) positive risk weights for government bonds in bank capital regulation, (ii) sovereign exposure limits, and (iii) haircuts for government bonds in bank liquidity regulation.

Concerning the banks' reaction in response to the reforms, it is pointed out that all reforms would lead to large adjustments in banks' balance sheets. In order to avoid abrupt bank reactions, a special focus should lie on the design of the transition period when repealing the preferential sovereign bond treatment. Moreover, the implementation date should be well-selected since all reforms would reduce banks' profitability, at least in the short run. Hence, in times of low interest rates or during economic downturns the introduction of these regulatory reforms could endanger the banks' solvency.

With respect to financial stability, it is shown that two of the three reforms, namely positive risk weights for government bonds and sovereign exposure limits, would make banks more resilient to sovereign risk. In particular, capital charges for government bonds would address sovereign credit risk and sovereign exposure limits would address concentration risk. Hence, both regulatory instruments would be able to make banks more resilient to sovereign risk. In contrast to these reforms, haircuts for sovereign bonds in liquidity regulation could make banks more vulnerable to sovereign risk and would not contribute to a more resilient banking sector. This is because they would incentivise banks to hold even more sovereign bonds which could be financed only with debt (as long as sovereign bonds do not have to be backed with equity). As a result, banks' leverage ratio would increase and the already strong link between sovereign risk and banks would be reinforced.

Side effects of regulatory effects should also be considered in order to avoid adverse effects for the banking sector. The discussion shows that changing the sovereign bond treatment in one field of banking regulation, for example, the large exposure framework, could be in conflict with other fields of regulation, such as the liquidity regulation framework. This is because sovereign exposure limits would restrict banks' sovereign bond holdings, whereas the current sovereign bond treatment under liquidity regulation incentivise banks to hold large amounts of sovereign bonds. Considering that the existence of a risk-free asset is crucial for banking practice, changing the regulation in the sense that some sovereign bonds are considered to be risky and less liquid, would increase the banks' demand for risk-free assets. Against this background, it is questionable whether banks would find enough close substitutes in the financial market with a "risk-free" status.

Nevertheless, a first step toward a regulatory framework which considers sovereign risk has already been made with the introduction of the leverage ratio introduced under Basel III. Within the leverage ratio, sovereign exposures do not receive a favourable treatment, meaning that the banks' total exposures have to be backed with equity capital – sovereign bonds also. However, this regulation is only binding for banks with a risk-weighted capital ratio below the leverage ratio.

Finally, the discussion points out that an increase in sovereign risk can severely strain the banking sector. Regulatory reforms such as the risk-weighting of sovereign exposures and the sovereign exposure limits could increase the resilience of the banking sector. However, it has also been shown that these reforms might lower the demand for sovereign bonds. This could lead to a decrease in sovereign bond prices and increasing yields which could be an issue for countries with large public debt. In this context, it should be noted that this paper does not discuss the effects of repealing the preferential sovereign bond treatment in banking regulation for sovereigns and their financing conditions – and it was also not the aim of the paper.

Bibliography

Abad, J. (2018). Breaking the feedback loop: Macroprudential regulation of banks' sovereign exposures. mimeo.

Acharya, V. and R. G. Rajan (2013). Sovereign debt, government myopia, and the financial sector. *The Review of Financial Studies 26*(6), 1526–1560.

Acharya, V. V. and S. Steffen (2015). The "greatest" carry trade ever? Understanding eurozone bank risks. *Journal of Financial Economics 115*(2), 215–236.

Adrian, T. and H. S. Shin (2010). Liquidity and leverage. *Journal of Financial Intermediation 19*(3), 418–437.

Alesina, A., M. de Broeck, A. Prati, and G. Tabellini (1992). Default risk on government debt in OECD countries. *Economic Policy 7*(15), 427–463.

Andritzky, J., N. Gadatsch, T. Körner, A. Schäfer, and I. Schnabel (2016). Removing privileges for banks' sovereign exposures – a proposal. *European Economy* (1), 139–153.

Ari, A. (2016). Sovereign risk and bank risk-taking. ECB Working Paper, No. 1894, European Central Bank.

Bank for International Settlements (2018). History of the Basel Committee. Available at `https://www.bis.org/bcbs/history.htm`. Accessed: 2019-03-21.

Barrios, S., P. Iversen, M. Lewandowska, and R. Setzer (2009). Determinants of intra-euro area government bond spreads during the financial crisis. Economic Papers, No. 388, European Commission.

Baum, C. F., D. Schäfer, and A. Stephan (2016). Credit rating agency downgrades and the eurozone sovereign debt crises. *Journal of Financial Stability 24*, 117–131.

Bayer, C., C. Kim, and A. Kriwoluzky (2018). The term structure of redenomination risk. DIW Discussion Papers No. 1740, Deutsches Institut für Wirtschaftsforschung.

BCBS (1988). International convergence of capital measurement and capital standards. Bank for International Settlements.

BCBS (2000). Principles for the management of credit risk. Bank for International Settlements.

BCBS (2004). International convergence of capital measurement and capital standards: A revised framework. Bank for International Settlements.

BCBS (2005). The application of Basel II to trading activities and the treatment of double default effects. Bank for International Settlements.

BCBS (2006). International convergence of capital measurement and capital standards: A revised framework – comprehensive version. Bank for International Settlements.

BCBS (2010a). Basel III: A global regulatory framework for more resilient banks and banking systems. Bank for International Settlements.

BCBS (2010b). Basel III: International framework for liquidity risk measurement, standards and monitoring. Bank for International Settlements.

BCBS (2013). Basel III: The liquidity coverage ratio and liquidity risk monitoring. Bank for International Settlements.

BCBS (2014a). Basel III leverage ratio framework and disclosure requirements. Bank for International Settlements.

BCBS (2014b). Basel III: The net stable funding ratio. Bank for International Settlements.

BCBS (2014c). Supervisory framework for measuring and controlling large exposures. Bank for International Settlements.

BCBS (2016). Minimum capital requirements for market risk. Bank for International Settlements.

BCBS (2017). The regulatory treatment of sovereign exposures. Discussion Paper, Bank for International Settlements.

Becker, B. and V. Ivashina (2017). Financial repression in the European sovereign debt crisis. *Review of Finance 22*(1), 83–115.

Bolton, P. and O. Jeanne (2011). Sovereign default risk and bank fragility in financially integrated economies. *IMF Economic Review 59*(2), 162–194.

Bonner, C. (2016). Preferential regulatory treatment and banks' demand for government bonds. *Journal of Money, Credit and Banking 48*(6), 1195–1221.

Broner, F., A. Erce, A. Martin, and J. Ventura (2014). Sovereign debt markets in turbulent times: Creditor discrimination and crowding-out effects. *Journal of Monetary Economics 61*, 114–142.

Bundesverfassungsgericht (2016). Constitutional complaints and Organstreit proceedings against the OMT programme of the European Central Bank unsuccessful. Press release No. 34/2016 of 21 June 2016.

Buschmann, C. and C. Schmaltz (2017). Sovereign collateral as a trojan horse: Why do we need an LCR+. *Journal of Financial Stability 33*, 311–330.

CGFS (2011). The impact of sovereign credit risk on bank funding conditions. CGFS Papers, No. 43, Bank for International Settlements.

Chari, V. V., A. Dovis, and P. J. Kehoe (2014). On the optimality of financial repression. mimeo.

Court of Justice of the European Union (2018). The ECS's PSPP programme for the purchase of government bonds on secondary markets does not infringe EU law. Press release No. 192/18 of 11 December 2018.

Damodaran, A. (2010). Into the abyss: What if nothing is risk free? mimeo.

Das, U. S., M. G. Papaioannou, and C. Trebesch (2012). Sovereign debt restructurings 1950–2010: Literature survey, data, and stylized facts. IMF Working Paper, No. WP/12/203, International Monetary Fund.

De Marco, F. and M. Macchiavelli (2016). The political origin of home bias: The case of Europe. Finance and Economics Discussion Series, No. 2016-060, Federal Reserve System.

Di Cesare, A., G. Grande, M. Manna, and M. Taboga (2012). Recent estimates of sovereign risk premia for euro-area countries. Occasional Paper, No. 128, Banca D'Italia.

EBA (2013). Report on appropriate uniform definitions of extremely high quality liquid assets (extremely HQLA) and high quality liquid assets (HQLA) and on optional requirements for liquid assets under Article 509(3) and (5) CRR.

ECB (2010). ECB announces change in eligibility of debt instruments issued or guaranteed by the Greek government. Available at `https://www.ecb.europa.eu/press/pr/date/2010/html/pr100503.en.html`. Press Release, Accessed: 2018-12-18.

ESRB (2015). ESRB report on the regulatory treatment of sovereign exposures. Available at `http://www.esrb.europa.eu/pub/pdf/other/`

esrbreportregulatorytreatmentsovereignexposures032015.en.pdf?c0cad80cf39a74e20d9d5947c7390df1. Accessed: 2018-12-18.

European Political Strategy Centre (2015). Severing the 'doom loop', further risk reduction in the banking union. Five Presidents' Report Series, No. 3, European Commission.

Gennaioli, N., A. Martin, and S. Rossi (2014). Sovereign default, domestic banks, and financial institutions. *The Journal of Finance 69*(2), 819–866.

Gros, D. (2013). Banking union with a sovereign virus. *Intereconomics 48*(2), 93–97.

Klose, J. and B. Weigert (2014). Sovereign yield spreads during the euro crisis: Fundamental factors versus redenomination risk. *International Finance 17*(1), 25–50.

Lanotte, M., G. Manzelli, A. M. Rinaldi, M. Taboga, and P. Tommasino (2016). Easier said than done? Reforming the prudential treatment of banks' sovereign exposures. *European Economy* (1), 73–104.

Lenarčič, A., D. Mevis, and D. Siklós (2016). Tackling sovereign risk in European banks. Discussion Paper Series, No. 1, European Stability Mechanism.

Matthes, D. and J. Rocholl (2017). Breaking the doom loop: The euro zone basket. ESMP White Paper, No. WP-17-01, ESMT European School of Management and Technology.

Neyer, U. and A. Sterzel (2017). Capital requirements for government bonds – Implications for bank behaviour and financial stability. DICE Discussion Paper, No. 275, Heinrich-Heine-Universität Düsseldorf.

Neyer, U. and A. Sterzel (2018). Preferential treatment of government bonds in liquidity regulation – Implications for bank behaviour and financial stability. DICE Discussion Paper, No. 301, Heinrich-Heine-Universität Düsseldorf.

Pepino, S. (2015). *Sovereign risk and financial crisis: The international political economy of the eurozone*. Basingstoke: Palgrave Macmillan.

Reinhart, C. M. and K. S. Rogoff (2010). *This time is different: Eight centuries of financial folly*. Princeton: Princeton University Press.

Weidmann, J. (2016). Dinner speech at the 6th Frankfurt Finance Summit, Frankfurt Main, May 11th. Available at https://www.bundesbank.de/en/press/speeches/dinner-speech-667106. Accessed: 2018-09-03.

Zettelmeyer, J., C. Trebesch, and M. Gulati (2013). The Greek debt restructuring: An autopsy. *Economic Policy 28*(75), 513–563.

Paper II:

Capital Requirements for Government Bonds – Implications for Bank Behaviour and Financial Stability*

Ulrike Neyer André Sterzel

Abstract

This paper analyses whether the introduction of capital requirements for bank government bond holdings increases financial stability by making the banking sector more resilient to sovereign debt crises. Using a theoretical model, we show that a sudden increase in sovereign default risk may lead to liquidity issues in the banking sector. Our model reveals that only in combination with a central bank acting as a lender of last resort, capital requirements for government bonds increase the shock-absorbing capacity of the banking sector and thus financial stability. The driving force is a regulation-induced change in bank investment behaviour.

JEL classification: G28, G21, G01.

Keywords: bank capital regulation, government bonds, sovereign risk, financial contagion, lender of last resort.

*We thank Matteo Crosignani, Maximilian Horst, Daniel Stempel, Jennifer Rontanger, three anonymous referees as well as participants at the 45th EFA Annual Meeting in Warsaw 2018, the 50th MMF Annual Conference in Edinburgh 2018, the 35th International Symposium on Money, Banking and Finance in Aix en Provence 2018, the Annual Conference of the VfS in Vienna 2017, the 10th RGS Doctoral Conference in Economics in Dortmund 2017, the 6th Workshop Banks and Financial Markets in Austria 2016, the Conference on Banking & Finance in Portsmouth 2016, the International Conference on Economic Prospects for the EU – Challenges for Economic Policy Until the End of the Decade in Düsseldorf 2016, and the 31st Annual Congress of the EEA in Geneva 2016 for very helpful comments and suggestions. Moreover, we have benefited from discussions with seminar audiences at the Paper Presentation Session Regulation of Banks and Risk Management in a Post Crisis World in Barcelona 2016, the Research Seminar Financial Markets and Financial Management in Düsseldorf 2015 and 2017, the Inter-University Doctoral Programme in Economics (MAGKS) in Rauischholzhausen 2015 and 2017, the Winter School on Applied Microeconomics: Theory and Empirics in Saas-Fee 2019, and the DICE Brown-Bag Seminar in Düsseldorf 2016.

Contents

List of Tables

List of Figures

1 Introduction

During the European sovereign debt crisis of 2009 onwards, significant contagion effects from sovereigns to banks could be observed. Serious doubts about the solvency of some EU member states put pressure on the balance sheets of banks with large sovereign debt exposures. Compared to other assets, sovereign debt is given privileged treatment in banking regulation with respect to capital and liquidity requirements as well as to large exposure regimes. Against this background, there is an ongoing debate about whether the abolishment of the preferential treatment of sovereign borrowers in banking regulation can mitigate possible contagion effects from sovereigns to banks. Jens Weidmann, president of the Deutsche Bundesbank, for example, strongly advocates in favour of the abolishment:

> "There is one field in regulation, however, where too little has been done so far – the treatment of sovereign exposures in banks' balance sheets. A banking system can only truly be stable if the fate of banks does not hinge on the solvency of their national sovereigns. Thus, I have been advocating, for quite some time now, a phasing-out of the preferential treatment of sovereign borrowers over private debtors."(Weidmann, 2016)

This paper deals with the preferential government bond treatment in capital regulation. Although the default probability of some EU Member States deviates significantly from zero, banks do not have to back the government bonds of these countries with equity. These bonds are assigned a zero risk weight in bank capital regulation.[1] European banks have significant euro exposures to sovereign debt, in particular banks in stressed euro area countries have more than doubled their total euro area sovereign debt exposures in recent years (see Figure 1). The problem is that banks' sovereign holdings can act as a contagion channel through which sovereign distress can severely affect the banking sector. Against this background, this paper investigates within a theoretical model whether the contagion channel from sovereigns to banks can be weakened through the introduction of capital requirements for government bonds, thereby making the banking sector more resilient to sovereign debt crises.

[1] See Capital Requirement Regulation (CRR) Article 114. The CRR and Capital Requirement Directive (CRD) IV implemented the Basel III Accords in EU law.

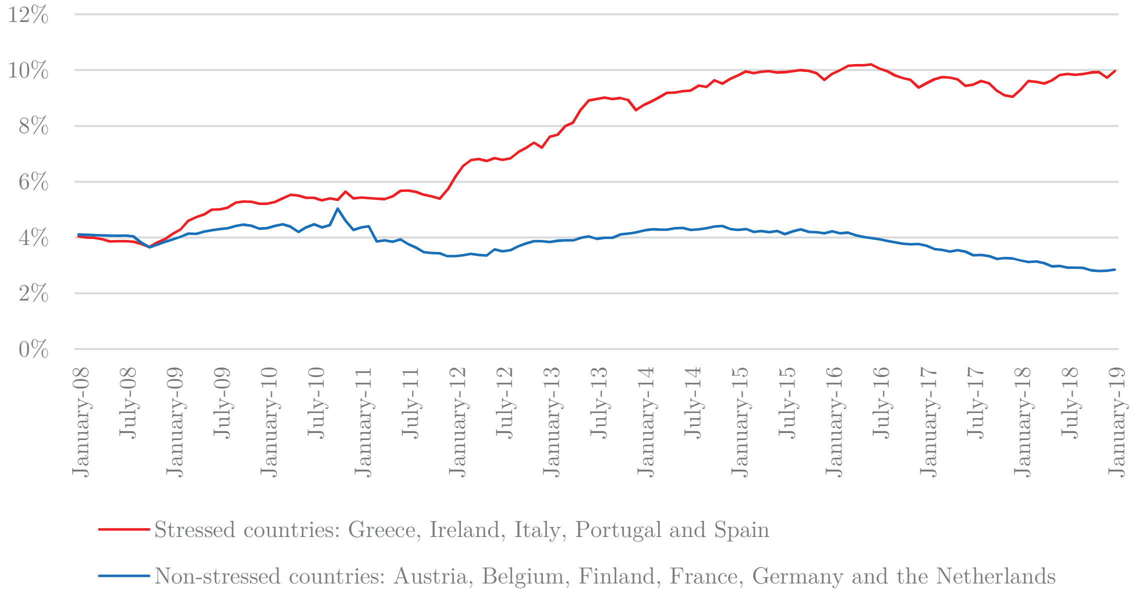

Figure 1: Banks' Total Euro Area Sovereign Debt Holdings as a Percentage of Their Total Assets in Certain Stressed and Non-Stressed Euro Area Countries, *Data Source: European Central Bank (ECB)*

In our model, we consider a banking sector raising deposits from risk-averse depositors. The banks' objective is to maximise their depositors' expected utility. The depositors have the usual Diamond-Dybvig preferences. These preferences imply that banks face idiosyncratic liquidity risks. Banks can invest in a risk-free short-term asset, which earns no 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.[2] Besides deposits, banks can raise equity capital to finance their investments. Raising costly equity capital allows banks to transfer the liquidity risks associated with highly profitable but totally illiquid loans from risk-averse depositors to risk-neutral investors. This increases depositors' expected utility as they can invest more in highly profitable but illiquid loans.

Within this model framework, in a first step we investigate the banks' investment and financing behaviour in different capital regulation scenarios. In the first considered scenario only loans have to be backed with equity, i.e. there is a preferential treatment of

[2]As pointed out by Gennaioli et al. (2018), for example, banks 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.

government bonds. It is shown that the introduction of this capital requirement implies that the potential for a beneficial liquidity risk transfer from depositors to investors is no longer fully exploited, resulting in a decrease of depositors' expected utility. However, banks adjust their investment behaviour in a way that mitigates the regulation-induced negative effect on their depositors' expected utility. If the newly introduced required capital ratio is relatively low (high), they will increase (decrease) their loan-to-liquid-asset ratio. In the second considered regulation scenario, we analyse the banks' reaction when, in addition to loans, risky government bonds also have to be backed with equity capital, i.e. when the preferential treatment of government bonds in capital regulation is repealed. This additional regulatory requirement further restricts the liquidity risk transfer from depositors to investors. To mitigate this negative effect, banks raise their investment in loans relative to their liquid asset holdings, increasing their loan-to-liquid asset ratio.

In a second step, we then investigate the banks' shock-absorbing capacity under the considered capital regulation scenarios. We suppose that the economy is hit by 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, leading to the insolvency of a huge number of banks (systemic crisis) which are illiquid but per se solvent. We show that capital requirements themselves cannot prevent illiquid but solvent banks from going bankrupt. However, combined with a central bank as a lender of last resort (LOLR) that provides additional liquidity against adequate collateral, the abolishment of the preferential treatment of government bonds in capital regulation increases the banking sector's shock-absorbing capacity. The driving force is that there is a regulation-induced change in bank investment behaviour (more loans relative to government bonds). This implies that banks then have more adequate collateral from which to obtain additional liquidity from the LOLR relative to the additional liquidity needs caused by the sovereign bond price drop.

The rest of the paper is structured as follows. Section 2 presents the related literature. Section 3 describes the model setup. Section 4 analyses both sides of the interbank market for government bonds and derives the market equilibrium. Section 5 outlines the liquidity-risk-transfer property of equity capital and derives the banks' optimal investment and financing behaviour in different capital regulation scenarios. Building on these analyses, Section 6 discusses the consequences of capital requirements for the 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 the literature. The first strand deals with financial contagion, the second with different institutions aiming to weaken the financial contagion channels between sovereigns and banks, and the third with the influence of capital requirements on bank behaviour.

In the literature, 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 if there is an interbank deposit market which allows banks to balance their different liquidity needs, a small liquidity preference shock initially affecting only one bank may spread to other banks, leading to the breakdown of the whole banking sector. Allen and Carletti (2006) model contagion effects from the insurance to the banking sector. The crucial point is that the credit-risk transfer between these sectors implies that banks and insurance companies hold the same securities. A crisis in the insurance sector forces the insurance companies to sell these securities. The resulting price drop of these assets then also affects banks' balance sheets, leading to severe problems in the banking sector. In a similar vein Heyde and Neyer (2010) show that credit-risk transfer within the banking sector may create a channel of financial contagion. Allen and Gale (2006) extend the Allen-Carletti model, enabling them to analyse the impact of bank capital regulation on systemic risk. They show that the introduction of binding capital requirements may increase systemic risk, as they induce inefficiencies for banks. These inefficiencies can be mitigated if banks share risks with the insurance sector. However, this risk-sharing increases the potential for contagion between banks and insurance companies.

Especially since the European sovereign debt crisis of 2009 onwards, there has been a growing theoretical literature on financial contagion between sovereigns and banks.[3] Gennaioli et al. (2014) identify banks' government bond holdings as a potential link through which a sovereign default can severely affect the banking sector. However, they claim that it is exactly the existence of this potential contagion channel which makes the occurrence of a strategic sovereign default less likely (and thus the occurrence of a banking crisis triggered by respective contagion). They argue that banks hold large amounts of domestic government bonds. This means that governments do not have an incentive to strategically default because a sovereign default would badly hit the domestic banking sector and thus the domestic economy.[4] In a similar way, Bolton and Jeanne (2011) analyse how much of an impact a sovereign default has on the banking sector in financially integrated economies. They find that, on the one hand, financial integration leads to risk diversification benefits for banks. However, on the other hand it generates a financial contagion channel between sovereigns and banks. Acharya et al. (2014) investigate the two-way-feedback risk transmission between sovereigns and banks. They argue that government bank bailouts lead to a rise in sovereign credit risk. This in turn weakens the banking sector as the value of the banks' sovereign bond holdings and the value of their implicit and explicit government guarantees decrease. Cooper and Nikolov (2013) also examine the diabolic loop between sovereigns and banks and, in this context, the role played by fiscal guarantees and equity capital. As a policy implication the authors stress the role of equity capital as an important regulatory tool to isolate banks from sovereign risk and they suggest the implementation of capital requirements on sovereign exposures. Broner et al. (2014) argue that in turbulent times sovereign debt offers a higher expected return to domestic than to foreign creditors (creditor discrimination). This is the case, as domestic residents are more likely to be treated favourably during a sovereign default. The creditor discrimination implies that banks increase their investment in domestic government bonds. If banks are financially constrained, which is especially the case in turbulent

[3] There is also a rapidly growing empirical literature on financial contagion between sovereigns and banks, see for example Acharya et al. (2014), Acharya and Steffen (2015), Altavilla et al. (2017) or Gennaioli et al. (2018).

[4] Acharya and Rajan (2013) analyse why countries have an incentive to serve their debt even if a government default would lead to little direct domestic cost. They argue that through a default, governments would lose access to debt markets, which would result in a decrease in fiscal spending and therefore in GDP, so that even short-horizon governments have an incentive to repay their debt.

times, this bank investment behaviour will be in line with a decrease of private sector loans (crowding-out effect). The bank investment behaviour not only reduces economic growth but also reinforces the risk of financial contagion between sovereigns and domestic banks.

Based on the literature dealing with the sovereign-bank doom loop, the second strand of related literature discusses different newly implemented or proposed institutions aiming to weaken the financial contagion channels between sovereigns and banks. One of the most prominent institutions to prevent contagion effects from banks to sovereigns is the European Banking Union, consisting of three pillars: the Single Supervisory Mechanism (SSM), the Single Resolution Mechanism (SRM) and the European Deposit Insurance Scheme (EDIS). Covi and Eydam (2018) argue that the *Bank Recovery and Resolution Directive* (BRRD), that implemented the SRM in European law, indeed weakens potential risk transmission from banks to sovereigns. They emphasis that due to the "bail-in" rule, bank insolvencies no longer strain public finances. With respect to the first pillar of the European Banking Union, the SSM, Farhi and Tirole (2018) show that a *shared supranational banking supervision* can diminish contagion effects from internationally operating banks to sovereigns. They claim that national governments may favour a lax banking supervision, particularly in times of a weak domestic banking sector, as losses in an internationally operating banking industry can be shifted to foreign investors. This issue can be mitigated with a shared supranational banking supervision. Note that only two of the three pillars, i.e. the SSM and the SRM have been implemented in European law, so far. Against this background, Acharya and Steffen (2017) underline the importance of a complemented European Banking Union and also of a *Fiscal Union* which are necessary for a functioning capital market union. They argue that there will only be fully integrated capital markets if the "risk-free" status of sovereign bonds from all EMU Member States is restored. For this outcome, a complemented European Banking Union and a Fiscal Union is required. Brunnermeier et al. (2016) develop a model which illustrates how to isolate banks from sovereign risk via the introduction of *European Safe Bonds* ("ESBies") issued by a European debt agency. They argue that holding these bonds disentangles banks from potential sovereign defaults, as ESBies are backed by a well-diversified portfolio of euro-area government bonds and are additionally senior on repayments. Then, in case of a sovereign default, banks holding ESBies would not be negatively affected. Buschmann and Schmaltz (2017) show that the existing preferential sovereign bond treatment in liquidity regulation reinforces the already strong link between sovereigns and banks. In order to mitigate contagion effects from sovereigns to banks, they propose an *alternative Liquidity Coverage Ratio* (LCR) which incorporates sovereign risk. Abad (2018) deals with the same institution as we do in this paper. He analyses the potential macroprudential implications of introducing *capital requirements for sovereign bonds* within a DSGE model. One of the main results is that capital requirements for government bonds can mitigate contagion effects between sovereigns and banks, and hence increase financial stability.

The third strand of related literature deals with the influence of capital requirements on bank behaviour. Kim and Santomero (1988) investigate the effects of bank capital regulation on banks' asset choices.[5] The authors show that a required uniform capital ratio may incentivise banks to reshuffle assets towards riskier ones which does not contribute to a more robust banking sector. The reason is that a uniform capital ratio ignores the banks' individual risk structure. However, a required risk-based capital requirement does not incentivise banks to increase their risky investments. Hence, it is able to make the banking sector more resilient as risk weights can be set appropriately, depending on the banks' individual risk structure. Regarding the banks' reaction in response to a binding required risk-weighted capital ratio, Blum (1999) comes to a different result. He points out that a binding required risk-weighted capital ratio may increase the risk-taking behaviour of banks. The argument is that banks will increase their risk today in order to yield higher returns tomorrow. These higher returns are necessary to fulfil the binding required capital ratio as equity capital is costly. Furlong and Keeley (1989) show that a value-maximising bank does not increase its asset risk in response to a higher required capital ratio. They emphasise that banks will meet a higher capital ratio by increasing equity capital, rather than by reducing debt. Hyun and Rhee (2011) find that the introduction of a binding required risk-adjusted capital ratio may imply that banks reduce their loan supply (instead of increasing their equity capital) to fulfil the capital requirement. In

[5] Flannery (1989) also analyses the banks' risk-taking incentives associated with higher capital requirements. However, the analysis focusses on the role played by the existence of a deposit insurance.

particular, the authors show that increasing equity capital is associated with a dilution of existing shareholders' value, whereas the reduction of loans is associated with lower loan returns. As long as the former effect exceeds the latter one, banks will reduce loan investment to cope with a higher required capital ratio. Harris et al. (2014) use a general equilibrium model to discuss the welfare consequences of higher bank capital requirements. They show that higher capital requirements have two effects for banks. The first effect, namely the funding capacity effect, incentivises banks to reduce credit supply, as it is less profitable for banks granting loans due to higher capital costs. The second effect arises as banks compete with outside investors (for example shadow banks). This effect causes banks to "search for yield" and forces them to increase their risky investments in order to stay profitable.

Our paper contributes to all three strands of the literature: In our theoretical analysis, banks hold government bonds to hedge their idiosyncratic liquidity risks. These government bond holdings generate a potential for financial contagion from sovereigns to banks (first strand). With respect to institutions aiming to weaken the financial contagion channel between banks and sovereigns (second strand), we derive that the introduction of binding capital requirements in general, and for government bond holdings in particular, are not sufficient to mitigate contagion effects from sovereigns to banks, but in addition, a central bank acting as a LOLR is necessary. Furthermore, we show how capital requirements influence bank investment and financing behaviour (third strand). Two capital regulation scenarios are considered. In the first scenario only loans have to be backed with equity capital. In the second scenario in addition to loans, government bonds also have to be covered by equity.

3 Model Framework

Our model is based on Allen and Carletti (2006). In the centre of the model is a banking sector, raising deposits from risk-averse consumers. The aim of the banks is to maximise depositors' expected utility. In doing so, banks can invest in three types of assets, in a short-term asset and in two long-term assets: government bonds and loans. Besides deposits, banks can raise equity capital from risk-neutral investors to finance their investments.

3.1 Technology

We consider three dates, $t = 0, 1, 2$ and a single all-purpose good that can be invested or consumed. 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, i.e. one unit at date 0 returns one unit at date 1. The two long-term assets are government bonds and loans. However, unlike in other theoretical works, government bonds are not completely safe but yield a random return S. With probability $1-\beta$ the investment fails and one unit of the all-purpose good invested in government bonds 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 at date 2. A government bond is a liquid asset and 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 $\alpha < \beta$. With probability $(1-\alpha)$ the investment fails and produces only $L < l < 1$ units at date 2. The loan portfolio is the asset with the highest expected return as $E(K) > E(S) > 1$ and the highest risk as the variance $Var(K) > Var(S)$. Furthermore, it is totally illiquid as loans cannot be traded at date 1. Banks discover whether the long-term assets succeed or fail at date 2. Table 1 summarises the returns on the different types of assets.

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

3.2 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 all-purpose good at date 0. 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

$$U(c) = ln(c). \tag{1}$$

However, at date 0 each consumer is unsure of their liquidity preference. He does not know whether he is an early or a late consumer. Therefore, he concludes 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.

While there is no aggregate liquidity risk (the fraction of early consumers is $\gamma = 0.5$ for sure) banks are subject to idiosyncratic liquidity risk. Accordingly, they do not know their individual proportion of early consumers. With probability ω a bank has a fraction γ_1 of early consumers and with probability $(1-\omega)$ a bank faces a fraction γ_2, with $\gamma_2 > \gamma_1$, of early consumers, 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 $\omega = 0.5$.[6] Because of this strong assumption, we have a) two types of banks: banks with only early consumers (*early banks*) and banks with only late consumers (*late banks*), and b) the probability of becoming an early or a late bank is 0.5 each. Banks can hedge their idiosyncratic liquidity

[6] 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 (3) 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.

risk by using an interbank market for government bonds: All banks invest in government bonds and the short-term asset at date 0. At date 1, when each bank has learnt whether it is an early or a late bank, it sells or buys government bonds in exchange for the short-term asset on the interbank market to balance its individual liquidity position.

In addition to the deposits, 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

$$U(e_0, e_1, e_2) = \rho(W_0 - e_0) + e_1 + e_2, \tag{2}$$

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

3.3 Optimisation Problem

As ex-ante, i.e. at date 0, all banks are identical, 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 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

$$\begin{aligned}\max E(U) = {} & 0.5ln(c_1) + 0.5[\alpha\beta ln(c_{2Hh}) + \alpha(1-\beta)ln(c_{2Hl}) \\ & + (1-\alpha)\beta ln(c_{2Lh}) + (1-\alpha)(1-\beta)ln(c_{2Ll})]\end{aligned} \tag{3}$$

$$\text{with} \quad c_1 = x + yp, \tag{4}$$

$$c_{2Hh} = uH + \left(\frac{x}{p} + y\right)h - e_{2Hh}, \tag{5}$$

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

$$c_{2Lh} = uL + \left(\frac{x}{p} + y\right) h - e_{2Lh}, \tag{7}$$

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

$$\text{s.t.} \quad \rho e_0 = 0.5(\alpha e_{2H} + (1-\alpha)e_{2L}) + 0.5(\alpha\beta e_{2Hh}$$

$$+ \alpha(1-\beta)e_{2Hl} + (1-\alpha)\beta e_{2Lh} + (1-\alpha)(1-\beta)e_{2Ll}), \tag{9}$$

$$CR^{min} = \frac{e_0}{\phi_x x + \phi_y y + \phi_u u}, \tag{10}$$

$$e_0 + 1 = x + y + u, \tag{11}$$

$$x, y, u, e_0, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll} \geq 0. \tag{12}$$

Equation (3) describes the expected utility of the bank's depositors. With probability 0.5 the bank is an early bank, i.e. all of its depositors are early consumers who 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 (4).

With probability 0.5 the bank is a late bank, i.e. 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, only the investment in the loan portfolio succeeds, only the investment in the government bonds succeeds, or both investments fail. We denote these four states simply as Hh, Hl, Lh Ll. Equations (5) to (8) 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 held by a late bank at date 2 consists of the units y it invested itself in government bonds at date 0, and of those it 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 date 2. Consequently, optimal deposit contracts between a bank and its risk-averse depositors require $e_1^* = 0$.

Equation (9) represents the investors' incentive-compatibility constraint. Investors will only be 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 (10) captures the capital requirements the bank may face. They are expressed as a required minimum capital ratio CR^{min} of the bank's equity e_0 to its (risk-)weighted assets $\phi_x x + \phi_y y + \phi_u u$. If $\phi_x = \phi_y = \phi_u = 0$, there will be no capital requirements. If $\phi_x = \phi_y = 0$ and $\phi_u > 0$, there will be a privileged treatment of (risky) government bonds as only loans are subject to financial regulation. This privileged treatment will be repealed if $\phi_y > 0$. Then, risky government bonds will also have to be backed with equity capital. The budget constraint is represented in equation (11), and the last set of constraints (12) represents the non-negativity constraints.

4 Interbank Market for Government Bonds

Before solving the banks' optimisation problem in the following section, we take a closer look at the interbank market for government bonds when there are no shocks. We show that in this case the equilibrium price for government bonds p^{**} is equal to one. 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.

$$\beta ln(h) + (1-\beta)ln(l) \geq ln(1) = 0. \tag{13}$$

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 at price p in exchange for their short-term asset if

$$\beta ln(h) + (1-\beta)ln(l) - ln(p) \geq ln(1), \tag{14}$$

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

$$p^{max} = h^{\beta} l^{(1-\beta)} \tag{15}$$

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 the banks are late banks, aggregate demand for government bonds at date 1 is

$$y^D = \begin{cases} 0.5\frac{x^*}{p} & \text{if} \quad p \leq p^{max}, \\ 0 & \text{if} \quad p > p^{max}. \end{cases} \tag{16}$$

Figure 2 illustrates this demand function. For all $p > p^{max}$ there is a perfectly inelastic demand for government bonds equal to zero. If p equals p^{max}, late banks are indifferent whether to buy government bonds or to keep their short-term asset, i.e. the demand for government bonds at this price is perfectly elastic. Equation 16 reveals that we break this in favour of selling the short-term asset in this case. 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

$$y^S = 0.5y^* \tag{17}$$

as illustrated in Figure 2.

Considering (16) and (17) and denoting the equilibrium price for government bonds p^{**},[7] the market clearing condition becomes

$$\frac{x^*}{p^{**}} = y^*. \tag{18}$$

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 $p^{**} < 1$,

[7] 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 interbank market equilibrium variables with **.

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 (13) and (15), $p^{max} \geq 1$, which implies that the interbank market is always cleared.

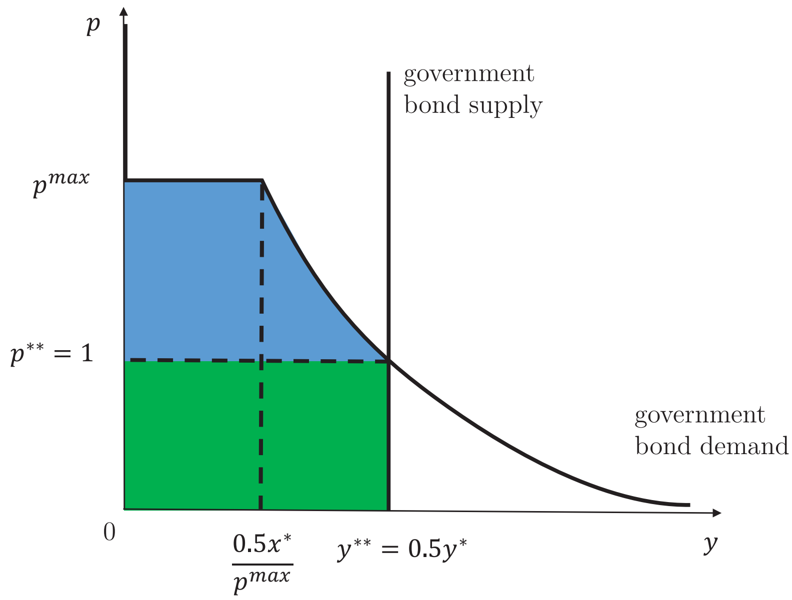

Figure 2: Interbank Market for Government Bonds at Date 1

Considering the aggregate demand and supply curves allows us to determine the surplus of the banking sector from interbank trading. The equilibrium government bond trading volume is denoted by y^{**}. The blue area reflects the surplus of the late banks. They benefit from interbank trading as the exchange of the short-term asset for government bonds leads to a higher expected utility of their depositors. The green area shows the surplus of the early banks from interbank trading. At date 1, government bonds produce no return so that their exchange in short-term assets allows for a higher date-1 consumption and thus a higher utility of early depositors.

5 Optimal Bank Investment and Financing Behaviour

This section analyses the impact of repealing the preferential treatment of government bonds in bank capital regulation on bank investment and financing behaviour. However, as a starting point we analyse bank behaviour without the possibility of raising equity capital. This allows us to point to the key property of equity capital in our model, which is the property to transfer liquidity risk from risk-averse depositors to risk-neutral investors and thereby to increase depositors' expected utility. The subsequent analysis shows that the introduction of binding capital requirements for loans yields that the potential for liquidity risk transfer is no longer fully exploited, which lowers depositors' expected utility. To compensate at least partially for this regulation-induced inefficiency, banks adjust their investment and financing behaviour. If the required minimum capital ratio for loans is relatively low, banks will raise more equity capital and will invest more in loans and in liquid assets. As the increase in loan investment is stronger than the increase in liquid asset holdings, the banks' loan-to-liquid-asset ratio increases. If the required minimum capital ratio for loans is relatively high, banks will raise more equity capital, they will invest less in loans and will increase their liquid asset holdings. In this case the banks' loan-to-liquid-asset ratio decreases. The introduction of capital requirements not only for loans but also for government bonds implies that the regulation-induced inefficiency will be reinforced. Aiming to reduce this inefficiency, banks raise additional equity capital, they grant more loans and they increase their liquid asset holdings. As the increase in loan investments is stronger than the increase in liquid asset holdings, the banks' loan-to-liquid-asset ratio increases when sovereign bonds are also subject to capital requirements.

To demonstrate a bank's optimal investment and financing behaviour in different regulation scenarios, we make use of a numerical example 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 $E(S) = 1.28$ 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 $\rho = 1.5$.

5.1 No Equity Capital

In the case with no equity capital, the constraints (9) and (10) are omitted, all $e_{(\cdot)} = 0$, and the budget restriction (11) becomes $x+y+u = 1$. Optimal banking behaviour in this case is shown in Table 2.

Balance Sheet

A			L
x^*	0.5	D	1
y^*	0.5		
u^*	0		
$\sum$	1	$\sum$	1

Deposit Contracts:

$c_1^* = 1 \quad c_{2h}^* = 1.3 \quad c_{2l}^* = 0.3$

$E(U) = 0.1165$

Proof: See Proof I in Appendix

Table 2: No Equity Capital: Banks' Optimal Balance Sheet Structure and Repayments to Depositors

Without having the opportunity to raise equity capital, banks invest their total amount of deposits in the short-term asset and in government bonds, i.e. only in liquid assets. They do not grant loans.[8] Basically, investing in loans has two effects on consumer consumption: First, it increases the expected consumption at date 2 as the expected loan return is higher than that of government bonds ($E(K) > E(S)$). Second, it decreases consumption at date 1 as, due to the budget constraint (11), an increase in loan investment implies a respective

[8]Diamond and Dybvig (1983) consider the explicit role of banks in an economy in the sense that banks transform illiquid assets into liquid liabilities, i.e. banks allow better risk-sharing among consumers with different consumption preferences. In our numerical example without equity capital, banks do not invest in illiquid loans so that banks are obsolete in this case. However, with the introduction of equity capital, banks start to invest in illiquid assets and create liquidity. Hence, there is a role for banks in our subsequent analyses.

decrease of investment in liquid assets ($\frac{\partial z}{\partial u}|_{no\ capital} = -1$), and early consumers are only repaid with the proceeds of the liquid assets. In our numerical example, the effects of the loans' illiquidity on consumption is so strong that even at point $u = 0$ the marginal utility of date-1 consumption exceeds the expected marginal utility of date-2 consumption, i.e. the non-negativity constraint on u becomes binding.[9]

Moreover, banks divide their investment equally into the liquid assets, $x^* = y^*$. 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 no aggregate liquidity uncertainty, so that at date 0 banks know the aggregate supply and demand in the government bond market for date 1 and, therefore, the equilibrium price $p^{**} = 1$ (see Section 4 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).

5.2 With Equity Capital

If banks have the opportunity to raise equity capital from investors, but do not face a required minimum capital ratio ($CR^{min} = 0$), we will get the solutions for optimal bank behaviour given in Table 3. Equity capital is costly for banks as the opportunity costs of investors, 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 ($\rho > E(K)$). Nevertheless, as shown by Table 3, banks have an incentive to raise equity capital, even when they are not subject to capital requirements. The reason is that raising equity allows them to transfer the liquidity risk involved with an investment in relatively highly profitable loans at least partly from risk-averse depositors to risk-neutral investors which leads to an increase in de-

[9]It is crucial that the banks' optimal investment behaviour depends on the consumers' expected utility of an investment in loans $EU^{loans} = \alpha ln(H) + (1-\alpha)ln(L)$ and the consumers' expected utility of an investment in government bonds $EU^{gov.\ bonds} = \beta ln(h) + (1-\beta)ln(l)$. If the variables determining the consumers' expected utility of an investment in loans, i.e. α, H and L, were changed, so that EU^{loans} substantially increased, the non-negativity constraint on u would not become binding and banks would invest in loans. However, this does not qualitatively change our results in the subsequent analyses.

Balance Sheet

A			L
x^*	0.4544	e_0^*	0.0853
y^*	0.4544	D	1
u^*	0.1765		
$\sum$	1.0853	$\sum$	1.0853

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 $\quad c_{2Hh}^*$=1.4532 $\quad c_{2Hl}^*$= 0.5444 $\quad c_{2Lh}^*$= 1.2256 $\quad c_{2Ll}^*$=0.3168

$E(U)$=0.1230

Proof: See Proof II in Appendix

Table 3: With Equity Capital: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors

positors' expected utility ($E(U)|_{CR^{min}=0} > E(U)|_{no\ capital}$, see Tables 2 and 3). Note, that a higher expected date-2 consumption ($E(c_2^*)|_{CR^{min}=0} = 1.4191 > E(c_2^*)|_{no\ capital} = 1.23$) implies that the consumers are willing to accept a repayment at date 1 of less than 1 ($c_1^* = 0.9088$).

A crucial point for our results is that with the possibility of raising equity capital, the banks' budget constraint is softened. In the case without this possibility (Section 5.1), an increase in loan investment leads to a decrease of investment in liquid assets to the same amount, $\frac{\partial z}{\partial u}|_{no\ capital} = -1$, and thus to a respective decline in date-1 consumption. However, with the possibility of raising equity capital, an increase in loans leads to a lower necessary decrease in liquid assets, $0 > \frac{\partial z}{\partial u}|_{CR^{min}=0} > -1$.[10] Consequently, an investment in relatively highly profitable but illiquid loans, which increases expected date-2 consumption, only implies a relatively small decrease of consumption at date 1, so that the depositors' expected utility increases.[11] The reason for the lower decrease in date-1

[10] In our numerical example $\frac{\partial z}{\partial u}|_{CR^{min}=0} = -0.5168 > -1 = \frac{\partial z}{\partial u}|_{no\ capital}$.

[11] Formally, with the possibility of raising equity capital, at point $u = 0$ the expected marginal utility of date-2 consumption exceeds the marginal utility of date-1 consumption, and it is optimal for banks to

consumption is that a 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 they are repaid at date 1 or date 2, so that it is optimal that they bear, at least partly, the liquidity risk involved with the banks' loan investment. The risk-averse depositors thus benefit from a liquidity risk transfer to the risk-neutral investors.

Optimal risk-sharing implies that the investors of an early bank receive the total proceeds from an early bank's loan investment[12] ($e_{2H}, e_{2L} > 0$), whereas the investors of a late bank receive nothing ($e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll} = 0$). Considering that investors thus get repaid with the total proceeds from the early 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 equity capital raised to be able to satisfy investors' claims. Formally, the investors' incentive-compatibility constraint given by equation (9) becomes $e_0\rho = 0.5uE(K)$, so that

$$\left.\frac{u}{e_0}\right|_{CR^{min}=0} = \frac{2\rho}{E(K)}. \tag{19}$$

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 to be able to satisfy investors' claims.[13] In our numerical example, loan investment must be at least $\frac{2\rho}{E(K)} = 2.0694$ higher than the amount of equity raised. Hence, it is not possible to finance additional loan investment exclusively by raising more equity. Consequently, also with the possibility of raising equity capital, an increase in loan investment is still associated with a decrease of investment in liquid assets, i.e. with a lower date-1 consumption for the depositors.

---

increase their investment in loans relative to their investment in liquid assets. This bank behaviour increases depositors' expected date-2 consumption and decreases their date-1 consumption and thus balances the marginal utilities.

[12]Note that they are totally useless for early consumers.

[13]In our model, the probability of becoming an early bank is $1 - \omega = 0.5$, see Section 3. Not inserting 0.5 for $1 - \omega$, we have $\frac{\rho}{(1-\omega)E(K)} = \frac{u}{e_0}|_{CR^{min}=0}$ which formally shows that investment in loans relative to the raised equity capital must be higher the lower the probability of becoming an early bank is, i.e. the lower the probability is that the investor actually gets repaid, and the lower the expected returns are of the loans compared to the investor's opportunity costs. Essentially, an increase in $\frac{\rho}{(1-\omega)E(K)}$ will increase the optimal investment in loans relative to equity capital, so that more deposits have to be used to finance loan investment (see equation (11)). The risk-averse depositors benefit less from liquidity risk transfer to the risk-neutral investors. Consequently, if $\frac{\rho}{(1-\omega)E(K)}$ increases banks will raise less capital and reduce their investment in loans.

Note that the banks' *optimal* loan-to-equity ratio is equal to $\frac{2\rho}{E(K)} = 2.0694$ as it is also shown by our results presented in Table 3: $\frac{u^*}{e_0^*} = 2.0694$. If $\frac{u}{e_0} < \frac{u^*}{e_0^*}$, the potential of a beneficial liquidity-risk-transfer will not be fully exploited. In this case, early bank loan investments are not sufficient to satisfy investors' claims. Banks make use of the possibility to invest in loans and to partly transfer the liquidity risk to risk-neutral investors, but at an inefficiently low level. Expected marginal utility of date-2 consumption exceeds the marginal utility of date-1 consumption. Hence, it is optimal for banks to increase their investment in loans relative to their investment in liquid assets to balance the (expected) marginal utilities of date-1 and date-2 consumption. If $\frac{u}{e_0} > \frac{u^*}{e_0^*}$, the potential of a beneficial liquidity-risk-transfer will be overexploited. The proceeds from early bank loan investments will allow them to repay investors, however, not all the proceeds will be used and they will be useless for early consumers. In this case, banks use the possibility to invest in loans and to transfer part of the liquidity risk, but at an inefficient high level. Marginal utility of date-1 consumption exceeds expected marginal utility of date-2 consumption and it is optimal for banks to reduce their investment in loans relative to their investment in liquid assets.

5.3 Binding Capital Requirement for Loans

In this section, we analyse bank behaviour when banks face a required minimum capital ratio with a preferential treatment of risky sovereign bonds. They are treated preferentially as – contrary to risky loans – they do not have to be backed with equity. We introduce a risk weight of 1 for loans, i.e. in constraint (10) we set $\phi_x = \phi_y = 0$ and $\phi_u = 1$. Hence, the capital regulation constraint becomes $CR^{min}|_{\phi_u=1,\phi_x=\phi_y=0} = \frac{e_0}{u}$. As the short-term asset does not have to be backed with capital in any of the capital regulation scenarios considered in this paper, we skip the subindex $\phi_x = 0$ throughout this paper for the sake of a clearer presentation. If banks do not face binding capital requirements (Section 5.2), they will choose an optimal capital ratio of $CR^{opt}|_{\phi_u=1,\phi_y=0} = \frac{e_0^*}{u^*} = \frac{0.0853}{0.1765} = 0.4833$. As we want to analyse the impact of a *binding* capital ratio on bank behaviour, $CR^{min}|_{\phi_u=1,\phi_y=0} > CR^{opt}|_{\phi_u=1,\phi_y=0}$ must hold. In our numerical analysis, we consider two different binding required capital ratios, $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$ and $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$.

The results for optimal bank behaviour under this additional constraint are displayed in Table 4. The comparison of the results given in Tables 3 and 4 reveals that the introduction

Balance Sheet

A			L		
$x^* =$	0.4591	(0.4909)	$e_0^* =$	0.1225	(0.1111)
$y^* =$	0.4591	(0.4909)	$D =$	1	
$u^* =$	0.2043	(0.1291)			
$\sum$	1.1225	(1.1111)	$\sum$	1.1225	(1.1111)

Contracts with Investors:

early banks:	e_{2H}^*=0.3147 (0.1988)	e_{2L}^*= 0.0511 (0.0323)			
late banks:	e_{2Hh}^*=0.0785 (0.1601)		e_{2Hl}^*=0 (0)	e_{2Lh}^*=0 (0)	e_{2Ll}^*=0 (0)

Deposit Contracts:

c_1^*= 0.9182 (0.9819)	c_{2Hh}^*=1.4299 (1.3152)	c_{2Hl}^*= 0.5901 (0.4934)	c_{2Lh}^*= 1.2448 (1.3088)	c_{2Ll}^*=0.3266 (0.3269)

$E(U)$=0.1222
(0.1176)

Proof: See Proof III in Appendix

Table 4: Capital Requirement for Loans: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors for $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$ and $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$ (The Results for the Latter are in Brackets)

of the binding required capital ratio for loans yields that the potential for liquidity risk transfer can no longer be fully exploited, $\frac{u^*}{e_0^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}} < \frac{u^*}{e_0^*}|_{CR^{min}=0}$. As a result, the depositors' expected utility decreases, $E(U)|_{CR^{min}|_{\phi_u=1,\phi_y=0}} < E(U)|_{CR^{min}=0}$. The comparison reveals furthermore, that the introduction of the relatively low capital ratio $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$ induces banks to raise more equity capital and to increase their investments in loans and liquid assets (short-term asset and government bonds). However, if the relatively high capital ratio $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$ is introduced, banks will raise more equity, they will increase their liquid asset holdings but they will reduce their loan investment. In the following, we explain this bank financing and investment behaviour in more detail.

Bank Behaviour Depending on the Size of $\mathbf{CR^{min}}$

In Section 5.2 it was shown that without capital requirements an investor will only get repaid if it turns out that his bank is an early bank. Then, at date 2, he receives the total proceeds from his bank's loan investment. Equation (19) shows that the expected returns from loans will only be sufficient to satisfy investors' claims if the loan investment is at least $\frac{2\rho}{E(K)}$ times higher than the raised equity capital. However, the capital regulation-induced decrease of $\frac{u}{e_0}$ implies that this is no longer the case, loan investment is less than $\frac{2\rho}{E(K)}$ times higher than the raised equity capital ($\frac{u}{e_0}|_{CR^{min}|_{\phi_u=1,\phi_y=0}} < \frac{u}{e_0}|_{CR^{min}=0} = \frac{2\rho}{E(K)}$). Expected returns from early bank loan investments are no longer sufficient to satisfy investors' claims. Consequently, late banks also have to pay a positive amount to their investors ($e_{2Hh}|_{CR^{min}=0} = 0$ but $e_{2Hh}|_{CR^{min}|_{\phi_u=1,\phi_y=0}} > 0$). Formally, the investors' incentive-compatibility constraint given by equation (9) becomes $e_0\rho = 0.5uE(K) + 0.5\alpha\beta e_{2Hh}$, so that

$$\frac{u}{e_0} = \frac{2\rho}{E(K)} - \frac{\alpha\beta e_{2Hh}}{E(K)e_0}, \quad \text{with} \quad e_{2Hh} > 0. \tag{20}$$

Considering that $\frac{u}{e_0} = \frac{1}{CR^{min}|_{\phi_u=1,\phi_y=0}}$, equation (20) reveals that the late banks' payment to their investors per unit of equity $\frac{e_{2Hh}}{e_0}$ increases in the required minimum capital ratio $CR^{min}|_{\phi_u=1,\phi_y=0}$.

We divide the following analysis of the changed bank investment and financing behaviour in response to the introduction of the binding required capital ratio for loans in two steps. First step: Banks increase e_0 while holding u constant to fulfil the capital requirement. The budget constraint then implies that the additional equity must be totally invested in liquid assets, i.e. z and thus date-1 consumption increases. Expected date-2 consumption, on the other hand, decreases as due to the reduction of $\frac{u}{e_0}$ late banks also have to pay a positive amount to their investors, $e_{2Hh} > 0$ (see equation (20)). Bank optimal behaviour without the capital requirement implies the equality of the (expected) marginal utilities of date-1 and date-2 consumption. The increase in date-1 consumption and the decrease in expected date-2 consumption as a consequence of the first-step bank behaviour thus implies a divergence of the (expected) marginal utilities, with the expected marginal utility of date-2 consumption being higher.

Second step: Sticking to the required capital ratio achieved in the first step, banks may now choose another combination of u, e_0 and z to reduce the first-step inefficiency. In principle, banks have two possibilities. First, they can increase u. Then, they also have to increase e_0 to keep constant the capital ratio achieved in the first step. However, as the required capital ratio $CR^{min}|_{\phi_u=1,\phi_y=0} = \frac{e_0}{u} < 1$, the increase in u must be stronger than in e_0, so that the budget constraint requires a reduction in z. Second, analogously they can decrease u as well as e_0 which is associated with an increase in z. Which possibility banks will choose depends on the size of the required capital ratio. For relatively low required capital ratios they will increase their loan investment u^* in the second step, so that $u^*|_{CR^{min}|_{\phi_u=1,\phi_y=0}} > u^*|_{CR^{min}=0}$. For relatively high required capital ratios they will decrease u^*, so that $u^*|_{CR^{min}|_{\phi_u=1,\phi_y=0}} < u^*|_{CR^{min}=0}$. The respective critical capital ratio $CR^{crit\ u}|_{\phi_u=1,\phi_y=0}$ equals 0.8186.[14] Consequently, we get that the introduction of $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$ ($CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$) will induce banks to invest more (less) in loans compared to the situation without capital regulation (see Tables 3 and 4).

The optimal second-step bank behaviour depends on the size of $CR^{min}|_{\phi_u=1,\phi_y=0}$. An increase in $CR^{min}|_{\phi_u=1,\phi_y=0}$ has a positive and a negative effect on u^*. The *positive effect* of $CR^{min}|_{\phi_u=1,\phi_y=0}$ on u^* results from the first-step divergence of the marginal utilities of date-1 and expected date-2 consumption which increases in $CR^{min}|_{\phi_u=1,\phi_y=0}$. In particular, a higher $CR^{min}|_{\phi_u=1,\phi_y=0}$ implies that more equity has to be raised in the first step. This induces a stronger increase in z and e_{2Hh}. Consequently, in the first step, date-1 consumption increases and expected date-2 consumption decreases in $CR^{min}|_{\phi_u=1,\phi_y=0}$. A second-step increase in u has a negative effect on date-1 consumption, due to the decrease in z, and a positive effect on expected date-2 consumption, due to the high expected loan

[14]By inserting $e_{2Hl} = e_{2Lh} = e_{2Ll} = 0$ in the bank optimisation problem (equations (3)-(12)) and by the use of the substitution method with respect to the three constraints (9)-(11), we can eliminate e_0, z, e_{2Hh}. Accordingly, the bank optimisation problem depends on u and $CR^{min}|_{\phi_u=1,\phi_y=0}$. By inserting $u^*|_{CR^{min}=0} = 0.1765$ in $\frac{\partial E(U)}{\partial u}$, we obtain two values for $CR^{min}|_{\phi_u=1,\phi_y=0}$, 0.4833 and 0.8186. Note that the first value corresponds to $CR^{opt}|_{\phi_u=1,\phi_y=0}$ when there are no capital requirements (see Section 5.2). The second value 0.8186 reveals the critical capital ratio $CR^{crit\ u}|_{\phi_u=1,\phi_y=0}$.

returns $E(K) > E(S)$. Consequently, the higher the divergence of the (expected) marginal utilities, the higher the banks' incentive to invest more in loans to reduce the inefficiency.

However, an increase in $CR^{min}|_{\phi_u=1,\phi_y=0}$ also has a *negative effect* on u^* as the late banks' payments to their investors per unit equity capital $\frac{e_{2Hh}}{e_0}$ increase in $CR^{min}|_{\phi_u=1,\phi_y=0}$ (see equation 20). This leads to a decrease in expected date-2 consumption, so that if $CR^{min}|_{\phi_u=1,\phi_y=0}$ increases, late depositors will benefit less and less from an additional unit of loan investment as more and more of the loan returns have to be given to the investors. Figure 3 illustrates schematically the banks' optimal loan investment u^* depending on $CR^{min}|_{\phi_u=1,\phi_y=0}$. Until $CR^{max\ u}|_{\phi_u=1,\phi_y=0}$, the positive effect of an increase

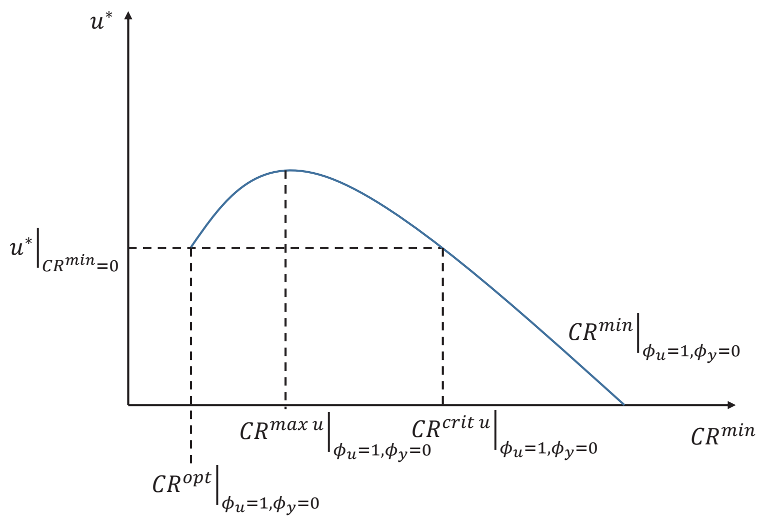

Figure 3: Optimal Bank Loan Investment Depending on $CR^{min}|_{\phi_u=1,\phi_y=0}$

in $CR^{min}|_{\phi_u=1,\phi_y=0}$ on u^* dominates but its influence decreases compared to the influence of the negative effect. Then, the negative effect becomes so strong that further increases in $CR^{min}|_{\phi_u=1,\phi_y=0}$ imply a decrease of u^*. If a required capital ratio higher than $CR^{crit\ u}|_{\phi_u=1,\phi_y=0}$ is introduced, banks will reduce their optimal loan investment compared to the situation without capital requirements ($u^*|_{CR^{min}|_{\phi_u=1,\phi_y=0}>CR^{crit\ u}|_{\phi_u=1,\phi_y=0}} < u^*|_{CR^{min}=0}$).

Summing up, the late banks' payments to their investors per unit of equity increase in the binding required capital ratio (note that this payment is zero when there are no capital requirements). Consequently, equity becomes more expensive, the higher the required capital ratio is. If a relatively low capital ratio is introduced, banks will increase their loan investment. Keeping loans constant and thus investing the additionally required costly equity in liquid assets only, means that banks do not benefit from the new equity, it only leads to higher costs. However, increasing loan investment allows them to use the required equity for some beneficial liquidity risk transfer, and thus to reduce the net costs of the introduced capital requirement. If a relatively high capital ratio is introduced, a beneficial liquidity risk transfer to reduce the net costs of the capital requirement is not possible. On the contrary, due to the necessary high payments of the late banks to their investors, equity has become so expensive that banks decrease their loan investment. This allows them to hold less costly equity capital.

The Banks' Loan-To-Liquid-Asset Ratio

In Section 6.3 we will see that with respect to financial stability not only the amount of loans u in the banks' balance sheets is important, but rather the loan-to-liquid-asset ratio $\frac{u}{z}$. In the following, we will therefore have a closer look at this ratio with regard to $CR^{min}|_{\phi_u=1,\phi_y=0}$. Figure 4 illustrates schematically the banks' optimal loan-to-liquid-asset ratio depending on the required capital ratio for loans. We argued above that if a

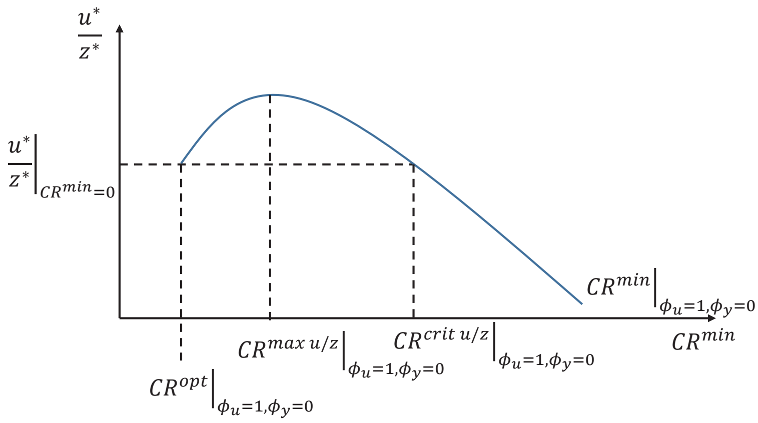

Figure 4: Optimal Bank Loan-to-Liquid-Asset Ratio Depending on $CR^{min}|_{\phi_u=1,\phi_y=0}$

relatively low binding required capital ratio is introduced, banks will reduce the first step inefficiency by increasing loans that allow them to use the additional required equity for some beneficial liquidity risk transfer. Hence, sufficiently low binding capital ratios allow them to invest a higher share of the newly raised equity in loans rather than in liquid assets. If a minimum capital ratio of 0.6 is introduced, about 75 percent of the newly raised equity is invested in loans and only 25 percent in liquid assets (see Tables 3 and 4). For this relatively low required capital ratio the optimal loan-to-liquid-asset ratio $\frac{u^*}{z^*}$ is higher compared to the situation without capital regulation. However, we also argued above that for an increasing $CR^{min}|_{\phi_u=1,\phi_y=0}$, u^* increases at first, but at a diminishing rate. This is because banks benefit less and less from an additional unit of loan investment so that more of the additional raised equity capital must be invested in liquid assets. That in turn implies that at first $\frac{u^*}{z^*}$ also increases in $CR^{min}|_{\phi_u=1,\phi_y=0}$ but at a diminishing rate. However, if $CR^{max\ u/z}|_{\phi_u=1,\phi_y=0}$ is reached, further increases in $CR^{min}|_{\phi_u=1,\phi_y=0}$ will lead to a decreasing $\frac{u^*}{z^*}$. At this point, the increase in z^* exceeds the increase in u^*. Required capital ratios exceeding $CR^{crit\ u/z}|_{\phi_u=1,\phi_y=0} = 0.8069$ imply that the banks' optimal loan-to-liquid-asset ratio falls below the ratio realised in the situation without a capital requirement.[15]

5.4 Binding Capital Requirements for Loans and Government Bonds

This section analyses optimal bank investment and financing behaviour when the required minimum capital ratio also includes a positive risk weight for government bond holdings, i.e. when risky sovereign exposures are also subject to capital regulation. We assume a risk weight for government bonds of $\phi_y = 0.05$.[16] The risk weight for loans is the same as in Section 5.3, i.e. $\phi_u = 1$. Also, the two considered required minimum capital ratios remain unchanged, i.e. we do our numerical analysis for $CR^{min}|_{\phi_u=1,\phi_y=0} = CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.6$ and $CR^{min}|_{\phi_u=1,\phi_y=0} = CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.86$. If banks do not face binding capital requirements (Section 5.2), they will choose an optimal capital ratio of $CR^{opt}|_{\phi_u=1,\phi_y=0.05} = \frac{e_0^*}{u^*+0.05y^*} = 0.4282$. Hence, the required capital ratios 0.6 and 0.86 are binding.

[15] By inserting $e_{2Hl} = e_{2Lh} = e_{2Ll} = 0$ into the bank's optimisation problem (equations (3)-(12)) and by using the substitution method with respect to the three constraints (9)-(11), we can eliminate e_0, z, e_{2Hh}. For z we obtain $1 + u(-1 + CR^{min}|_{\phi_u=1,\phi_y=0})$. The bank's optimisation problem depends on u and $CR^{min}|_{\phi_u=1,\phi_y=0}$. By inserting $\frac{u^*}{z^*}|_{CR^{min}=0} = 0.1942 = \frac{u}{1+u(-1+CR^{min}|_{\phi_u=1,\phi_y=0})}$ in $\frac{\partial E(U)}{\partial u}$ and solving for $CR^{min}|_{\phi_u=1,\phi_y=0}$ we obtain 0.4833 and 0.8069. Note that the first value corresponds to CR^{opt} when there are no capital requirements (see Section 5.2). The second value 0.8069 reveals the critical capital ratio $CR^{crit\ u/z}|_{\phi_u=1,\phi_y=0}$ at which banks reduce their loan-to-liquid-asset ratio with respect to the scenario without capital regulation.

[16] As we want to analyse the impact of capital requirements for government bonds on bank behaviour, we assume $\phi_y = 0.05$. As $\phi_u = 1 > \phi_y = 0.05$, we consider sovereign bonds to be less risky than loans.

Balance Sheet

A					L
$x^* =$	0.4597	(0.4994)	$e_0^* =$	0.1552	(0.1614)
$y^* =$	0.4597	(0.4994)	$D =$	1	
$u^* =$	0.2358	(0.1626)			
$\sum$	1.1552	(1.1614)	$\sum$	1.1552	(1.1614)

Contracts with Investors:

early banks:	e_{2H}^*=0.3631 (0.2504)	e_{2L}^*= 0.0590 (0.0407)			
late banks:	e_{2Hh}^*=0.1360 (0.2723)		e_{2Hl}^*=0 (0)	e_{2Lh}^*=0 (0)	e_{2Ll}^*=0 (0)

Deposit Contracts:

c_1^*= 0.9194 (0.9987)	c_{2Hh}^*=1.4224 (1.2764)	c_{2Hl}^*= 0.6390 (0.5500)	c_{2Lh}^*= 1.2543 (1.3390)	c_{2Ll}^*=0.3348 (0.3403)

$E(U)$=0.1214
(0.1143)

Proof: See Proof IV in Appendix

Table 5: Capital Requirements for Loans and Government Bonds: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors for $CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.6$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.86$ (The Results for the Latter are in Brackets)

Comparing the results for both capital ratios, 0.6 and 0.86, given in Tables 4 and 5 shows that if government bonds are also subject to capital regulation, the potential to transfer the liquidity risk from depositors to investors will be used even less, $\frac{u^*}{e_0^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}} < \frac{u^*}{e_0^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}} < \frac{u^*}{e_0^*}|_{CR^{min}=0}$ so that the depositors' expected utility will decrease even more, $E(U)|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}} < E(U)|_{CR^{min}|_{\phi_u=1,\phi_y=0}} < E(U)|_{CR^{min}=0}$. With respect to the optimal bank financing and investment behaviour, for both capital ratios the introduction of positive risk weights for government bonds induces banks to raise additional equity capital, to grant more loans and to increase their liquid asset holdings. Furthermore, the banks' optimal loan-to-liquid-asset ratio increases for both capital ratios ($\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}=0.6} > \frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}=0.6}$ and $\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}=0.86} > \frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}=0.86}$).

Bank Behaviour Depending on the Size of $\mathbf{CR^{min}}$

To understand this bank behaviour, we do the same two-step analysis as in the previous section. We assume that there have been no capital requirements so far ($CR^{min} = 0$), and now a binding minimum capital ratio is introduced ($CR^{min}|_{\phi_u=1,\phi_y=0.05}$), which requires loans and government bonds to be backed with equity. In the first step of our analysis, banks increase e_0 while holding u constant to fulfil the capital requirement, i.e. as in the previous section, the additionally raised capital is totally invested in liquid assets, z increases. However, if government bonds are also subject to capital requirements, more equity has to be raised to fulfil the requirements, so that the increase in e_0 will be higher. This has two effects on consumer consumption. First, due to the budget constraint, z must also increase more than in the case in which only loans have to be backed with equity. Consequently, the first-step increase in date-1 consumption will be stronger. Second, we have a lower loan-to-equity ratio ($\frac{u}{e_0}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}} < \frac{u}{e_0}|_{CR^{min}|_{\phi_u=1,\phi_y=0}}$), which induces a higher payment of the late banks to their investors per unit equity capital ($\frac{e_{2Hh}}{e_0}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}} > \frac{e_{2Hh}}{e_0}|_{CR^{min}|_{\phi_u=1,\phi_y=0}}$, see equation (20)). A higher amount of equity capital in combination with higher payments per unit equity induces a stronger first-step decrease in expected date-2 consumption. Due to the higher increase in date-1 consumption and the stronger decrease in expected date-2 consumption, the first-step divergence of the marginal utilities of date-1 consumption and expected date-2 consumption will be larger if not only loans but also government bonds have to be backed with equity.

In the second step banks may reduce this inefficiency by changing u. Analogously to the case in which only loans are subject to capital requirements, optimal loan investment u^* depends on the size of $CR^{min}|_{\phi_u=1,\phi_y=0.05}$. An increase in $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ has qualitatively the same positive and the same negative effects on u^* as in the previous section. The positive effect exists as an increase in $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ leads to a higher inefficiency, i.e. the first-step divergence of the (expected) marginal utilities of date-1 and date-2 consumption, caused by the first-step bank behaviour. The higher the inefficiency, the stronger the banks' incentive to invest in high-yielding loans to reduce this inefficiency (see Section 5.3). The negative effect of an increasing $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ on u^* is due to the increasing payments the late banks make to their investors which increase in $CR^{min}|_{\phi_u=1,\phi_y=0.05}$. In particular, if $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ increases, $\frac{u}{e_0}$ decreases which leads to higher payments of the late banks to their investors per unit equity $\frac{e_{2Hh}}{e_0}$ (see equation (20)). Consequently, an increasing $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ means that late depositors will benefit less and less from an additional unit of loan investment.

Analogously to the blue line in Figure 3, the red line in Figure 5 illustrates schematically the banks' optimal loan investment u^* depending on $CR^{min}|_{\phi_u=1,\phi_y=0.05}$. Until $CR^{max\ u}|_{\phi_u=1,\phi_y=0.05}$, the positive effect of an increase in $CR^{min}|_{\phi_u=1,\phi_y=0}$

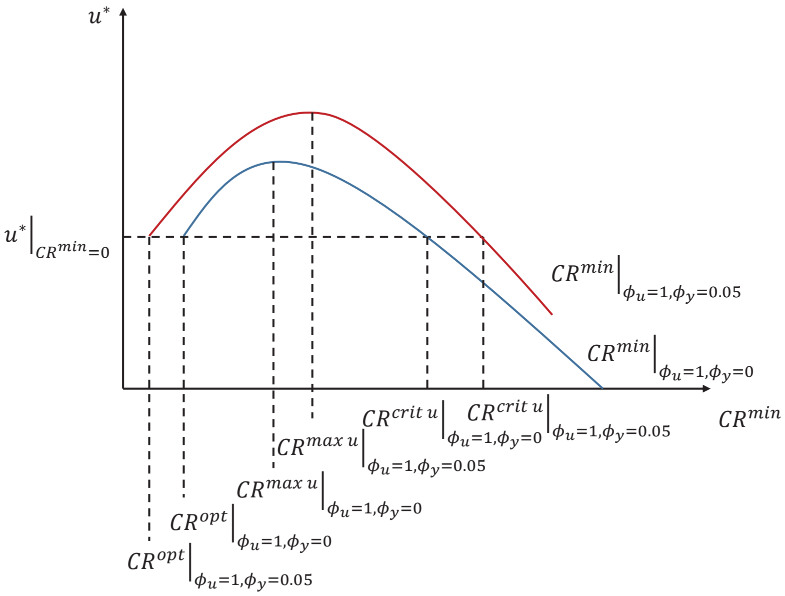

Figure 5: Optimal Bank Loan Investment Depending on $CR^{min}|_{\phi_u=1,\phi_y=0}$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05}$

on u^* dominates. Then the negative effect becomes so strong that further increases in $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ imply a decrease of u^*. If a required capital ratio higher than $CR^{crit\ u}|_{\phi_u=1,\phi_y=0.05} = 0.8522$ is introduced, banks will reduce their optimal loan investment compared to the situation without capital requirements ($u^*|_{CR^{min}|_{\phi_u=1,\phi_y=0.05} > CR^{crit\ u}|_{\phi_u=1,\phi_y=0.05}} < u^*|_{CR^{min}=0}$).[17]

[17]By inserting $e_{2Hl} = e_{2Lh} = e_{2Ll} = 0$ in the bank optimisation problem (equations (3)-(12)) and by using the substitution method with respect to the three constraints (9)-(11), we can eliminate e_0, z, e_{2Hh}. Accordingly, the bank optimisation problem depends on u and $CR^{min}|_{\phi_u=1,\phi_y=0.05}$. By inserting $u^*|_{CR^{min}=0} = 0.1765$ in $\frac{\partial E(U)}{\partial u}$, we obtain two values for $CR^{min}|_{\phi_u=1,\phi_y=0.05}$, 0.4128 and 0.8522. The first value depicts the banks' optimal capital ratio when they have to back 5% of their sovereign bonds with equity capital. Note, that this value is not equal to $CR^{opt}|_{\phi_u=1,\phi_y=0.05} = 0.4282$. This is because it is never optimal for banks to finance liquid sovereign bonds with costly equity capital. $CR^{crit\ u}|_{\phi_u=1,\phi_y=0.05} = 0.8522$ depicts the critical capital ratio for loans *and* government bonds at which banks grant fewer loans with respect to the scenario without capital regulation.

However, a crucial aspect in our analysis is that for each CR^{min}, we will have a higher optimal loan investment if government bonds also have to be backed with equity. The reason is that for each CR^{min} the positive effect which is associated with the introduction of a binding required capital ratio on u^* is larger, whereas the negative effect on u^* is smaller. The stronger positive effect results from the higher first-step inefficiency. Thus, with a higher investment in u banks can reduce the higher inefficiency caused by the first-step bank behaviour. The weaker negative effect results from lower late-bank payments to their investors per unit of loans. In particular, if only loans have to be backed with equity, e_0 must increase by CR^{min}, for example, by 0.6 per unit increase in loans. However, if government bonds are also subject to capital requirements, the increase in e_0 will be smaller per unit increase in loans – in our example smaller than 0.6. Hence, the increase in u combined with the decrease in z (and thus with y) allows for the release of equity tied up in government bonds, so that the necessary increase in e_0 and thus the necessary payments to late banks' investors e_{2Hh} can be smaller per unit of loan investment. In other words: loan investment becomes more attractive for banks. The result that for each CR^{min} optimal loan investment will be higher if the privileged treatment of government bonds is repealed, is also illustrated schematically in Figure 5.

Summing up, note that the key property of equity is to transfer the liquidity risk associated with investments from risk-averse consumers to risk-neutral investors. Government bonds do not bear a liquidity risk, inducing that banks do not have any incentive to finance government bonds with costly equity. However, the investment in highly profitable loans is associated with liquidity risks for banks, as loans are totally illiquid at date 1. Hence, financing loans with equity capital is beneficial for them as it at least allows the loans' liquidity risk to be transferred from risk-averse consumers to risk-neutral investors (see Section 5.2). The requirement of backing sovereign bonds with equity capital induces banks to increase their equity. However, it is more profitable for banks to invest these additional funds in loans rather than in liquid assets as this allows them to benefit from the liquidity risk-shift-property of additionally required costly equity capital.

The Banks' Loan-To-Liquid-Asset Ratio

As already argued in Section 5.3, for our discussion on financial stability, the loan-to-liquid-asset ratio will play a crucial role. Analogously to the blue line in Figure 4, the red line in Figure 6 illustrates schematically the banks' optimal loan-to-liquid-asset ratio $\frac{u^*}{z^*}$ depending on $CR^{min}|_{\phi_u=1,\phi_y=0.05}$. The argumentation concerning the optimal bank

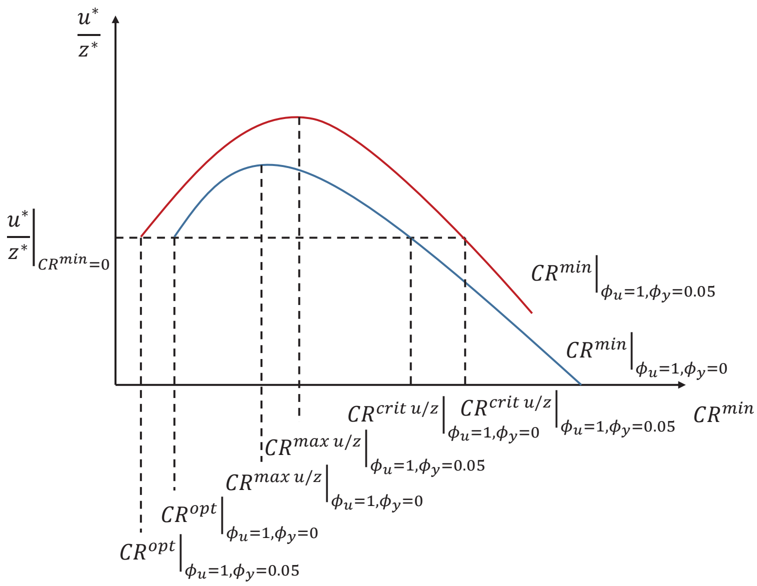

Figure 6: Optimal Bank Loan-to-liquid Asset Ratio Depending on $CR^{min}|_{\phi_u=1,\phi_y=0}$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05}$

loan-to-liquid-asset ratio depending on a binding required capital ratio is identical to the argumentation in Section 5.3. For capital ratios lower than $CR^{crit\ u/z}|_{\phi_u=1,\phi_y=0.05}$, banks invest a higher share of the newly raised equity capital in loans rather than in liquid assets. Hence, for relatively low capital ratios the banks' optimal loan-to-liquid asset ratio is higher compared to the situation without capital regulation. If the capital ratio $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ exceeds $CR^{crit\ u/z}|_{\phi_u=1,\phi_y=0.05}$, the banks' optimal loan-to-liquid asset ratio is lower than in the situation without capital regulation.

However, as we want to analyse the effects of repealing the preferential treatment of sovereign bonds in banking regulation, for us the difference between the bank optimal loan-to-liquid asset ratio for the capital ratios $CR^{min}|_{\phi_u=1,\phi_y=0}$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05}$ is crucial. Figure 6 displays that for *each* CR^{min} the optimal loan-to-liquid asset ratio will be higher if government bonds also have to be backed with equity ($\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}} >$

$\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}}$). The reason is that capital requirements for government bonds make the investment in loans more attractive for banks in comparison to an investment in liquid assets.

6 Financial Stability

The aim of this paper is to analyse the resilience of the banking sector in the case of a sovereign debt crisis under different capital regulation scenarios. 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. A central bank acting as a LOLR can avoid bank insolvencies due to liquidity issues. It turns out that in the presence of a LOLR the abolishment of the preferential treatment of sovereign bonds in financial regulation strengthens the resilience of the banking sector in the case of a sovereign debt crisis.

6.1 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 $E(S) > \overline{E(S)}$. Like 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.[18]

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 (15)

[18]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 26 for details.

and (16)). 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, independent of their default probability (see equation (17)).

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

$$p^{crit} = 1. \tag{21}$$

Setting in equation (15) p^{max} equal to p^{crit} and then solving the equation for $(1-\beta)$ gives us the critical default probability

$$(1-\beta^{crit}) = \frac{ln(h) - ln(p^{crit})}{ln(h) - ln(l)} = \frac{ln(h)}{ln(h) - ln(l)}. \tag{22}$$

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 equilibrium government bond price will fall below one, early banks will be illiquid and insolvent. The threshold $(1-\beta^{crit})$ allows us to distinguish between a small $(1-\overline{\beta^{small}}) \leq (1-\beta^{crit})$ and a large government shock $(1-\overline{\beta^{large}}) > (1-\beta^{crit})$. In the following, we comment on the consequences of both shocks in more detail.

Small Government Bond Shock

Figure 7 illustrates the interbank market for a small government bond shock. 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, $\overline{p^{**small}} = p^{**} = 1$, $\overline{y^{**small}} = y^{**} = 0.5y^{*}$. Consequently, the small shock only implies a decline in the late banks' surplus from interbank trading as at the same price late banks receive the same quantity of government bonds but they yield a lower expected return. This is illustrated by the blue shaded area in Figure 7. The early banks' surplus does not change as their depositors value consumption only at date 1 so that for them the decreased expected (date-2) return on government bonds plays no role.

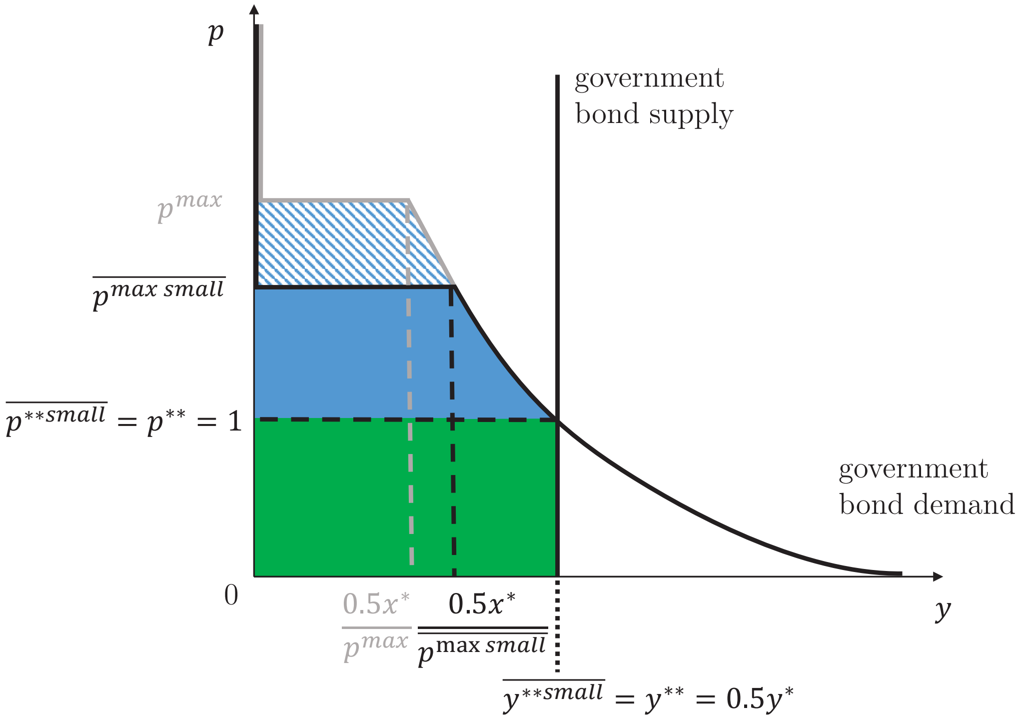

Figure 7: Interbank Market for Government Bonds at Date 1 for $(1-\overline{\beta^{small}}) \leq (1-\beta^{crit})$

In the following, we will discuss in more detail who actually bears the costs of a small government bond shock. Early-bank depositors are not affected by the shock as there is neither a shock-induced change in the equilibrium price, nor in the equilibrium transaction volume on the interbank market for government bonds, so that their consumption does not change:

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

Early-bank investors are not affected by the shock either as they are only repaid from the proceeds of the loan portfolio. However, the shock influences late-bank depositors as due to the decreased expected return on government bonds their expected date-2 consumption decreases.[19] Whether late-bank investors are affected depends on whether there is a

[19]Note, that nevertheless late banks do not become insolvent as they can still fulfil the contracts with their depositors as the contractually agreed repayments are not influenced by the shock, $\overline{c_{2(\cdot)}^{small}} = c_{2(\cdot)}^*$ (see equations (5)-(8)).

binding capital requirement. If there is no binding capital requirement, the shock will not impact late-bank investors as then, independent of the shock, their repayment will anyhow be equal to zero (see Section 5.2). However, binding capital requirements imply that if both government bonds and the loan portfolio succeed (state Hh), late-bank investors will also get some repayment at date 2 (see Sections 5.3 and 5.4). As the shock implies that the occurrence probability of this event becomes smaller, their expected date-2 repayment decreases.

Large Government Bond Shock

Figure 8 illustrates the interbank market for a large government bond shock. The increase in the government bonds' default probability is so high that their expected return becomes so low that the maximum price late banks are willing to pay for a bond falls below one. Considering equation (15), the after-shock equilibrium price thus becomes

$$\overline{p^{**large}} = \overline{p^{max\ large}} < 1. \tag{24}$$

At the equilibrium price $\overline{p^{**large}}$, there is an excess demand for government bonds[20] but the equilibrium trading volume has not changed: $\overline{y^{**large}} = y^{**} = 0.5y^*$. As $\overline{p^{max\ large}} = \overline{p^{**large}}$ the late-banks' surplus from interbank trading becomes zero. In addition, the fall of the equilibrium price ($\overline{p^{**large}} < p^{**}$) also leads to a decrease of the early banks' surplus from interbank trading. They receive a smaller quantity of the short-term asset in exchange for their total holdings of government bonds. The decrease of the equilibrium price below 1 means that early banks are no longer able to fulfil their deposit contracts:

$$\overline{c_1^{large}} = x^* + y^*\overline{p^{**large}} < x^* + y^*p^{**} = x^* + y^* = c_1^*. \tag{25}$$

Early banks are thus insolvent and are liquidated at date 1. In contrast to the small government bond shock, depositors and investors of both early and late banks are affected by the large shock. Early-bank depositors suffer as their date-1 consumption decreases

[20]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.

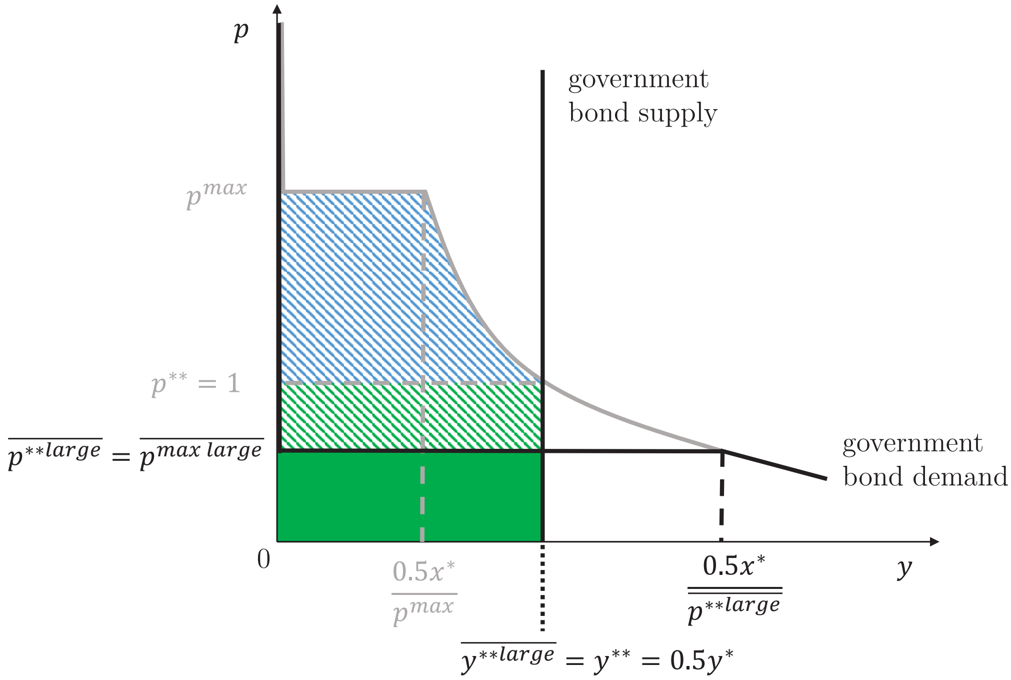

Figure 8: Interbank Market for Government Bonds at Date 1 for $(1 - \overline{\beta^{large}}) > (1 - \beta^{crit})$

$(\overline{c_1^{large}} < c_1^*)$ and early-bank investors suffer as the loan portfolio's liquidation value at date 1 is zero, so that early-bank investors do not get any repayment at all.[21] With respect to the late-bank depositors and investors the same argument as in the small-shock scenario holds. Depositors are affected by the shock as their expected date-2 consumption decreases due to the decreased expected return on government bonds. Investors will be affected by the shock if there is a binding capital ratio, as only then may they be repaid, but the probability of actually being repaid declines.

6.2 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 may lead 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).[22] The central bank provides liquidity

[21] If one assumes that a liquidator keeps the loan portfolio until date 2, so that a positive return on the portfolio is realised (either H of L), it does not prevent the early banks from going bankrupt at date 1. However, the early-bank investors would not be affected by the shock. Note that it is not possible to let the investors bear the costs of the shock instead of the depositors by paying them the proceeds of the loan portfolio at date 2 as they only value consumption at date 1.

[22] 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.

to troubled banks against adequate collateral. In our model, banks' loan portfolios serve as collateral.[23] 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[24]

$$\psi = u^* L. \tag{26}$$

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):

$$\tau = c_1^* - \overline{c_1^{large}} = y^*(p^{**} - \overline{p^{**large}}) = y^*(1 - \overline{p^{**large}}). \tag{27}$$

Equation (27) 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 that the additional liquidity needs are larger the higher the bank's holdings of government bonds y^* are.

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

$$p^{critLOLR} = 1 - \frac{u^* L}{y^*} < 1. \tag{28}$$

[23]Note, that in our model government bonds do not serve as collateral. If this were the case, the central bank would have to buy government bonds for the price of 1, protecting illiquid banks from going bankrupt. This would induce a subsidy by the central bank as the market price for government bonds is lower than 1 after the large shock. Furthermore, the central bank would be exposed to credit risks as in the case of bond failures, the central bank would bear losses ($l < p = 1$).

[24]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 $\frac{u^*}{\tilde{z}^*}$ is higher without a preferential treatment of sovereign debt in bank capital regulation, the $SAC^{LOL\tilde{R}}$ will be higher in this case (see equation (32)).

Inserting $p^{critLOLR}$ for $\overline{p^{**large}}$ in equation (24) and then solving the equation for $(1 - \overline{\beta^{large}})$, gives us the critical default probability

$$(1 - \beta^{critLOLR}) = \frac{ln(h) - ln(p^{critLOLR})}{ln(h) - ln(l)} = \frac{ln(h) + ln(\frac{u^*L}{y^*})}{ln(h) - ln(l)} = \frac{ln(h) + ln(\frac{u^*}{z^*}2L)}{ln(h) - ln(l)}. \quad (29)$$

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 insolvent banks.[25] 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 LOLR (see equations (22) and (29)) reveals that with a LOLR the critical default probability is higher. However, the comparison also shows that with a LOLR the critical default probability depends not only on the possible government bond returns h and l, as it 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 in the critical default probability as then an early bank needs more additional liquidity after a government bond shock (see equation (27)). The critical default probability increases in u^* and L, as then an early bank's collateral increases in quantity and value, so that in the case of a shock it can obtain more additional liquidity from the central bank (see equation (26)).[26] This has important implications for the banking sector's shock-absorbing capacity under the different capital regulation approaches as we will see in Section 6.3.

[25] 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 ($\tau > \psi$).

[26] 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 this case the probability of loan success is negatively affected by the government bond shock, i.e. if $\alpha > \overline{\alpha}$, the expected consumer 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 6.3), spillover effects from the sovereign to loans have no impact on our results.

If the central bank acts as a LOLR and if $(1-\beta^{crit}) < (1-\overline{\beta^{large}}) \leq (1-\beta^{critLOLR})$, early-bank depositors are not affected by the shock, their consumption does not change:

$$\overline{c_1^{large}} = x^* + y^*\overline{p^{**large}} + \tau = x^* + y^* = c_1^* \tag{30}$$

Early-bank investors, however, are affected by the shock as they get repaid from the proceeds of the loan portfolio and a part of these proceeds has to be used to repay the central bank. With respect to the late-bank depositors and investors the same arguments as in the scenarios without a LOLR hold. Depositors are affected by the shock as their expected date-2 consumption decreases. Investors will be affected if there is a binding capital requirement.[27] However, if $(1-\overline{\beta^{large}}) > (1-\beta^{critLOLR})$ early banks are insolvent and thus the central bank does not provide liquidity. Then, depositors and investors of both early and late banks are affected by the shock and the identical arguments hold as in the large-shock scenario without a LOLR.

6.3 The Shock-Absorbing Capacity of the Banking Sector

The above analysis allows us to discuss the (government bond) shock-absorbing capacity of the banking sector, and in this sense its stability,[28] in different capital regulation scenarios. 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 (22) and (29) and denoting the shock-absorbing capacity by SAC and SAC^{LOLR} respectively, we get

$$SAC = (1-\beta^{crit}) - (1-\beta) = \frac{ln(h)}{ln(h)-ln(l)} - (1-\beta) \tag{31}$$

[27] Note that again late-bank depositors are *only* affected by the shock due to the decreased expected return on government bonds. Late banks do not borrow any additional liquidity from the central bank so that they do not have to use part of the proceeds from the loan portfolio to repay the central bank.

[28] 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.

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

$$SAC^{LOLR} = (1 - \beta^{critLOLR}) - (1 - \beta) = \frac{ln(h) + ln(\frac{u^*}{z^*}2L))}{ln(h) - ln(l)} - (1 - \beta) \qquad (32)$$

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

Equation (31) reveals that without a LOLR, the shock-absorbing capacity is not at all influenced by capital requirements. The reason is that without a LOLR early banks will become insolvent if the maximum price for government bonds that late banks are willing to pay falls below one. Then, early banks will no longer be able to satisfy their customers according to the deposit contract. However, the maximum price late banks are willing to pay is only determined by the expected return on a government bond (see equation (15)) which will not change if capital requirements are introduced. Hence, if there is no LOLR, the shock-induced liquidity problem cannot be solved by any kind of capital requirements: the difference $(1-\beta^{crit}) - (1-\beta) = SAC$ is always the same. Figure 9 illustrates the SAC of the banking sector without a LOLR in different regulation scenarios.

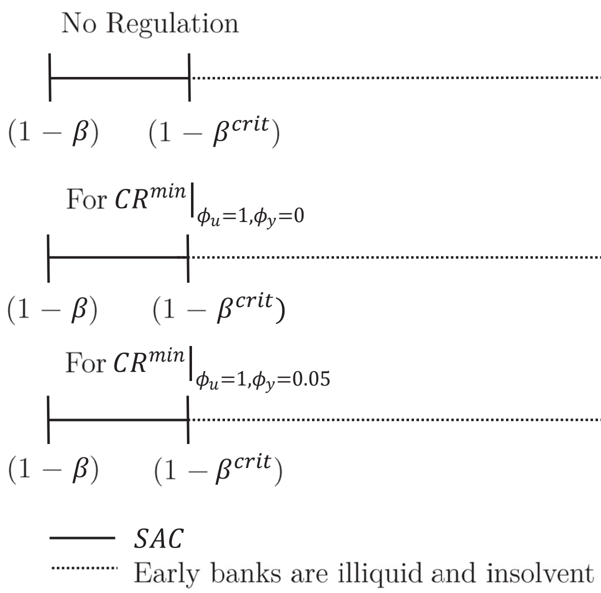

Figure 9: Shock-Absorbing Capacity of the Banking Sector Without a LOLR for $CR^{min}|_{\phi_u=1,\phi_y=0}$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05}$

However, as shown by equation (32), with a LOLR binding capital requirements will influence the shock-absorbing capacity of the banking sector. The reason is that they affect the banks' investment behaviour and therefore their optimal loan-to-liquid-asset ratio $\frac{u^*}{z^*}$ (see Sections 5.3 and 5.4). If there is a LOLR, it is crucial that the shock-absorbing capacity of the banking sector increases in $\frac{u^*}{z^*}$. The reason is that an increase in u^* implies that banks have more collateral at their disposal to obtain additional liquidity from the central bank (see equation (26)), whereas a decrease of z^* (and thus in y^*) means that banks' additional liquidity needs after a government bond shock become smaller (see equation (27)).

The analyses of a capital regulation which requires only loans to be backed with equity in Section 5.3 has shown that the introduction of a relatively low required capital ratio of $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$ leads to an increase in the banks' optimal loan-to-liquid-asset ratio ($\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}=0.6} > \frac{u^*}{z^*}|_{CR^{min}=0}$). However, the banks' reaction to the introduction of a relatively high required capital ratio for loans of $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$ is to reduce loan investment and increase liquid asset holdings, leading to a decrease in the optimal loan-to-liquid-asset ratio ($\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}=0.86} < \frac{u^*}{z^*}|_{CR^{min}=0}$). With respect to financial stability the changed investment behaviour yields that the shock-absorbing capacity will increase if $CR^{min}|_{\phi_u=1,\phi_y=0} < CR^{crit\ u/z}|_{\phi_u=1,\phi_y=0}$. However, the shock-absorbing capacity will decrease if $CR^{min}|_{\phi_u=1,\phi_y=0} > CR^{crit\ u/z}|_{\phi_u=1,\phi_y=0}$. Figure 10 illustrates these results.

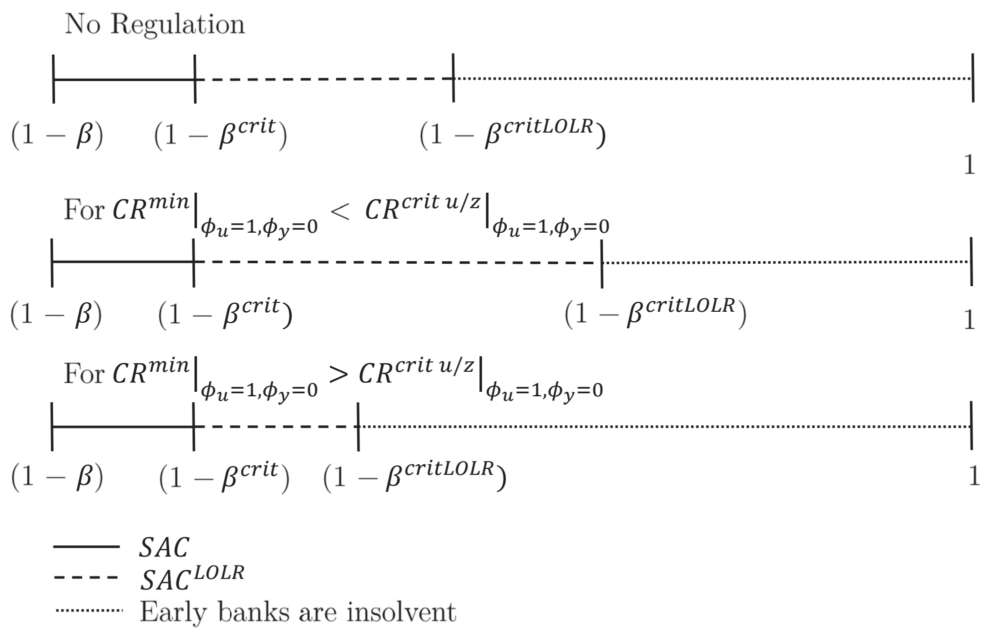

Figure 10: Shock-Absorbing Capacity of the Banking Sector With a LOLR for $CR^{min}|_{\phi_u=1,\phi_y=0}$

The aim of this paper is to analyse the consequences for the banks' shock-absorbing capacity if sovereign bonds also have to be backed with equity. It is crucial that for *each* CR^{min} the banks' optimal loan-to-liquid-asset ratio is always higher compared to the case in which only loans are subject to capital regulation ($\frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0.05}} > \frac{u^*}{z^*}|_{CR^{min}|_{\phi_u=1,\phi_y=0}}$), see Section 5.4. Consequently, the government bond shock-absorbing capacity of the banking sector will increase if the preferential treatment of government bonds is repealed for all required capital ratios but only if there is a LOLR. Figure 11 demonstrates this result.

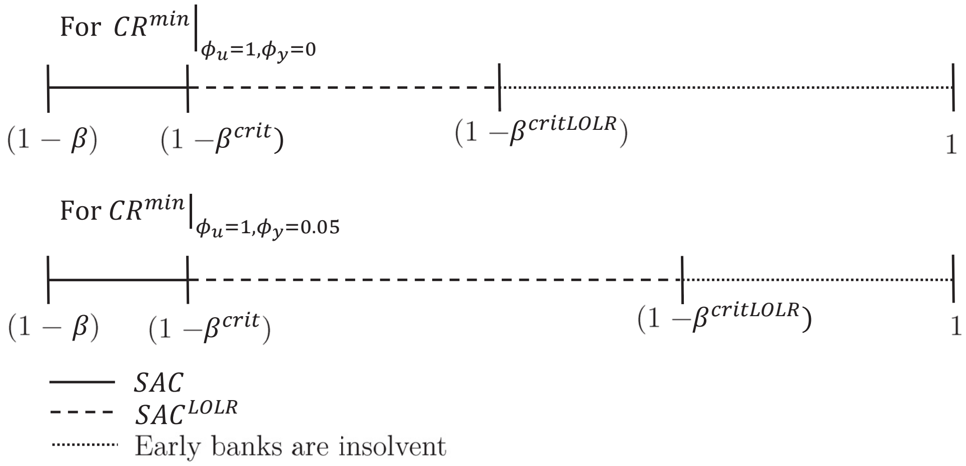

Figure 11: Shock-Absorbing Capacity of the Banking Sector With a LOLR for $CR^{min}|_{\phi_u=1,\phi_y=0}$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05}$

7 Summary

In many countries within the EU, banks hold large undiversified amounts of government bonds in their portfolios. These bank sovereign exposures can act as a significant financial contagion channel between sovereigns and banks. The European sovereign debt crisis of 2009 onwards highlighted that it was assumed that some countries within the EU may have severe problems with repaying or refinancing their debt. The resulting price drops of sovereign bonds severely strained the banks' balance sheets. Against this background, there is an ongoing debate over whether the abolishment of the preferential treatment of government bonds in bank capital regulation can weaken this financial contagion channel from sovereigns to banks (sovereign debt of EU member states are still considered to be risk-free and thus do not have to be backed with equity capital). Our paper adds to this debate in two ways. First, by analysing the consequences of introducing capital requirements for sovereign bonds for bank investment and financing behaviour. Second, by investigating whether these additional capital requirements thus contribute to making the banking sector more resilient to sovereign debt crises.

As pointed out, for example, by Gennaioli et al. (2018) 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 to balance their idiosyncratic liquidity needs by using an interbank market for government bonds. Increasing sovereign solvency doubts 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 in the absence of a LOLR the introduction of capital requirements in general and for government bonds in particular are not able to weaken this financial contagion channel. However, this will be the case if there is a LOLR. The reason is that banks can obtain additional liquidity from the LOLR against adequate collateral. In our model, loans serve as adequate collateral, and the introduction of capital requirements for government bonds induces banks to increase their investment in these loans relative to their government bond holdings. This means that they will be able to get more additional liquidity from the central bank, in the case of financial contagion, in relation to their liquidity needs.

Our model shows that on the one hand the introduction of capital requirements also for government bonds leads to a decrease of depositors' expected utility as binding capital requirements restrict the possibility of a beneficial liquidity risk transfer from depositors to investors. However, on the other hand these additional capital requirements will contribute to a more resilient banking sector in the case of a sovereign debt crisis conditioned on the existence of a LOLR. In this context, it should be noted that our paper does not allow for a comprehensive welfare analysis of introducing capital requirements for sovereign bond – and it was also not the aim of the paper.

A Appendix

Proof I. Using the Lagrangian $\mathcal{L}$, the bank's optimisation problem can be formulated as

$$\begin{aligned}\max_{x,y,u} \mathcal{L} = 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\ +0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] \\ -\lambda(x + y + u - 1) - \mu_x x - \mu_y y - \mu_u u,\end{aligned} \tag{A.1}$$

$$\begin{aligned}\text{with} \quad c_1 &= x + yp^{**}, \\ c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 1.3, \\ c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 0.3, \\ c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 1.3, \\ c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 0.3,\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (11) and μ_x, μ_y and μ_u are the Lagrange multipliers corresponding to the non-negativity conditions (12). Considering that $p^{**} = 1$ (see Section 4) banks equally split their investment in liquid assets in order to hedge their idiosyncratic liquidity risks, so we have $x^* = y^* = 0.5z^*$ (for a detailed explanation see Section 5.1). Differentiating $\mathcal{L}$ with respect to z, u, λ, μ_z and μ_u gives

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial z} =& \frac{0.5}{z} + \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot 1.3}{1.3z + 1.54u} + \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot 0.3}{0.3z + 1.54u} \\ &+ \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot 1.3}{1.3z + 0.25u} + \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot 0.3}{0.3z + 0.25u} - \lambda - \mu_z \stackrel{!}{=} 0,\end{aligned} \tag{A.2}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial u} =& \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot 1.54}{1.3z + 1.54u} + \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot 1.54}{0.3z + 1.54u} \\ &+ \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot 0.25}{1.3z + 0.25u} + \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot 0.25}{0.3z + 0.25u} - \lambda - \mu_u \stackrel{!}{=} 0,\end{aligned} \tag{A.3}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = 1 - z - u \stackrel{!}{=} 0, \tag{A.4}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_z} = -z \overset{!}{=} 0, \tag{A.5}$$
$$\frac{\partial \mathcal{L}}{\partial \mu_u} = -u \overset{!}{=} 0. \tag{A.6}$$

Multiplying both sides of equation (A.2) with z, of equation (A.3) with u, adding the two equations and regarding equation (A.4), we obtain $\lambda^* = 1$. Testing whether a non-negativity constraint binds, reveals that this constraint binds for u, so that $u^* = 0$ and hence $\mu_u^* \neq 0$. Considering the constraint (11) and $u^* = 0$, induces that $z^* = 1$, i.e. the representative bank invests its total amount of deposits in liquid assets. ■

Proof II. When equity capital is available for banks their optimisation problem reads

$$\begin{aligned}\max_{x,y,u,e_{2Hh},e_{2Hl},e_{2Lh},e_{2Ll}} \quad \mathcal{L} = {} & 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\ & +0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] - \lambda\Bigg(x + y + u \\ & -1 - \Bigg[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\ & +0.0686e_{2Lh} + 0.0014e_{2Ll})\Bigg]\Bigg) - \mu_x x - \mu_y y - \mu_u u \\ & -\mu_{e_{2Hh}} e_{2Hh} - \mu_{e_{2Hl}} e_{2Hl} - \mu_{e_{2Lh}} e_{2Lh} - \mu_{e_{2Ll}} e_{2Ll},\end{aligned} \tag{A.7}$$

$$\begin{aligned}\text{with} \quad c_1 &= x + yp^{**}, \\ c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right)1.3 - e_{2Hh}, \\ c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right)0.3 - e_{2Hl}, \\ c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right)1.3 - e_{2Lh}, \\ c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right)0.3 - e_{2Ll},\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (11). We capture the investors' incentive-compatibility constraint (9) by respectively replacing e_0 in the budget constraint. The variables $\mu_x, \mu_y, \mu_u, \mu_{e_{2Hh}}, \mu_{e_{2Hl}}, \mu_{e_{2Lh}}, \mu_{e_{2Ll}}$ are the Lagrange multipliers corresponding to the non-negativity conditions (12). As the same argumentation holds as in Sections 4 and 5.1, we have $p^{**} = 1$ and $x^* = y^* = 0.5z^*$. By differentiating the Lagrange function with respect to z, u, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll}, μ_z, μ_u, λ, $\mu_{e_{2Hh}}$, $\mu_{e_{2Hl}}$, $\mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$, we obtain

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial z} =&\frac{0.5}{z}+\frac{0.5\cdot 0.93\cdot 0.98\cdot 1.3}{1.3z+1.54u-e_{2Hh}}+\frac{0.5\cdot 0.93\cdot 0.02\cdot 0.3}{0.3z+1.54u-e_{2Hl}}\\ &+\frac{0.5\cdot 0.07\cdot 0.98\cdot 1.3}{1.3z+0.25u-e_{2Lh}}+\frac{0.5\cdot 0.07\cdot 0.02\cdot 0.3}{0.3z+0.25u-e_{2Ll}}-\lambda-\mu_z\overset{!}{=}0,\end{aligned} \tag{A.8}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial u} =&\frac{0.5\cdot 0.93\cdot 0.98\cdot 1.54}{1.3z+1.54u-e_{2Hh}}+\frac{0.5\cdot 0.93\cdot 0.02\cdot 1.54}{0.3z+1.54u-e_{2Hl}}\\ &+\frac{0.5\cdot 0.07\cdot 0.98\cdot 0.25}{1.3z+0.25u-e_{2Lh}}+\frac{0.5\cdot 0.07\cdot 0.02\cdot 0.25}{0.3z+0.25u-e_{2Ll}}\\ &-\lambda\left(1-\left(\frac{0.5\cdot 1.4497}{1.5}\right)\right)-\mu_u\overset{!}{=}0,\end{aligned} \tag{A.9}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Hh}} =\frac{0.5\cdot 0.93\cdot 0.98\cdot(-1)}{1.3z+1.54u-e_{2Hh}}-\lambda\left(-\frac{0.5}{1.5}\cdot 0.9114\right)-\mu_{e_{2Hh}}\overset{!}{=}0, \tag{A.10}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Hl}} =\frac{0.5\cdot 0.93\cdot 0.02\cdot(-1)}{0.3z+1.54u-e_{2Hl}}-\lambda\left(-\frac{0.5}{1.5}\cdot 0.0186\right)-\mu_{e_{2Hl}}\overset{!}{=}0, \tag{A.11}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Lh}} =\frac{0.5\cdot 0.07\cdot 0.98\cdot(-1)}{1.3z+0.25u-e_{2Lh}}-\lambda\left(-\frac{0.5}{1.5}\cdot 0.0686\right)-\mu_{e_{2Lh}}\overset{!}{=}0, \tag{A.12}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Ll}} =\frac{0.5\cdot 0.07\cdot 0.02\cdot(-1)}{0.3z+0.25u-e_{2Ll}}-\lambda\left(-\frac{0.5}{1.5}\cdot 0.0014\right)-\mu_{e_{2Ll}}\overset{!}{=}0, \tag{A.13}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial \lambda} =&z+u-1-\Bigg[\frac{0.5}{1.5}(1.4497u+0.9114e_{2Hh}+0.0186e_{2Hl}\\ &+0.0686e_{2Lh}+0.0014e_{2Ll})\Bigg]\overset{!}{=}0,\end{aligned} \tag{A.14}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_z} =-z\overset{!}{=}0, \tag{A.15}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_u} =-u\overset{!}{=}0, \tag{A.16}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Hh}}} =-e_{2Hh}\overset{!}{=}0, \tag{A.17}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Hl}}} =-e_{2Hl}\overset{!}{=}0, \tag{A.18}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Lh}}} =-e_{2Lh}\overset{!}{=}0, \tag{A.19}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Ll}}} =-e_{2Ll}\overset{!}{=}0. \tag{A.20}$$

Multiplying both sides of equation (A.8) with z, of (A.9) with u, of (A.10) with e_{2Hh}, of (A.11) with e_{2Hl}, of (A.12) with e_{2Lh} and of (A.13) with e_{2Ll}, adding the six equations and regarding equation (A.14), we again obtain $\lambda^* = 1$. After testing which non-negativity conditions bind, we derive that the non-negativity conditions for $e_{2Hh}, e_{2Hl}, e_{2Ll}$ and e_{2Ll} become binding, i.e. $e^*_{2Hh} = e^*_{2Hl} = e^*_{2Lh} = e^*_{2Ll} = 0$ and thus $\mu^*_{e_{2Hh}} = \mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. Solving then for z^* and u^* we get $z^* = 0.9088$ and $u^* = 0.1765$ and regarding the constraint (9) the optimal amount of equity capital is $e^*_0 = 0.0853$. ■

Proof III. When a bank faces capital requirements for loans, $CR^{min}|_{\phi_u=1,\phi_y=0} = \frac{e_0}{u}$, its optimisation problem can be formulated as

$$\begin{aligned}
\max_{x,y,u,e_{2Hh},e_{2Hl},e_{2Lh},e_{2Ll}} \quad \mathcal{L} = 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\
+0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] \\
-\lambda\Bigg(x + y + u - 1 - \Bigg[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} \\
+0.0186e_{2Hl} + 0.0686e_{2Lh} + 0.0014e_{2Ll})\Bigg]\Bigg) \\
-\mu_x x - \mu_y y - \mu_u u - \mu_{e_{2Hh}} e_{2Hh} \\
-\mu_{e_{2Hl}} e_{2Hl} - \mu_{e_{2Lh}} e_{2Lh} - \mu_{e_{2Ll}} e_{2Ll} - \mu_{CR} \\
\Bigg(\frac{\frac{0.5}{1.5}}{u}\Bigg[1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\
+0.0686e_{2Lh} + 0.0014e_{2Ll}\Bigg] - CR^{min}|_{\phi_u=1,\phi_y=0}\Bigg),
\end{aligned} \tag{A.21}$$

$$\begin{aligned}
\text{with} \quad c_1 &= x + yp^{**}, \\
c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right)1.3 - e_{2Hh}, \\
c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right)0.3 - e_{2Hl}, \\
c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right)1.3 - e_{2Lh}, \\
c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right)0.3 - e_{2Ll},
\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (11). We capture the investors' incentive-compatibility constraint (9) by respectively replacing e_0 in the budget constraint and in the regulation constraint. The variables $\mu_x, \mu_y, \mu_u, \mu_{e_{2Hh}}, \mu_{e_{2Hl}}, \mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ are the Lagrange multipliers corresponding to the non-negativity conditions (12) and μ_{CR} is the Lagrange multiplier corresponding to the regulation constraint (10). Considering that $p^{**} = 1$ (see Section 4) as well as $x^* = y^* = 0.5z^*$ (for a detailed explanation see Section 5.1) and differentiating $\mathcal{L}$ with respect to z, u, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll}, λ, μ_{CR} $\mu_{e_{2Hh}}$, $\mu_{e_{2Hl}}$, $\mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ gives

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial z} =&\frac{0.5}{z} + \frac{0.5\cdot 0.93\cdot 0.98\cdot 1.3}{1.3z+1.54u-e_{2Hh}} + \frac{0.5\cdot 0.93\cdot 0.02\cdot 0.3}{0.3z+1.54u-e_{2Hl}}\\ &+\frac{0.5\cdot 0.07\cdot 0.98\cdot 1.3}{1.3z+0.25u-e_{2Lh}} + \frac{0.5\cdot 0.07\cdot 0.02\cdot 0.3}{0.3z+0.25u-e_{2Ll}} - \lambda - \mu_z \stackrel{!}{=} 0,\end{aligned} \tag{A.22}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial u} =&\frac{0.5\cdot 0.93\cdot 0.98\cdot 1.54}{1.3z+1.54u-e_{2Hh}} + \frac{0.5\cdot 0.93\cdot 0.02\cdot 1.54}{0.3z+1.54u-e_{2Hl}}\\ &+\frac{0.5\cdot 0.07\cdot 0.98\cdot 0.25}{1.3z+0.25u-e_{2Lh}} + \frac{0.5\cdot 0.07\cdot 0.02\cdot 0.25}{0.3z+0.25u-e_{2Ll}}\\ &-\lambda\left(1-\left(\frac{0.5\cdot 1.4497}{1.5}\right)\right) + \mu_{CR}\left(\frac{\frac{0.5}{1.5}}{u^2}[0.9114e_{2Hh}\right.\\ &\left.+0.0186e_{2Hl}+0.0686e_{2Lh}+0.0014e_{2Ll}]\right) - \mu_u \stackrel{!}{=} 0,\end{aligned} \tag{A.23}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial e_{2Hh}} =&\frac{0.5\cdot 0.93\cdot 0.98\cdot(-1)}{1.3z+1.54u-e_{2Hh}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.9114\right) - \mu_{e_{2Hh}}\\ &-\mu_{CR}\left(\frac{\frac{0.5}{1.5}\cdot 0.9114}{u}\right) \stackrel{!}{=} 0,\end{aligned} \tag{A.24}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial e_{2Hl}} =&\frac{0.5\cdot 0.93\cdot 0.02\cdot(-1)}{0.3z+1.54u-e_{2Hl}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0186\right) - \mu_{e_{2Hl}}\\ &-\mu_{CR}\left(\frac{\frac{0.5}{1.5}\cdot 0.0186}{u}\right) \stackrel{!}{=} 0,\end{aligned} \tag{A.25}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial e_{2Lh}} =&\frac{0.5\cdot 0.07\cdot 0.98\cdot(-1)}{1.3z+0.25u-e_{2Lh}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0686\right) - \mu_{e_{2Lh}}\\ &-\mu_{CR}\left(\frac{\frac{0.5}{1.5}\cdot 0.0686}{u}\right) \stackrel{!}{=} 0,\end{aligned} \tag{A.26}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial e_{2Ll}} =&\frac{0.5\cdot 0.07\cdot 0.02\cdot(-1)}{0.3z+0.25u-e_{2Ll}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0014\right) - \mu_{e_{2Ll}}\\ &-\mu_{CR}\left(\frac{\frac{0.5}{1.5}\cdot 0.0014}{u}\right) \stackrel{!}{=} 0,\end{aligned} \tag{A.27}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial \lambda} =&z+u-1-\left[\frac{0.5}{1.5}(1.4497u+0.9114e_{2Hh}+0.0186e_{2Hl}\right.\\ &\left.+0.0686e_{2Lh}+0.0014e_{2Ll})\right] \stackrel{!}{=} 0.\end{aligned} \tag{A.28}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial \mu_{CR}} =&\frac{\frac{0.5}{1.5}}{u}\left[1.4497u+0.9114e_{2Hh}+0.0186e_{2Hl}\right.\\ &\left.+0.0686e_{2Lh}+0.0014e_{2Ll}\right] - CR^{min}|_{\phi_u=1,\phi_y=0} \stackrel{!}{=} 0.\end{aligned} \tag{A.29}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_z} = -\, z \overset{!}{=} 0, \tag{A.30}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_u} = -\, u \overset{!}{=} 0, \tag{A.31}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Hh}}} = -\, e_{2Hh} \overset{!}{=} 0, \tag{A.32}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Hl}}} = -\, e_{2Hl} \overset{!}{=} 0, \tag{A.33}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Lh}}} = -\, e_{2Lh} \overset{!}{=} 0, \tag{A.34}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Ll}}} = -\, e_{2Ll} \overset{!}{=} 0. \tag{A.35}$$

Multiplying both sides of equation (A.22) with z, of (A.23) with u, of (A.24) with e_{2Hh}, of (A.25) with e_{2Hl}, of (A.26) with e_{2Lh} and of (A.27) with e_{2Ll}, adding the six equations and regarding equation (A.28), we again obtain $\lambda^* = 1$. We do our analyses for two different binding required minimum capital ratios $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$ and $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$. After testing which non-negativity conditions bind for $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.6$, we derive that the non-negativity conditions for e_{2Hl}, e_{2Lh} and e_{2Ll} become binding, i.e. $e^*_{2Hl} = e^*_{2Lh} = e^*_{2Ll} = 0$ and thus $\mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. Solving then for z^*, u^* and e^*_{2Hh} we get $z^* = 0.9182$, $u^* = 0.2043$ and $e^*_{2Hh} = 0.0785$. Regarding constraint (9), the optimal amount of equity capital is $e^*_0 = 0.1225$. After testing which non-negativity conditions bind for $CR^{min}|_{\phi_u=1,\phi_y=0} = 0.86$, we derive that the non-negativity conditions for e_{2Hl}, e_{2Lh} and e_{2Ll} become binding, i.e. $e^*_{2Hl} = e^*_{2Lh} = e^*_{2Ll} = 0$ and thus $\mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. Solving then for z^*, u^* and e^*_{2Hh} we get $z^* = 0.9819$, $u^* = 0.1291$ and $e^*_{2Hh} = 0.1601$. Regarding constraint (9), the optimal amount of equity capital is $e^*_0 = 0.1111$. ■

Proof IV. When banks face capital requirements for loans and government bonds ($CR^{min}|_{\phi_u=1,\phi_y=0.05} = \frac{e_0}{u+0.05y}$), their optimisation problem becomes

$$\begin{aligned}
\max_{x,y,u,e_{2Hh},e_{2Hl},e_{2Lh},e_{2Ll}} \quad \mathcal{L} = & \; 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\
& +0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] \\
& -\lambda\Bigg(x + y + u - 1 - \left[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} \right. \\
& \left. +0.0186e_{2Hl} + 0.0686e_{2Lh} + 0.0014e_{2Ll})\right]\Bigg) \\
& -\mu_x x - \mu_y y - \mu_u u - \mu_{e_{2Hh}} e_{2Hh} \\
& -\mu_{e_{2Hl}} e_{2Hl} - \mu_{e_{2Lh}} e_{2Lh} - \mu_{e_{2Ll}} e_{2Ll} - \mu_{CR} \\
& \Bigg(\frac{\frac{0.5}{1.5}}{u + 0.05y}\Big[1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\
& +0.0686e_{2Lh} + 0.0014e_{2Ll}\Big] - CR^{min}|_{\phi_u=1,\phi_y=0.05}\Bigg),
\end{aligned} \tag{A.36}$$

$$\begin{aligned}
\text{with} \quad c_1 &= x + yp^{**}, \\
c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right)1.3 - e_{2Hh}, \\
c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right)0.3 - e_{2Hl}, \\
c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right)1.3 - e_{2Lh}, \\
c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right)0.3 - e_{2Ll},
\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (11). We capture the investors' incentive-compatibility constraint (9) by respectively replacing e_0 in the budget constraint and in the regulation constraint. The variables $\mu_x, \mu_y, \mu_u, \mu_{e_{2Hh}}, \mu_{e_{2Hl}}, \mu_{e_{2Lh}}, \mu_{e_{2Ll}}$ are the Lagrange multipliers corresponding to the non-negativity conditions (12) and μ_{CR} is the Lagrange multiplier corresponding to the regulation constraint (10). Considering that $p^{**} = 1$ (see Section 4) banks equally split their investment in liquid assets ($x^* = y^* = 0.5z^*$) also when sovereign bonds are subject to capital regulation. By differentiating $\mathcal{L}$ with respect to z, u, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll}, λ, μ_{CR}, $\mu_{e_{2Hh}}$, $\mu_{e_{2Hl}}$, $\mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ we obtain

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial z} =& \frac{0.5}{z} + \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot 1.3}{1.3z + 1.54u - e_{2Hh}} + \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot 0.3}{0.3z + 1.54u - e_{2Hl}} \\
&+ \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot 1.3}{1.3z + 0.25u - e_{2Lh}} + \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot 0.3}{0.3z + 0.25u - e_{2Ll}} - \lambda - \mu_z \\
&+ \mu_{CR} \Bigg(\frac{\frac{0.5 \cdot 0.025}{1.5}}{(u + 0.025z)^2} [1.4497u + 0.9114e_{2Hh} \\
&+ 0.0186e_{2Hl} + 0.0686e_{2Lh} + 0.0014e_{2Ll}] \Bigg) \stackrel{!}{=} 0,
\end{aligned} \tag{A.37}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial u} =& \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot 1.54}{1.3z + 1.54u - e_{2Hh}} + \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot 1.54}{0.3z + 1.54u - e_{2Hl}} \\
&+ \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot 0.25}{1.3z + 0.25u - e_{2Lh}} + \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot 0.25}{0.3z + 0.25u - e_{2Ll}} \\
&- \lambda \left(1 - \left(\frac{0.5 \cdot 1.4497}{1.5} \right) \right) + \mu_{CR} \Bigg(\frac{\frac{0.5}{1.5}}{(u + 0.025z)^2} \\
&[1.4497 \cdot 0.025z + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\
&+ 0.0686e_{2Lh} + 0.0014e_{2Ll}] \Bigg) - \mu_u \stackrel{!}{=} 0,
\end{aligned} \tag{A.38}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial e_{2Hh}} =& \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot (-1)}{1.3z + 1.54u - e_{2Hh}} - \lambda \left(-\frac{0.5}{1.5} \cdot 0.9114 \right) - \mu_{e_{2Hh}} \\
&- \mu_{CR} \left(\frac{0.3038}{u + 0.025z} \right) \stackrel{!}{=} 0,
\end{aligned} \tag{A.39}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial e_{2Hl}} =& \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot (-1)}{0.3z + 1.54u - e_{2Hl}} - \lambda \left(-\frac{0.5}{1.5} \cdot 0.0186 \right) - \mu_{e_{2Hl}} \\
&- \mu_{CR} \left(\frac{0.062}{u + 0.025z} \right) \stackrel{!}{=} 0,
\end{aligned} \tag{A.40}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial e_{2Lh}} =& \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot (-1)}{1.3z + 0.25u - e_{2Lh}} - \lambda \left(-\frac{0.5}{1.5} \cdot 0.0686 \right) - \mu_{e_{2Lh}} \\
&- \mu_{CR} \left(\frac{0.02286}{u + 0.025z} \right) \stackrel{!}{=} 0,
\end{aligned} \tag{A.41}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial e_{2Ll}} =& \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot (-1)}{0.3z + 0.25u - e_{2Ll}} - \lambda \left(-\frac{0.5}{1.5} \cdot 0.0014 \right) - \mu_{e_{2Ll}} \\
&- \mu_{CR} \left(\frac{0.00046}{u + 0.025z} \right) \stackrel{!}{=} 0,
\end{aligned} \tag{A.42}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \lambda} =& z + u - 1 - \Bigg[\frac{0.5}{1.5} (1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\
&+ 0.0686e_{2Lh} + 0.0014e_{2Ll}) \Bigg] \stackrel{!}{=} 0.
\end{aligned} \tag{A.43}
$$

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial \mu_{CR}} =& \frac{\frac{0.5}{1.5}}{u + 0.025z} \Bigg[1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\
&+ 0.0686e_{2Lh} + 0.0014e_{2Ll} \Bigg] - CR^{min}|_{\phi_u=1, \phi_y=0.05} \stackrel{!}{=} 0.
\end{aligned} \tag{A.44}
$$

$$\frac{\partial \mathcal{L}}{\partial \mu_z} = -\, z \stackrel{!}{=} 0, \tag{A.45}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_u} = -\, u \stackrel{!}{=} 0, \tag{A.46}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Hh}}} = -\, e_{2Hh} \stackrel{!}{=} 0, \tag{A.47}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Hl}}} = -\, e_{2Hl} \stackrel{!}{=} 0, \tag{A.48}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Lh}}} = -\, e_{2Lh} \stackrel{!}{=} 0, \tag{A.49}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Ll}}} = -\, e_{2Ll} \stackrel{!}{=} 0, \tag{A.50}$$

Multiplying both sides of equation (A.37) with z, of (A.38) with u, of (A.39) with e_{2Hh}, of (A.40) with e_{2Hl}, of (A.41) with e_{2Lh} and of (A.42) with e_{2Ll}, adding the six equations and regarding equation (A.43), we again obtain $\lambda^* = 1$. We do our analyses for two different binding required minimum capital ratios $CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.6$ and $CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.86$. After testing which non-negativity conditions bind for $CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.6$, we derive that the non-negativity conditions for e_{2Hl}, e_{2Lh} and e_{2Ll} become binding, i.e. $= e^*_{2Hl} = e^*_{2Lh} = e^*_{2Ll} = 0$ and thus $\mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. Solving then for z^*, u^* and e^*_{2Hh}, we get $z^* = 0.9194$, $u^* = 0.2358$ and $e^*_{2Hh} = 0.1360$. Inserting z^*, u^* and e^*_{2Hh} in constraint (9), the optimal amount of equity capital a bank raises is $e^*_0 = 0.1552$. After testing which non-negativity conditions bind for $CR^{min}|_{\phi_u=1,\phi_y=0.05} = 0.86$, we derive that the non-negativity conditions for e_{2Hl}, e_{2Lh} and e_{2Ll} become binding, i.e. $= e^*_{2Hl} = e^*_{2Lh} = e^*_{2Ll} = 0$ and thus $\mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. Solving then for z^*, u^* and e^*_{2Hh}, we get $z^* = 0.9987$, $u^* = 0.1626$ and $e^*_{2Hh} = 0.2723$. Inserting z^*, u^* and e^*_{2Hh} in constraint (9), the optimal amount of equity capital a bank raises is $e^*_0 = 0.1614$. ■

Bibliography

Abad, J. (2018). Breaking the feedback loop: Macroprudential regulation of banks' sovereign exposures. mimeo.

Acharya, V. V., I. Drechsler, and P. Schnabl (2014). A pyrrhic victory? Bank bailouts and sovereign credit risk. *The Journal of Finance 69*(6), 2689–2739.

Acharya, V. V. and R. G. Rajan (2013). Sovereign debt, government myopia, and the financial sector. *The Review of Financial Studies 26*(6), 1526–1560.

Acharya, V. V. and S. Steffen (2015). The "greatest" carry trade ever? Understanding eurozone bank risks. *Journal of Financial Economics 115*(2), 215–236.

Acharya, V. V. and S. Steffen (2017). The importance of a banking union and fiscal union for a capital markets union. European Economy – Discussion Paper, No. 62, European Commission.

Allen, F. and E. Carletti (2006). Credit risk transfer and contagion. *Journal of Monetary Economics 53*(1), 89–111.

Allen, F. and D. Gale (2000). Financial contagion. *Journal of Political Economy 108*(1), 1–33.

Allen, F. and D. Gale (2006). Systemic risk and regulation. In M. Carey and R. M. Stulz (Eds.), *The Risks of Financial Institutions*, pp. 341–376. Chicago: Chicago University Press.

Altavilla, C., M. Pagano, and S. Simonelli (2017). Bank exposures and sovereign stress transmission. *Review of Finance 21*(6), 2103–2139.

Bagehot, W. (1873). *Lombard Street: A description of the money market.* New York: Scribner, Armstrong & Company.

Blum, J. M. (1999). Do capital adequacy requirements reduce risks in banking? *Journal of Banking & Finance 23*(5), 755–771.

Bolton, P. and O. Jeanne (2011). Sovereign default risk and bank fragility in financially integrated economies. *IMF Economic Review 59*(2), 162–194.

Broner, F., A. Erce, A. Martin, and J. Ventura (2014). Sovereign debt markets in turbulent times: Creditor discrimination and crowding-out effects. *Journal of Monetary Economics 61*, 114–142.

Brunnermeier, M. K., L. Garicano, P. R. Lane, M. Pagano, R. Reis, T. Santos, D. Thesmar, S. van Nieuwerburgh, and D. Vayanos (2016). The sovereign-bank diabolic loop and ESBies. *The American Economic Review 106*(5), 508–512.

Buschmann, C. and C. Schmaltz (2017). Sovereign collateral as a trojan horse: Why do we need an LCR+. *Journal of Financial Stability 33*, 311–330.

Cooper, R. and K. Nikolov (2013). Government debt and banking fragility: The spreading of strategic uncertainty. NBER Working Paper Series, No. 19278, National Bureau of Economic Research.

Corsetti, G., K. Kuester, A. Meier, and G. J. Müller (2013). Sovereign risk, fiscal policy, and macroeconomic stability. *The Economic Journal 123*(566), 99–132.

Covi, G. and U. Eydam (2018). End of the sovereign-bank doom loop in the European Union? The bank recovery and resolution directive. *Journal of Evolutionary Economics*, 1–26.

Diamond, D. W. and P. H. Dybvig (1983). Bank runs, deposit insurance, and liquidity. *Journal of Political Economy 91*(3), 401–419.

Farhi, E. and J. Tirole (2018). Deadly embrace: Sovereign and financial balance sheets doom loops. *The Review of Economic Studies 85*(3), 1781–1823.

Flannery, M. J. (1989). Capital regulation and insured banks choice of individual loan default risks. *Journal of Monetary Economics 24*(2), 235–258.

Furlong, F. T. and M. C. Keeley (1989). Capital regulation and bank risk-taking: A note. *Journal of Banking & Finance 13*(6), 883–891.

Gennaioli, N., A. Martin, and S. Rossi (2014). Sovereign default, domestic banks, and financial institutions. *The Journal of Finance 69*(2), 819–866.

Gennaioli, N., A. Martin, and S. Rossi (2018). Banks, government bonds, and default: What do the data say? *Journal of Monetary Economics 98*, 98–113.

Harris, M., C. C. Opp, and M. M. Opp (2014). Higher capital requirements, safer banks? Macroprudential regulation in a competitive financial system. Mimeo.

Heyde, F. and U. Neyer (2010). Credit default swaps and the stability of the banking sector. *International Review of Finance 10*(1), 27–61.

Hyun, J.-S. and B.-K. Rhee (2011). Bank capital regulation and credit supply. *Journal of Banking & Finance 35*(2), 323–330.

Kim, D. and A. M. Santomero (1988). Risk in banking and capital regulation. *The Journal of Finance 43*(5), 1219–1233.

Weidmann, J. (2016). Dinner speech at the 6th Frankfurt Finance Summit, Frankfurt Main, May 11th. Available at `https://www.bundesbank.de/en/press/speeches/dinner-speech-667106`. Accessed: 2018-09-03.

Paper III:

Preferential Treatment of Government Bonds in Liquidity Regulation – Implications for Bank Behaviour and Financial Stability*

Ulrike Neyer André Sterzel

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 may lead to liquidity issues in the banking sector, implying the insolvency of a significant number of banks. Liquidity requirements do not contribute to a more resilient banking sector in the case of sovereign distress. However, the central bank acting as a lender of last resort can prevent illiquid banks from going bankrupt. Then, introducing liquidity requirements in general and repealing the preferential treatment of government bonds in liquidity regulation in particular actually undermines financial stability. The driving force is a regulation-induced change in bank investment behaviour.

JEL classification: G28, G21, G01.

Keywords: Bank liquidity regulation, government bonds, sovereign risk, financial contagion, lender of last resort.

*We thank Jennifer Rontanger and participants at the 35^{th} International Symposium on Money, Banking and Finance in Aix en Provence 2018 for very helpful comments and suggestions. Moreover, we have benefited from discussions with seminar audiences at the Research Seminar Financial Markets and Financial Management in Düsseldorf 2017, the Inter-University Doctoral Programme in Economics (MAGKS) in Rauischholzhausen 2018, and the Winter School on Applied Microeconomics: Theory and Empirics in Lenzerheide 2018.

Contents

List of Tables

List of Figures

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 global minimum liquidity standards for banks within the Basel III regulation framework. However, within this liquidity regulation framework, government bonds receive a preferential treatment.[1] In particular, they are regarded as highly liquid assets, which means that banks can use government bonds to meet their liquidity requirements without applying any haircuts or quantitative limits, i.e. in liquidity regulation government bonds are treated as liquidity risk-free. However, this is actually not the case. In the European sovereign debt crisis, for example, the credit risk applied to some EU member states increased substantially and the sovereign bonds of these countries could not be easily and quickly liquidated without leading to substantial losses for banks (liquidity risk). Accordingly, the crisis has highlighted severe contagion effects from sovereigns to banks. Against this background, there is an ongoing debate addressing the abolishment of the favourable treatment of sovereign bonds in the Basel Accords and in EU banking regulation. This paper adds to this debate by investigating in a theoretical way whether the contagion channel from sovereigns to banks can be weakened through the abolishment of the preferential treatment of government bonds in liquidity regulation.

In our model, there are three agents: depositors, banks and investors.[2] The objective of banks is to maximise their depositors' expected utility. The depositors have the usual Diamond-Dybvig preferences. These preferences imply that banks face idiosyncratic liquidity risks. Banks can invest in three assets: 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. Whereas loans are totally illiquid, government bonds are liquid as there exists an interbank market for this asset. Thus, investing in government bonds

[1]In the Basel Accords sovereign bonds are also given privileged treatment 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).

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 which implies an increase in their depositors' expected utility. Banks may be subject to liquidity regulation, requiring them to hold more liquid assets (short-term assets and government bonds) than they would choose to hold without regulation.

Within this model framework, in a first step we analyse the banks' investment and financing behaviour under different liquidity regulations. As a starting point, we determine the bank optimal behaviour when there is no regulation. Then, we consider two different possible liquidity regulation scenarios with respect to the regulatory treatment of government bonds. In the first scenario, there is a preferential treatment of government bonds, in the sense that government bonds and the short-term asset are classified as equally liquid although there exists a market liquidity risk for government bonds. In response to the introduction of this 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. In the second scenario, the preferential treatment of government bonds in liquidity regulation is repealed, by classifying government bonds as less liquid than the short-term asset. This implies that the observed bank behaviour in the first scenario is reinforced. Banks further increase their holdings of the short-term asset as well as of government bonds and decrease their loan investment and reduce their equity capital.

In a second step, we first investigate the banks' shock-absorbing capacity in the absence of liquidity regulation and then in the two different liquidity regulation scenarios with respect to government bond treatment. We consider a shock in the form of an increase in the default probability of sovereign bonds (government bond shock). These increasing doubts about sovereign solvency may lead to a sovereign bond price drop and hence to liquidity issues of a significant number of banks (systemic crisis). The price drop may even imply that per se solvent (but illiquid) banks go bankrupt. We show that liquidity re-

[3] As pointed out by BCBS (2017), for example, banks hold government bonds for a variety of reasons. So government bonds do play an important role in managing a bank's daily activities. In our model, banks hold government bonds to manage their liquidity.

quirements 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 (LOLR) exists, which provides additional liquidity against adequate collateral. In our model, loans serve as adequate collateral. However, then the introduction of liquidity requirements in general and repealing the preferential treatment of government bonds in liquidity regulation in particular actually reduce the shock-absorbing capacity of the Banking sector. The driving force is the regulation-induced change in bank investment behaviour (more government bonds and fewer loans). This implies that banks face higher additional liquidity needs caused by the government bond shock and they have less collateral to obtain 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 the Basel III Accord. Section 4 describes the model setup. Section 5 analyses the banks' optimal investment and financing behaviour under different liquidity regulations. Based on these analyses, Section 6 discusses the consequences of the different liquidity requirements for financial stability in the case of a sovereign crisis 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 two strands of literature: the literature on financial contagion[4], especially between sovereigns and banks, and the literature dealing with liquidity requirements and their impact on bank behaviour and financial stability. Since the European sovereign debt crisis of 2009 onwards, there has been a growing literature on financial contagion between sovereigns and banks (sovereign-bank nexus). A huge part of the literature dealing with the sovereign-bank nexus discusses newly implemented or proposed institutions aiming to weaken potential financial contagion channels between sovereigns and banks. In this respect, the European Banking Union is one of the most well-known

[4]As in Allen and Gale (2000) 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.

recent reforms. Referring to the European Banking Union, Covi and Eydam (2018) argue that the second pillar of the Banking Union the *Single Resolution Mechanism* (SRM) weakens the contagion channel from banks to sovereigns because of a "bail-in" rule, implying that bank insolvencies no longer strain public finances. Farhi and Tirole (2018) argue that the *Single Supervisory Mechanism*, i.e. the first pillar of the Banking Union, can diminish contagion effects between internationally operating banks and sovereigns as due to a shared supranational banking supervision banks' adverse risk-shifting incentives are impeded. Acharya and Steffen (2017) stress the need for a complemented *banking and fiscal union*. Both are necessary to build a functioning capital market union that minimises the probability of sovereign-bank contagion. Brunnermeier et al. (2016) develop a model which illustrates how to isolate banks from sovereign risk via the introduction of *European Safe Bonds* ("ESBies") issued by a European debt agency. The idea is that holding these bonds disentangles banks from sovereign distress as "ESBies" are 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 contagion effects from sovereigns to banks in combination with the central bank acting as a LOLR. In the same context, Abad (2018) shows within a dynamic general equilibrium model that the preferential treatment of government bonds in capital regulation amplifies the sovereign-bank nexus. He also suggests backing government bonds with equity capital to disentangle bank and sovereign risks. Buschmann and Schmaltz (2017) point out that the Liquidity Coverage Ratio (LCR) may reinforce contagion effects from sovereign to banks. Within the LCR framework, government bonds are classified as high quality liquid assets irrespective of their inherent liquidity risks. This classification makes sovereign bonds an attractive asset for banks, so that they may increase their sovereign holdings to meet the LCR. Then, in times of sovereign distress banks are exposed to severe liquidity risks associated with their sovereign bond holdings. The authors propose an *alternative LCR* (LCR+), that incorporates sovereign risk in order to reduce the contagion effects from sovereigns to banks.

In recent years, there has been a growing theoretical literature on the impact of liquidity regulation on bank behaviour and financial stability.[5] Diamond and Kashyap (2016), modify the Diamond and Dybvig (1983) model and show that binding liquidity requirements reduce the bank-run probability and thus increases financial stability. In particular, they show that incomplete customers information about the banks' solvency could lead to a bank-run. The costumers do not know whether their banks hold sufficient liquid assets in order to fulfil their contracts. Liquidity regulation can reduce the bank-run probability as higher liquidity holdings reduce the customers incentive to start a bank-run. Calomiris et al. (2015) develop a theoretical model which analyses the effectiveness of a liquidity requirement that takes the form of a cash requirement. They show that introducing cash requirements makes financial crises less likely as banks' default risks are reduced. The reason is that higher holdings of risk-free cash reduces the banks' portfolio risk, so that they gain market confidence. In times of distress they are thus able to attract and retain deposits, which reduces the probability of liquidity issues. Ratnovski (2013) argues that a liquidity buffer can prevent bank insolvencies only in the case of a small liquidity shock as the size of the liquidity buffer is limited. He points out the importance of banks' transparency, and accordingly the ability to communicate solvency information to outsiders. This allows banks to gain access to external financing and thus to also withstand large liquidity shocks. Farhi and Tirole (2012) argue from a welfare-theoretical perspective that banks are engaged in excessive maturity transformation by issuing large amounts of short-term debt. This enables banks to increase their leverage, but also exposes banks to potential refinancing risks in the case of a liquidity shock. To reduce the excessive maturity transformation the optimal form of regulation is a liquidity requirement, which reduces banks' short-term funding. Perotti and Suarez (2011) also emphasise that banks choose a higher amount of short-term funding than is socially optimal. They analyse whether liquidity regulation, and in particular which form of liquidity regulation, is able to restore the socially optimal amount of banks' short-term funding. It is shown, that

[5] There has also been an increasing number of empirical papers dealing with this issue. For respective papers analysing the impact of liquidity requirements on bank behaviour see, for example: Baker et al. (2017), Banerjee and Mio (2017), Bonner (2012), Bonner (2016), Bonner et al. (2015), De Haan and van den End (2013), DeYoung and Jang (2016), Duijm and Wierts (2014), Gobat et al. (2014), King (2013) and Scalia et al. (2013). For empirical literature dealing with the impact of liquidity requirements on financial stability see, for example, Lallour and Mio (2016) or Hong et al. (2014).

both a simple Pigovian tax on short-term debt and a ratio-based liquidity regulation are able to contain banks' liquidity risks. However, which of the two regulations is the most efficient depends on banks' heterogeneity in risk-taking incentives and in their ability to extend credits. Ratnovski (2009) shows that banks will hold insufficient liquid assets if they assume that the central bank acts as a LOLR, providing liquidity in a systemic crisis. Quantitative liquidity regulation forces banks to hold a liquidity buffer, implying that banks do not rely on the support of the central bank. However, this regulation is costly. To reduce these costs Ratnovski supposes a LOLR policy based on information on the banks' capitalisation. Building on this information the central bank sets repayment conditions to reduce the incentives for banks to gamble for LOLR support. König (2015) develops a theoretical model which 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. The solvency effect arises as liquid assets have lower returns than illiquid assets. Thus, a liquidity buffer induces lower bank returns and therefore increases the banks' insolvency risk. As a result, liquidity regulation only increases the resilience of the banking sector as long as the liquidity effect exceeds the solvency effect. Referring to the 'lemon-problem' introduced by Akerlof (1970), Malherbe (2014) emphasises that liquidity regulation worsens adverse selection in markets for long-term assets which may lead to a market breakdown. In particular, a bank sells long-term assets for two reasons: first, to receive liquidity, and second, to prevent a loss when they realise before maturity that the asset is a "lemon", i.e. that it will fail. However, the latter is private information. This information asymmetry may lead to adverse selection in the market for the long-term asset. The introduction of bank liquidity regulation induces banks to increase their liquid asset holdings. This means that it becomes more likely that banks will sell a long-term asset because it is a "lemon" rather than to receive liquidity. This regulation-induced change in bank behaviour reinforces the adverse selection problem and therefore increases the probability of a market breakdown. Hartlage (2012) evaluates whether the LCR is a regulatory tool that effectively regulates banks' liquidity. His main result is that a binding LCR may undermine financial stability as it incentivises banks to engage in regulatory arbitrage. This incentive for banks arises as in the LCR retail deposits are classified as a less volatile funding source than wholesale funds. As a consequence, banks replace wholesale funding with retail deposits to meet the LCR. Hartlage argues that this undermines financial stability, as retail deposits especially from large-volume depositors, which are not secured by the deposit insurance, are a less stable funding source than assumed by the regulator.

Our contribution to this literature: We show that liquidity requirements actually reinforce the contagion channel from sovereigns to banks due to a regulation-induced change in bank investment behaviour. Furthermore, we show that the contagion effects from sovereigns to banks will be reinforced if a preferential treatment of government bonds in bank liquidity regulation is repealed.

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 for the proper functioning of the financial system. In response to the financial crisis the BCBS (2008) published principles for a sound bank liquidity risk management. To complement these principles, the BCBS (2010) introduced two minimum standards for funding liquidity within the Basel III framework: the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR).

Liquidity Coverage Ratio

The aim of the LCR is to promote the short-term resilience of banks' liquidity profiles by ensuring that banks have sufficient unencumbered high-quality liquid assets (HQLA) to withstand a significant stress scenario of a duration of at least one month. Following a consultant period from 2011 onwards, in January 2013 the BCBS published the final version of the LCR framework. In July 2013, the European Commission implemented the Basel LCR framework into European law by way of the fourth Capital Requirement Directive (CRD IV) and the Capital Requirement Regulation (CRR). After an observation period, the LCR was phased in gradually within an implementation period from October 2015 to January 2018. The LCR is defined as:

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

It consists of two components: the stock of HQLA (numerator) and the total expected net cash outflows over the next 30 calendar days (denominator). HQLA are assets with a high potential to be easily and quickly liquidated 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 consist of coins and banknotes, central bank reserves and a range of sovereigns securities, level 2A assets also include some sovereign securities, corporate debt securities and covered bonds, and the asset class 2B contains lower-rated corporate debt securities, mortgage-backed securities and common equity shares (see BCBS, 2013, paragraph 50, 52 and 54). Whereas there is no limit for level 1 assets, level 2A assets can only comprise up to 40% of the stock of HQLA, and the stock of level 2B assets is limited up to 15%. Furthermore, level 1 assets are also not subject to haircuts. However, a haircut of 15% is applied to level 2A assets, and level 2B assets are subject to haircuts of 25% to 50%. The denominator represents the total expected net cash outflows over the next 30 calender days. This term is defined as the total expected cash outflows minus the minimum of total expected cash inflows. However, to ensure a minimum level of HQLA holdings, total expected cash inflows are subject to a cap of 75% of the total expected cash outflows.

Net Stable Funding Ratio

The NSFR is designed to supplement the LCR. It requires banks to have a sustainable maturity structure of their assets and liabilities over a one-year time horizon. The BCBS proposed the NSFR framework in 2010. After a consultant period and a re-proposal (in January 2014) the final version of the NSFR was published in October 2014 (BCBS, 2014). It was scheduled to become a minimum standard for banks by January 2018 (BCBS, 2014).

By now (June 2018) the CRR contains only a reporting obligation for banks and the NSFR has not become a binding requirement yet. Formally, the liquidity ratio is defined as:

$$NSFR = \frac{\text{Available amount of stable funding}}{\text{Required amount of stable funding}} \geq 100\%. \tag{2}$$

It consists of two components: the available amount of stable funding (numerator) and the required amount of stable funding (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 stress scenario. The total value of the instruments in each category is then weighted with an available stable funding (ASF) factor and finally summed up. Note that funding instruments which are regarded as stable funding sources receive a high ASF factor and vice versa. The required amount of stable funding is based on the liquidity characteristics of banks' assets and off-balance-sheet (OBS) exposures. Accordingly, the banks' assets and OBS exposures are assigned to one of eight required stable funding (RSF) categories. The amount of each category is weighted with an RSF factor and then summed up. Note that the higher the liquidity value of an asset or an OBS exposure, the lower the RSF factor and vice versa.

Preferential Treatment of Sovereign Exposures

Within the LCR framework as well as within the NSFR framework, government bonds receive a preferential treatment with respect to other asset classes. Considering the LCR, sovereign bonds are eligible to be classified as level 1 assets, and are thereby not subject to haircuts and quantification limits when they satisfy at least one of the following three conditions (see BCBS, 2013, paragraph 50): (i) they are assigned a 0% risk-weight under the Basel II standardised approach, (ii) they are 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 bond holdings which are denominated in foreign currency are eligible up the amount of the bank's net cash outflows in that foreign currency in times of distress. Moreover, the LCR framework requires that the HQLA should be well diversified within each asset class. However, there is an exception for sovereign bonds (as well as for cash, central bank reserves and central bank debt securities) of the bank's jurisdiction in which the bank operates, or of its home jurisdiction (see BCBS, 2013, paragraph 44). Also, with respect to the NSFR framework, sovereign bonds are assigned a favourable treatment. As government bonds are classified as level 1 assets in the LCR, they are assigned an RSF factor of 5% within the NSFR. Only coins, banknotes and central bank reserves are assigned a lower RSF factor of 0%, whereas level 2 assets are assigned RSF factors of between 15% and 50%. This privileged treatment makes sovereign securities an attractive asset for banks to meet the LCR as well as the NSFR compared to other securities.

4 Model Framework

The model framework, except for the bank regulation part, and the modelling of the interbank market, corresponds exactly to the framework presented 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 $t = 0$, 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. Investing one unit at $t = 0$ returns one unit at $t = 1$. The two long-term assets are government bonds and loans. Government bonds are not completely safe but yield a random return S. With probability β, the investment succeeds and will produce $h > 1$ units of this good at $t = 2$. With probability $(1-\beta)$ the investment fails and one unit invested at $t = 0$ will produce only $l < 1$ units at $t = 2$. The government bond is a liquid asset, it can be sold on an interbank market at $t = 1$. The loan portfolio yields a random return K. If the loan investment succeeds, one unit invested at $t = 0$ will generate a return of $H > h > 1$ units at $t = 2$ with probability $\alpha < \beta$. If the investment fails, it will produce only $L < l < 1$ units of the single good at $t = 2$ with probability $(1 - \alpha)$.

The loan portfolio is the asset with the highest expected return ($E(K) > E(S) > 1$), it has the highest risk ($Var(K) > Var(S)$), and it is totally illiquid at $t = 1$. At $t = 2$ banks learn whether the long-term assets (government bonds and loans) succeed or fail.

4.2 Agents and Preferences

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 $t = 0$.

Like in Diamond and Dybvig (1983) consumers can be categorised into two groups. One group values consumption only at $t = 1$ (early consumers), the other group only at $t = 2$ (late consumers). We assume both groups are the same size so that 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 given by

$$U(c) = ln(c). \tag{3}$$

However, at $t = 0$ a consumer does not know whether he is an early or late consumer. Therefore, he concludes 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 $t = 0$ and can withdraw c_1^* units of the all-purpose good at $t = 1$ or c_2^* units of this good at $t = 2$. 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 certain). 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 $\gamma_2 > \gamma_1$ 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 for the sake of simplicity the extreme case in which $\gamma_1 = 0$ and $\gamma_2 = 1$, so that $\omega = 0.5$. 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*). The probability of becoming an early or a late bank is 0.5 each.

In addition to the risk-averse 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 $t = 0$. The contract concluded between a bank and an investor defines the units of the all-purpose good which are provided at $t = 0$ as equity capital ($e_0^* \geq 0$) and the units which are repaid to the investors at $t = 1$ and $t = 2$ ($e_1^* \geq 0$ and $e_2^* \geq 0$). As in Allen and Carletti (2006), the utility function of a risk-neutral investor is given by

$$U(e_0, e_1, e_2) = \rho(W_0 - e_0) + e_1 + e_2, \tag{4}$$

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

4.3 Optimisation Problem

At $t = 0$, all banks are identical, so we can consider a representative bank when analysing the banks' optimal investment and financing behaviour. 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 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

$$\begin{aligned}\max E(U) = 0.5ln(c_1) + 0.5[&\alpha\beta ln(c_{2Hh}) + \alpha(1-\beta)ln(c_{2Hl}) \\ &+ (1-\alpha)\beta ln(c_{2Lh}) + (1-\alpha)(1-\beta)ln(c_{2Ll})]\end{aligned} \tag{5}$$

$$\text{with} \quad c_1 = x + yp, \tag{6}$$

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

$$c_{2Hl} = uH + \left(\frac{x}{p} + y\right) l - e_{2Hl}, \tag{8}$$

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

$$c_{2Ll} = uL + \left(\frac{x}{p} + y\right) l - e_{2Ll}, \tag{10}$$

$$\text{s.t.} \quad \rho e_0 = 0.5(\alpha e_{2H} + (1-\alpha)e_{2L}) + 0.5(\alpha\beta e_{2Hh} + \alpha(1-\beta)e_{2Hl} + (1-\alpha)\beta e_{2Lh} + (1-\alpha)(1-\beta)e_{2Ll}), \tag{11}$$

$$LR^{min} = \frac{\kappa_x x + \kappa_y y}{1}, \tag{12}$$

$$e_0 + 1 = x + y + u, \tag{13}$$

$$x, y, u, e_0, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll} \geq 0. \tag{14}$$

Equation (5) 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 $t = 1$. 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 equation (6).

With probability 0.5 the bank is a late bank, thus all of its depositors are late consumers and withdraw their deposits at $t = 2$. 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 (7) to (10) 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 $t = 2$ consists of the units $\frac{x}{p}$ it has bought on the interbank market in exchange for its units of the short-term asset at $t = 1$, and of those it invested itself in government bonds y at $t = 0$. The last term depicts the amount a bank has to pay to the risk-neutral investors at $t = 2$. Due to their risk-neutrality, they are indifferent between whether to consume at $t = 1$ or $t = 2$. Consequently, optimal deposit contracts between a bank and its risk-averse consumer require $e_1^* = 0$.

Equation (11) depicts the investors' incentive-compatibility constraint. Investors will only be 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 the bank will use its total amount of the short-term asset, including those units obtained in exchange for its total amount of government bonds on the interbank market, to satisfy all its depositors at $t = 1$. From the proceeds of the loan portfolio, which accrue at $t = 2$, early depositors do not benefit, so that the investors receive the total proceeds from this asset (and only from this asset), i.e. $e_{2H} = uH$ or $e_{2L} = uL$. With probability 0.5 the bank is a late bank. Then, at $t = 2$, 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. Note that this residual payment may be zero.

Constraint (12) describes a possible required minimum liquidity ratio LR^{min}. The ratio LR^{min} captures the LCR (equation (1)), as it requires banks to back potential short-term liquidity withdrawals with a specified amount of liquid assets. In particular, it is expressed as a ratio of banks' liquid assets (short-term assets and government bonds) weighted with a corresponding liquidity factor (κ_x and κ_y) to the maximum possible deposit withdrawals at $t = 1$, which are equal to one. If $\kappa_x = \kappa_y$, the regulator classifies a short-term asset and a government bond as equally liquid. In this regulation scenario government bonds are treated preferentially to the short-term asset as they have to be sold on an interbank market to obtain liquidity, implying that government bonds are exposed to a potential market liquidity risk unlike the short asset. This privileged treatment will be repealed if the liquidity factor assigned to government bonds is lower than the factor assigned to the short-term asset, $\kappa_y < \kappa_x$. Then, the potential market liquidity risk is taken into account by the regulator and government bonds are classified as less liquid than the short asset. The budget constraint is represented in equation (13), and the last constraints (14) represent the non-negativity constraints.

4.4 Interbank Market for Government Bonds

Banks use government bonds to balance their idiosyncratic liquidity needs: All banks invest in government bonds at $t = 0$. When each bank has learnt whether it is an early bank or a late bank at $t = 1$, the early banks sell their government bonds to the late banks in exchange for the short-term asset to repay their depositors. We assume that the 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.

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

If it were not for this assumption, banks would have no incentive to invest in government bonds at $t = 0$, which means that an interbank market for government bonds with a positive market price would not exist at $t = 1$.[6] In the following, we briefly describe the demand- and the supply-side of the interbank market for government bonds and derive the equilibrium.[7]

Late banks will only buy government bonds at the price p if in this case the expected utility of their depositors is at least as high as when they simply store the short-term asset, i.e. if

$$\beta ln(h) + (1-\beta)ln(l) - ln(p) \geq ln(1). \tag{16}$$

This implies that there is a maximum price late banks are willing to pay for a government bond given by

$$p^{max} = h^{\beta} l^{(1-\beta)}. \tag{17}$$

All banks are identical and thus solve the same optimisation problem at $t = 0$. 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

[6] Then, late banks would only be willing to pay a lower price than 1 for a government bond at $t = 1$. However, this would mean that a government bond is worth less than the short-term asset at $t = 1$, so that banks would prefer to invest in the short-term asset instead of investing in government bonds at $t = 0$.

[7] For a more detailed description of this government bond market see Neyer and Sterzel (2017).

bank correspond to the respective aggregate quantities invested in each asset type. As half the banks are late banks, aggregate demand for government bonds at $t = 1$ is

$$y^D = \begin{cases} 0.5\frac{x^*}{p} & \text{if} \quad p \leq p^{max}, \\ 0 & \text{if} \quad p > p^{max}. \end{cases} \tag{18}$$

For $p \leq p^{max}$ the demand curve for government bonds is downward sloping because late banks want to sell their total amount of the short-term asset which is limited to $0.5x^*$. Consequently, a lower price p implies that more government bonds can be bought. However, early consumers only value consumption at $t = 1$ so that early banks want to sell all their government bonds at this date independently of the price. The supply of government bonds is thus perfectly price inelastic:

$$y^S = 0.5y^*. \tag{19}$$

Considering equations (18) and (19) and denoting the equilibrium price for government bonds p^{**},[8] the market clearing condition becomes

$$\frac{x^*}{p^{**}} = y^*. \tag{20}$$

As there is no aggregate liquidity uncertainty and as all banks solve the same optimisation problem at $t = 0$, the aggregate supply and demand for government bonds and thus the date-1 equilibrium variables are known at $t = 0$. This implies that the equilibrium government bond price at $t = 1$ must be

$$p^{**} = 1. \tag{21}$$

If $p^{**} < 1$, the return on government bonds would be smaller than on the short-term asset at $t = 1$, so that no bank would invest in government bonds at $t = 0$. If $p^{**} > 1$, a government bond would be worth more than the short-term asset at $t = 1$, so that no

[8]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 **.

bank would invest in the short-term asset at $t = 0$. In both cases, there would not be an interbank market for government bonds with a positive price. Considering equations (15) and (17), $p^{max} \geq 1$, which implies that the interbank market is always cleared with the exchanged quantity of government bonds in equilibrium given by

$$y^{**} = 0.5y^{*}. \tag{22}$$

5 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 regulation. We then analyse how their behaviour will change if a binding required minimum liquidity ratio LR^{min} is introduced. In a first regulation scenario the regulator classifies the short-term asset and government bonds as equally liquid (preferential treatment of government bonds). Our analysis shows that compared to the case without any binding required liquidity ratio, bank investment in liquid assets will increase at the expense of a decrease in their loan investment, if a binding required liquidity ratio is introduced. However, the decrease in loans is higher than the increase in liquid assets, i.e. the regulation also implies that banks raise less equity capital. In a second regulation scenario the regulator regards government bonds as less liquid than the short-term asset (repealing the preferential treatment of government bonds). It turns out that then the effects observed in the first regulation scenario 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 $t = 0$ yields the expected return $E(S) = 1.28$ at $t = 2$. Loans are also state-dependent and return at $t = 2$. 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 $t = 2$ is $E(K) = 1.4497$. Investors' opportunity costs are $\rho = 1.5$.

5.1 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 on

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 I in Appendix

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

two aspects in more detail: first, the equally high 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 and there are no capital requirements.

Regarding the result $x^* = y^*$ it is important that half the banks are early banks whereas the other half are late banks, and that there is idiosyncratic but no aggregate liquidity uncertainty. The latter implies that banks know the equilibrium price $p^{**} = 1$ at $t = 0$ (see Section 4.4 for details). Accordingly, all banks invest an 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 $t = 1$.

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 there are no capital requirements, banks raise costly equity capital. Equity capital is costly because 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 ($\rho > E(K)$). The reason for raising this costly equity capital is that it allows the liquidity risk involved with an investment in relatively highly profitable loans to be transferred at least partially from risk-averse depositors to risk-neutral investors, leading to an increase in depositors' expected utility. In more detail, 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, i.e. if it turns out that he is an early consumer, he will not benefit at all from this investment. Without the possibility for banks to raise equity capital, the consumers would bear the total liquidity risk themselves.[9] An investment in highly profitable but totally illiquid loans will increase the expected late consumers' consumption, but due to the budget constraint (13) the investment in liquid assets must be reduced to the same amount, $\frac{\partial z}{\partial u}|_{no\ capital} = \frac{\partial c_1}{\partial u}|_{no\ capital} = -1$, so that there is a respective decline in early consumer consumption.[10]

With the possibility of raising equity capital the budget constraint (13) is softened and an increase in loans leads to a lower necessary decrease in liquid assets, $\frac{\partial z}{\partial u}|_{with\ capital} > -1 = \frac{\partial z}{\partial u}|_{no\ capital}$. Consequently, an investment in loans, which increases the expected date-2 consumption, only implies a relatively small decrease of consumption at $t = 1$, so that there is an overall increase in depositors' expected utility.[11] 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 being repaid either at $t = 1$ or $t = 2$, so it is optimal that they bear the liquidity risk involved with the

[9] For a detailed explanation of banks' investment and financing behaviour without the possibility of raising equity capital see Neyer and Sterzel (2017, Section 5.2).

[10] In our numerical example, this decline in date-1 consumption and thus in early depositors' utility would be so strong that banks would not invest (at all) in illiquid loans but only in liquid assets (short-term asset, government bonds).

[11] Note that the possibility to have thus a higher expected consumption at $t = 2$ ($E(c_2^*) = 1.4191$) implies that the consumers are willing to except a repayment at $t = 1$ of less than 1 ($c_1^* = 0.9088$).

banks' loan investment. This means 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 $t = 2$ ($e_{2H}, e_{2L} > 0$). However, 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 early 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.[12] Hence, 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 ($-1 < \frac{\partial z}{\partial u}|_{with\ capital} < 0$).

5.2 Liquidity Requirements: Preferential Treatment of Government Bonds

In this section, we analyse bank behaviour when banks face a required minimum liquidity ratio in which government bonds are preferentially treated, i.e. the short-term asset and government bonds are treated as equally liquid. In the constraint (12) we have $\kappa_x = \kappa_y = 1$. Government bonds are treated preferentially to the short-term asset as, unlike the short-term asset, they have to be sold on an interbank market to obtain liquidity. Hence, government bonds are exposed to a potential market liquidity risk. If banks do not face binding liquidity requirements (Section 5.1), 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 $LR^{min} = 0.92$.[13]

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 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

[12]Formally, the investors' incentive-compatibility constraint given by equation (11) becomes $e_0\rho = 0.5uE(K)$, 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 2.0694 times higher than the amount of raised equity.

[13]We want to analyse the impact of a *binding* required liquidity ratio on bank behaviour. Therefore, we assume a minimum liquidity ratio which is slightly higher than LR^{opt}. Note, that if $0.9088 < LR^{min} < 1$, the qualitative effects would be the same. However, if $LR^{min} = 1$, banks were forced to invest their total deposits in liquid assets. In this case, banks were obsolete.

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 c_{2Hh}^*=1.4344 c_{2Hl}^*= 0.5144 c_{2Lh}^*= 1.2347 c_{2Ll}^*=0.3147

$E(U)$=0.1229

Proof: See Proof II in Appendix

Table 2: Liquidity Regulation with a Preferential Government Bond Treatment: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors

higher than the increase in liquid assets, i.e. the regulation also implies that banks raise less equity capital. As a result, the depositors' expected utility decreases.

The regulation-induced change in bank investment and financing behaviour can be explained as follows. The introduction of the binding minimum liquidity ratio forces banks to increase their liquid assets. One possibility to finance these additional investments could be to raise more equity capital. This strategy requires a disproportionately higher increase in loan investment as optimal risk-sharing implies that the amount invested in loans exceeds the amount of raised equity capital.[14] However, the regulation constraint (12) in combination with the budget constraint (13) prohibits such a strategy. Consequently, the additional required investment in liquid assets has to be carried out at the expense of a decrease in loan investment. This decrease implies that investors' claims can no longer be satisfied only with the proceeds of the early banks' loan portfolio. However, optimal liquidity risk-sharing requires exactly this. As a result, the decrease of loan investment is

[14]In our numerical example additional loan investment must be more than twice as high as additional equity capital, see footnote 12.

accompanied by a respective decrease of equity capital.[15] 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.

5.3 Liquidity Requirements: Repealing the Preferential Treatment of Government Bonds

This section analyses bank optimal investment and financing behaviour when the preferential treatment of government bonds is repealed under bank liquidity regulation, i.e. when the regulator considers the potential market liquidity risk of government bonds. Formally, government bonds are assigned a lower liquidity factor than the short-term asset ($\kappa_y < \kappa_x$) in the required minimum liquidity ratio (12). Accounting for that we set $\kappa_x = 1$ and $\kappa_y = 0.95$.[16] The required minimum liquidity ratio then becomes $LR^{min} = \frac{\kappa_x x + \kappa_y y}{1} = x + 0.95y = 0.92$. The resulting optimal bank behaviour in this regulation scenario is shown in Table 3.

Comparing the results given in Tables 2 and 3 reveals 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 the binding minimum liquidity ratio 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 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). Consequently, the beneficial liquidity

[15] Formally: From the budget constraint (13) we have that $dz + du = de_0$. The investors' incentive-compatibility constraint (11) in combination with bank's optimal risk-sharing require $du = 2.0694 de_0$ (see also Section 5.1). 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 $de_0 = -0.0105$.

[16] The liquidity factor κ_y has been chosen arbitrarily within the interval $[0.84, 1[$, i.e. it may not reflect the exact liquidity risk of government bonds. Considering the exact liquidity risk is not necessary in our analysis as we only want to determine the *qualitative* effects on bank behaviour and financial stability when repealing the preferential treatment of government bonds in liquidity regulation, and these effects are the same for all $\kappa_y \geq 0.84$. If $\kappa_y < 0.84$, banks would no longer invest in government bonds. Banks invest in government bonds to hedge their idiosyncratic liquidity risks which means that $x^* = y^*$ (see Sections 4.4 and 5.1). However, if $\kappa_y < 0.84$, hedging the idiosyncratic liquidity by using an interbank market for government bonds will no longer be possible as banks would then have to invest more than their amount of deposits into liquid assets to fulfil the liquidity requirements ($x + y > 1 = D$).

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 III in Appendix

Table 3: Liquidity Regulation in which the Preferential Government Bond Treatment is Repealed: Banks' Optimal Balance Sheet Structure and Repayments to Investors and Depositors

risk transfer will be further restricted, leading to a further reduction in the depositors' expected utility.

A binding minimum liquidity ratio with identical liquidity factors for the short asset and government bonds implies that banks are required to hold more liquid assets than they will do if it is not for the regulation. In a regulation scenario in which government bonds are classified as less liquid than the short-term asset, *banks must hold in total even more liquid assets* to fulfil the requirement compared to a scenario in which both assets are treated as equally liquid.[17] However, 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 investment in loans and a reduction in equity capital because of the budget constraint (13) in combination with the investors' incentive-compatibility constraint (11). The impact of introducing a binding minimum liquidity ratio, in which the short-term

[17] Note that the different treatment of government bonds and the short-term asset in bank liquidity regulation has no influence on the result that $x^* = y^*$ as long as $\kappa_y \geq 0.84$ (see footnote 16).

asset and government bonds are classified as equally liquid on bank behaviour, will thus be reinforced if government bonds are classified as less liquid in bank liquidity regulation.

6 Financial Stability

At the beginning of this section we show that increasing doubts about sovereign solvency may lead to liquidity issues in the banking sector triggered by a respective price drop for sovereign bonds. Illiquid but per se solvent banks go bankrupt. Within our model framework we derive that liquidity requirements cannot prevent these bankruptcies. However, a central bank acting as a LOLR can avoid bank insolvencies due to liquidity issues. Against this background, introducing liquidity requirements in general, and repealing the preferential treatment of government bonds in liquidity regulation in particular, undermines financial stability in the case of a sovereign debt crisis. Note that the modelling of the government bond shock and of the LOLR corresponds exactly to the modelling in Neyer and Sterzel (2017).

6.1 Government Bond Shock

After the banks have made their financing and investment decisions at $t = 0$, but before the start of interbank trading at $t = 1$, the economy is hit by a shock in the form of a sudden 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 $E(S) > \overline{E(S)}$. When investment decisions are made, this government bond shock is assigned a zero probability at $t = 0$, as the liquidity shock in Allen and Gale (2000). The return on the short-term asset and the expected return on the loan portfolio are not affected by the shock.[18]

Regarding the interbank trading at $t = 1$, the shock influences the *late banks' demand* for sovereign bonds in the interbank market. The decline in the expected return on

[18]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.

government bonds implies that the maximum price late banks are willing to pay for a bond decreases (see equations (17) and (18)). The *early banks' supply* of government bonds is not affected by the shock. As their depositors only value consumption at $t = 1$, they want to sell their total holdings of government bonds at the same time, independent of their default probability (see equation (19)).

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

$$p^{crit} = 1. \tag{23}$$

Setting in equation (17) p^{max} equal to p^{crit} and then solving the equation for $(1-\beta)$ gives the critical default probability

$$(1-\beta)^{crit} = \frac{ln(h) - ln(p^{crit})}{ln(h) - ln(l)} = \frac{ln(h)}{ln(h) - ln(l)}. \tag{24}$$

If the aftershock default probability of government bonds exceeds this critical probability, the expected return on government bonds will become so low that the equilibrium price for a government 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 $(1 - \overline{\beta^{small}}) \leq (1-\beta)^{crit}$. The increased sovereign default probability induces a decrease in the maximum price late banks are willing to pay for a sovereign bond. However, as it does not fall below one ($1 \leq \overline{p^{max\ small}} < p^{max}$), the equilibrium price and the equilibrium transaction volume do not change, $\overline{p^{**small}} = p^{**} = 1$, $\overline{y^{**small}} = y^{**} = 0.5y^{*}$. As a result, a small government bond shock does not lead to liquidity issues in the banking sector.[19]

A *large government bond 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

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

so low that the maximum price late banks are willing to pay for a bond falls below one. Considering equation (17), the aftershock equilibrium price becomes

$$\overline{p^{**large}} = \overline{p^{max\ large}} < 1. \tag{25}$$

Note that due to the perfectly price inelastic supply the equilibrium trading volume has not changed, $\overline{y^{**large}} = y^{**} = 0.5y^{*}$. The decrease of the equilibrium price below 1 means that early banks are no longer able to fulfil their deposit contracts:

$$\overline{c_1^{large}} = x^{*} + y^{*}\overline{p^{**large}} < x^{*} + y^{*}p^{**} = x^{*} + y^{*} = c_1^{*}. \tag{26}$$

Early banks are thus insolvent and are liquidated at $t = 1$.

6.2 Central Bank as a Lender of Last Resort

To avoid bankruptcies of illiquid but per se solvent banks we introduce a central bank as a LOLR in the sense of Bagehot (1873). The central bank provides liquidity to troubled banks against adequate collateral. In our model, banks' loan portfolios serve as collateral.[20] 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

$$\psi = u^{*}L. \tag{27}$$

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):

$$\tau = c_1^{*} - \overline{c_1^{large}} = y^{*}(p^{**} - \overline{p^{**large}}) = y^{*}(1 - \overline{p^{**large}}). \tag{28}$$

[20]Note, that in our model government bonds do not serve as collateral. If this were the case, the central bank would have to buy government bonds for the price of 1, protecting illiquid banks from going bankrupt. This would induce a subsidy by the central bank as the market price for government bonds is lower than 1 after the large shock. Furthermore, the central bank would be exposed to credit risks as in the case of bond failures, the central bank would bear losses ($l < p = 1$).

Comparing the 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

$$p^{critLOLR} = 1 - \frac{u^*L}{y^*} < 1. \tag{29}$$

If $\overline{p^{**large}} < p^{critLOLR}$ the bank is illiquid and insolvent. Inserting $p^{critLOLR}$ for $\overline{p^{**large}}$ in equation (25) and then solving the equation for $(1 - \overline{\beta^{large}})$, gives us the critical default probability

$$(1-\beta)^{critLOLR} = \frac{ln(h) + ln(\frac{u^*L}{y^*})}{ln(h) - ln(l)} = \frac{ln(h) + ln(\frac{u^*}{z^*}2L)}{ln(h) - ln(l)}. \tag{30}$$

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 liquidity issue leads to a solvency issue as the price drop is so huge that the early banks do not have sufficient collateral to obtain enough liquidity from the LOLR to satisfy their depositors.

Comparing the critical default probability with and without a central bank as a LOLR (see equations (24) and (30)) 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 depends not only on the possible government bond returns h and l, as it is the case without a LOLR, but, in addition, on the loan portfolio return L and the banks' investment in government bonds y^* and loans u^*.[21] This has important implications for the banking sector's shock-absorbing capacity under the different liquidity regulation approaches as we will see in the next section.

[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. If the probability of loan success were negatively affected by the government bond shock, i.e. if $\alpha > \overline{\alpha}$, the discussed liquidity issues for the early banks would not be affected. The crucial point is that the decrease in α would neither induce a change in the liquidity provision by the central bank (ψ) nor would it lead to an additional liquidity demand (τ). As these variables determine the shock-absorbing capacity of the banking sector (see Section 6.3), spillover effects from sovereign to loans have no impact on our results.

6.3 The Shock-Absorbing Capacity of the Banking Sector

The above analysis allows us to discuss the (government bond) shock-absorbing capacity of the banking sector, and in this sense its stability[22], in different liquidity regulation scenarios. 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 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 (24) and (30) and denoting the shock-absorbing capacity by SAC and SAC^{LOLR} respectively, we get for the banking sector's shock-absorbing capacity without a LOLR

$$SAC = (1-\beta)^{crit} - (1-\beta) = \frac{ln(h)}{ln(h) - ln(l)} - (1-\beta) \tag{31}$$

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

$$SAC^{LOLR} = (1-\beta)^{critLOLR} - (1-\beta) = \frac{ln(h) + ln(\frac{u^*}{z^*}2L))}{ln(h) - ln(l)} - (1-\beta). \tag{32}$$

Equation (31) 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 a government bonds falls below 1 i.e. in the case of a large government bond shock. Early banks then will no longer be able to satisfy their customers' claims. The government bond price drop is only determined by the expected return on a government bond (see equation (25)) which is not affected by liquidity regulation at all. Hence, if there is no LOLR, the sovereign shock-induced liquidity problem cannot be solved by any kind of liquidity requirements, i.e. the difference $(1-\beta)^{crit} - (1-\beta) = SAC$ is always the same. This result is illustrated in Figure 1 by the solid line.

However, with a LOLR liquidity requirements influence the banking sector's shock-absorbing capacity. The reason is that the required minimum liquidity ratios influence bank optimal investment behaviour (see Section 5). In both liquidity regulation scenarios

[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.

banks increase their government bond investments y^* and decrease their loan investments u^*, and both variables have an influence on SAC^{LOLR} as equation (32) shows. The increase in government bond holdings implies an increase in the banks' additional liquidity needs τ after the shock (see equation (28)). The decrease in loan investment leads to a decrease in the additional liquidity ψ the central bank is willing to provide (see equation (27)). Both effects induce a decrease of the SAC^{LOLR}. As the increase in y^* and the decrease in u^* is the strongest in the liquidity regulation scenario where government bonds are classified as less liquid than the short-term assets, the (government bond) shock-absorbing capacity of the banking sector will be the lowest if the preferential treatment of government bonds within the LR^{min} is repealed. This result is illustrated in Figure 1 by the broken line.

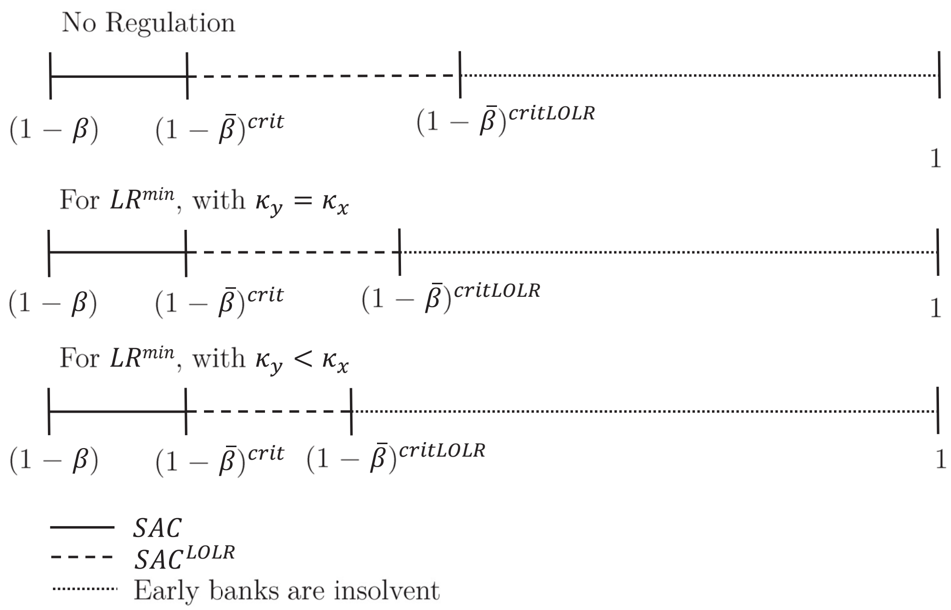

Figure 1: Shock-Absorbing Capacity of the Banking Sector

7 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 EU countries were having severe problems with repaying or refinancing their public debt. The resulting price drops of sovereign bonds severely strained banks' balance sheets. The liquidity requirements proposed by the BCBS, aiming to strengthen banks' liquidity profiles, do not account for sovereign risk. In particular, government bonds are treated preferentially with respect to other asset classes, i.e. they are classified as risk-free and highly-liquid irrespective of their inherent credit risk. Hence, there are neither quantitative limits nor haircuts applied to sovereign bonds under this liquidity regulation framework. However, neglecting sovereign risk in liquidity regulation may undermine financial stability. There is an ongoing debate addressing the abolishment of the preferential treatment of sovereign borrowers in EU banking 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 how far liquidity requirements in general and the abolishment of the preferential government bond treatment in liquidity regulation in particular contribute to making the banking sector more resilient against sovereign debt crises.

One important reason for relatively large government bond holdings is that banks use them to manage their everyday business. Capturing this idea, in our model banks hold government bonds to balance their idiosyncratic liquidity needs. Increasing sovereign risk may induce a price drop for government bonds, implying liquidity issues in the banking sector which then leads to the insolvency of a huge number of banks (systemic crisis). This model shows that liquidity requirements, regardless of the government bond treatment, are not able to increase financial stability in case of a sovereign crisis. Preventing banks from going bankrupt due to liquidity issues, a central bank acting as LOLR is necessary. Banks can then obtain additional liquidity from the LOLR against adequate collateral. It is then crucial that the banks' investment structure determines the resilience of the banking sector in the case of sovereign distress. A required minimum liquidity ratio, and especially repealing the preferential treatment of government bonds in liquidity regulation, induces banks to hold more liquid assets in total (government bonds and the short-term asset) at the expense of a decrease in loan investment. Due to this regulation-induced change in banks' investments, in a sovereign debt crisis banks face higher liquidity needs in order to fulfil the contracts with their consumers as contractually agreed. However, on the other hand, they have less collateral to obtain additional liquidity from the central bank. As a result, the abolishment of the preferential treatment of government bonds in liquidity regulation does not contribute to a more resilient banking sector in sovereign crises.

A Appendix

Proof I. Using the Lagrangian $\mathcal{L}$ the bank's optimisation problem can be formulated as

$$\begin{aligned}
\max_{x,y,u,e_{2Hh},e_{2Hl},e_{2Lh},e_{2Ll}} \mathcal{L} = {} & 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\
& +0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] - \lambda\Bigg(x + y + u \\
& -1 - \left[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \right. \\
& \left. +0.0686e_{2Lh} + 0.0014e_{2Ll})\right]\Bigg) - \mu_x x - \mu_y y - \mu_u u \\
& -\mu_{e_{2Hh}} e_{2Hh} - \mu_{e_{2Hl}} e_{2Hl} - \mu_{e_{2Lh}} e_{2Lh} - \mu_{e_{2Ll}} e_{2Ll},
\end{aligned} \tag{A.1}$$

$$\begin{aligned}
\text{with} \quad c_1 &= x + yp^{**}, \\
c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 1.3 - e_{2Hh}, \\
c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 0.3 - e_{2Hl}, \\
c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 1.3 - e_{2Lh}, \\
c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 0.3 - e_{2Ll},
\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (13) and also includes the investors' incentive-compatibility constraint (11), whereas $\mu_x, \mu_y, \mu_u, \mu_{e_{2Hh}}, \mu_{e_{2Hl}}, \mu_{e_{2Lh}}, \mu_{e_{2Ll}}$ are Lagrange multipliers corresponding to the non-negativity conditions (14). As the same argumentation holds as in Sections 4.4 and 5.1 we have $p^{**} = 1$ and $x^* = y^* = 0.5z^*$. By differentiating the Lagrange function with respect to z, u, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll}, λ, μ_z, μ_u, $\mu_{e_{2Hh}}$, $\mu_{e_{2Hl}}$, $\mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ we obtain

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial z} =&\frac{0.5}{z} + \frac{0.5\cdot 0.93\cdot 0.98\cdot 1.3}{1.3z+1.54u-e_{2Hh}} + \frac{0.5\cdot 0.93\cdot 0.02\cdot 0.3}{0.3z+1.54u-e_{2Hl}} \\ &+ \frac{0.5\cdot 0.07\cdot 0.98\cdot 1.3}{1.3z+0.25u-e_{2Lh}} + \frac{0.5\cdot 0.07\cdot 0.02\cdot 0.3}{0.3z+0.25u-e_{2Ll}} - \lambda - \mu_z \overset{!}{=} 0,\end{aligned} \tag{A.2}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial u} =&\frac{0.5\cdot 0.93\cdot 0.98\cdot 1.54}{1.3z+1.54u-e_{2Hh}} + \frac{0.5\cdot 0.93\cdot 0.02\cdot 1.54}{0.3z+1.54u-e_{2Hl}} \\ &+ \frac{0.5\cdot 0.07\cdot 0.98\cdot 0.25}{1.3z+0.25u-e_{2Lh}} + \frac{0.5\cdot 0.07\cdot 0.02\cdot 0.25}{0.3z+0.25u-e_{2Ll}} \\ &- \lambda\left(1-\left(\frac{0.5\cdot 1.4497}{1.5}\right)\right) - \mu_u \overset{!}{=} 0,\end{aligned} \tag{A.3}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Hh}} =\frac{0.5\cdot 0.93\cdot 0.98\cdot(-1)}{1.3z+1.54u-e_{2Hh}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.9114\right) - \mu_{e_{2Hh}} \overset{!}{=} 0, \tag{A.4}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Hl}} =\frac{0.5\cdot 0.93\cdot 0.02\cdot(-1)}{0.3z+1.54u-e_{2Hl}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0186\right) - \mu_{e_{2Hl}} \overset{!}{=} 0, \tag{A.5}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Lh}} =\frac{0.5\cdot 0.07\cdot 0.98\cdot(-1)}{1.3z+0.25u-e_{2Lh}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0686\right) - \mu_{e_{2Lh}} \overset{!}{=} 0, \tag{A.6}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Ll}} =\frac{0.5\cdot 0.07\cdot 0.02\cdot(-1)}{0.3z+0.25u-e_{2Ll}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0014\right) - \mu_{e_{2Ll}} \overset{!}{=} 0, \tag{A.7}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial \lambda} =&z+u-1-\left[\frac{0.5}{1.5}(1.4497u+0.9114e_{2Hh}+0.0186e_{2Hl}\right. \\ &\left.+0.0686e_{2Lh}+0.0014e_{2Ll})\right] \overset{!}{=} 0,\end{aligned} \tag{A.8}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_z} =-z \overset{!}{=} 0, \tag{A.9}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_u} =-u \overset{!}{=} 0, \tag{A.10}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Hh}}} =-e_{2Hh} \overset{!}{=} 0, \tag{A.11}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Hl}}} =-e_{2Hl} \overset{!}{=} 0, \tag{A.12}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Lh}}} =-e_{2Lh} \overset{!}{=} 0, \tag{A.13}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Ll}}} =-e_{2Ll} \overset{!}{=} 0. \tag{A.14}$$

Multiplying both sides of the equations (A.2) with z, (A.3) with u, (A.4) with e_{2Hh}, (A.5) with e_{2Hl}, (A.6) with e_{2Lh}, and (A.7) with e_{2Ll}, adding the six equations and regarding equation (A.8), we obtain $\lambda^* = 1$. After testing which non-negativity conditions bind, we derive that the non-negativity conditions for e_{Hh}, e_{Hl}, e_{Ll} and e_{Ll} become binding, i.e. $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} = e^*_{Ll} = 0$ and thus $\mu^*_{e_{2Hh}} = \mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. Solving then for z^* and u^* we get $z^* = 0.9088$ and $u^* = 0.1765$ and regarding the constraint (11) the optimal amount of equity capital is $e_0^* = 0.0853$. ■

Proof II. When a bank faces a required minimum liquidity ratio ($LR^{min} = 0.92 = \frac{x+y}{1}$), its optimisation problem can be formulated in the form of the Lagrange function

$$\begin{aligned}
\max_{x,y,u,e_{2Hh},e_{2Hl},e_{2Lh},e_{2Ll}} \mathcal{L} = {} & 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\
& +0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] \\
& -\lambda\Bigg(x + y + u - 1 - \left[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh}\right. \\
& \left.\left. +0.0186e_{2Hl} + 0.0686e_{2Lh} + 0.0014e_{2Ll})\right]\Bigg) \qquad \text{(A.15)} \\
& -\mu_x x - \mu_y y - \mu_u u - \mu_{e_{2Hh}} e_{2Hh} \\
& -\mu_{e_{2Hl}} e_{2Hl} - \mu_{e_{2Lh}} e_{2Lh} - \mu_{e_{2Ll}} e_{2Ll} - \mu_{LR} \\
& (x + y - 0.92),
\end{aligned}$$

$$\begin{aligned}
\text{with} \quad c_1 &= x + yp^{**}, \\
c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 1.3 - e_{2Hh}, \\
c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 0.3 - e_{2Hl}, \\
c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 1.3 - e_{2Lh}, \\
c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 0.3 - e_{2Ll},
\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (13) and also includes the investors' incentive-compatibility constraint (11). The variables $\mu_x, \mu_y, \mu_u, \mu_{e_{2Hh}}, \mu_{e_{2Hl}}, \mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ are the Lagrange multipliers corresponding to the non-negativity conditions (14) and μ_{LR} is the Lagrange multiplier corresponding to the required minimum liquidity ratio (12). Considering that $p^{**} = 1$ (see Section 4.4) as well as $x^* = y^* = 0.5z^*$ (for a detailed explanation see text in Section 5.1) and differentiating $\mathcal{L}$ with respect to z, u, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll}, λ, μ_{LR}, μ_z, μ_u, $\mu_{e_{2Hh}}$, $\mu_{e_{2Hl}}$, $\mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ gives

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial z} =& \frac{0.5}{z} + \frac{0.5\cdot 0.93\cdot 0.98\cdot 1.3}{1.3z+1.54u-e_{2Hh}} + \frac{0.5\cdot 0.93\cdot 0.02\cdot 0.3}{0.3z+1.54u-e_{2Hl}} \\ &+ \frac{0.5\cdot 0.07\cdot 0.98\cdot 1.3}{1.3z+0.25u-e_{2Lh}} + \frac{0.5\cdot 0.07\cdot 0.02\cdot 0.3}{0.3z+0.25u-e_{2Ll}} - \lambda - \mu_z - \mu_{LR} \stackrel{!}{=} 0,\end{aligned} \tag{A.16}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial u} =& \frac{0.5\cdot 0.93\cdot 0.98\cdot 1.54}{1.3z+1.54u-e_{2Hh}} + \frac{0.5\cdot 0.93\cdot 0.02\cdot 1.54}{0.3z+1.54u-e_{2Hl}} \\ &+ \frac{0.5\cdot 0.07\cdot 0.98\cdot 0.25}{1.3z+0.25u-e_{2Lh}} + \frac{0.5\cdot 0.07\cdot 0.02\cdot 0.25}{0.3z+0.25u-e_{2Ll}} \\ &- \lambda\left(1-\left(\frac{0.5\cdot 1.4497}{1.5}\right)\right) - \mu_u \stackrel{!}{=} 0,\end{aligned} \tag{A.17}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Hh}} = \frac{0.5\cdot 0.93\cdot 0.98\cdot(-1)}{1.3z+1.54u-e_{2Hh}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.9114\right) - \mu_{e_{2Hh}} \stackrel{!}{=} 0, \tag{A.18}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Hl}} = \frac{0.5\cdot 0.93\cdot 0.02\cdot(-1)}{0.3z+1.54u-e_{2Hl}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0186\right) - \mu_{e_{2Hl}} \stackrel{!}{=} 0, \tag{A.19}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Lh}} = \frac{0.5\cdot 0.07\cdot 0.98\cdot(-1)}{1.3z+0.25u-e_{2Lh}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0686\right) - \mu_{e_{2Lh}} \stackrel{!}{=} 0, \tag{A.20}$$

$$\frac{\partial\mathcal{L}}{\partial e_{2Ll}} = \frac{0.5\cdot 0.07\cdot 0.02\cdot(-1)}{0.3z+0.25u-e_{2Ll}} - \lambda\left(-\frac{0.5}{1.5}\cdot 0.0014\right) - \mu_{e_{2Ll}} \stackrel{!}{=} 0, \tag{A.21}$$

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial \lambda} =& z+u-1-\Bigg[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl} \\ &+ 0.0686e_{2Lh} + 0.0014e_{2Ll})\Bigg] \stackrel{!}{=} 0.\end{aligned} \tag{A.22}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{LR}} = z - 0.92 \stackrel{!}{=} 0. \tag{A.23}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_z} = -z \stackrel{!}{=} 0, \tag{A.24}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_u} = -u \stackrel{!}{=} 0, \tag{A.25}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Hh}}} = -e_{2Hh} \stackrel{!}{=} 0, \tag{A.26}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Hl}}} = -e_{2Hl} \stackrel{!}{=} 0, \tag{A.27}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Lh}}} = -e_{2Lh} \stackrel{!}{=} 0, \tag{A.28}$$

$$\frac{\partial\mathcal{L}}{\partial \mu_{e_{2Ll}}} = -e_{2Ll} \stackrel{!}{=} 0. \tag{A.29}$$

Considering that $x^* = y^* = 0.5z^*$ and $LR^{min} = 0.92 = x + y$, we obtain that $z^* = 0.92$ ($\mu^*_{LR} \neq 0$). After testing which non-negativity conditions bind, we derive that the non-negativity conditions for e_{Hh}, e_{Hl}, e_{Ll} and e_{Ll} become binding, i.e. $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} = e^*_{Ll} = 0$ and thus $\mu^*_{e_{2Hh}} = \mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. By inserting $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} =$

$e^*_{Ll} = 0$ and $z^* = 0.92$ in equation (A.22) and solving for u^* we get $u^* = 0.1548$. Solving then for e^*_0 by inserting $u^* = 0.1548$ and $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} = e^*_{Ll} = 0$ in equation (11) we get $e^*_0 = 0.0748$. ■

Proof III. When banks face a required minimum liquidity ratio and government bonds are applied a lower liquidity factor than the short-term asset ($LR^{min} = \frac{\kappa_x x + \kappa_y y}{1} = x + 0.95y = 0.92$), their optimisation problem in the form of a Lagrangian is then

$$\begin{aligned}
\max_{x,y,u,e_{2Hh},e_{2Hl},e_{2Lh},e_{2Ll}} \quad \mathcal{L} = {} & 0.5ln(c_1) + 0.5[0.93 \cdot 0.98ln(c_{2Hh}) + 0.93 \cdot 0.02ln(c_{2Hl}) \\
& +0.07 \cdot 0.98ln(c_{2Lh}) + 0.07 \cdot 0.02ln(c_{2Ll})] \\
& -\lambda\Bigg(x + y + u - 1 - \Bigg[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} \\
& +0.0186e_{2Hl} + 0.0686e_{2Lh} + 0.0014e_{2Ll})\Bigg]\Bigg) \qquad \text{(A.30)} \\
& -\mu_x x - \mu_y y - \mu_u u - \mu_{e_{2Hh}} e_{2Hh} \\
& -\mu_{e_{2Hl}} e_{2Hl} - \mu_{e_{2Lh}} e_{2Lh} - \mu_{e_{2Ll}} e_{2Ll} - \mu_{LR} \\
& (x + 0.95y - 0.92),
\end{aligned}$$

$$\begin{aligned}
\text{with} \quad c_1 &= x + yp^{**}, \\
c_{2Hh} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 1.3 - e_{2Hh}, \\
c_{2Hl} &= 1.54u + \left(\frac{x}{p^{**}} + y\right) 0.3 - e_{2Hl}, \\
c_{2Lh} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 1.3 - e_{2Lh}, \\
c_{2Ll} &= 0.25u + \left(\frac{x}{p^{**}} + y\right) 0.3 - e_{2Ll},
\end{aligned}$$

where λ is the Lagrange multiplier corresponding to the budget constraint (13) and also includes the investors' incentive-compatibility constraint (11), $\mu_x, \mu_y, \mu_u, \mu_{e_{2Hh}}, \mu_{e_{2Hl}}, \mu_{e_{2Lh}}, \mu_{e_{2Ll}}$ are the Lagrange multipliers corresponding to the non-negativity conditions (14) and μ_{LR} is the Lagrange multiplier corresponding to the required minimum liquidity ratio (12). Considering that $p^{**} = 1$ (see Section 4.4) banks equally split their investment in liquid assets ($x^* = y^* = 0.5z^*$) also when sovereign bonds are applied a lower liquidity factor than the short-term asset (see footnote 17). By differentiating $\mathcal{L}$ with respect to z, u, e_{2Hh}, e_{2Hl}, e_{2Lh}, e_{2Ll}, λ, μ_{LR}, μ_z, μ_u, $\mu_{e_{2Hh}}$, $\mu_{e_{2Hl}}$, $\mu_{e_{2Lh}}$ and $\mu_{e_{2Ll}}$ we obtain

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial z} =& \frac{0.5}{z} + \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot 1.3}{1.3z + 1.54u - e_{2Hh}} + \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot 0.3}{0.3z + 1.54u - e_{2Hl}} \\ &+ \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot 1.3}{1.3z + 0.25u - e_{2Lh}} + \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot 0.3}{0.3z + 0.25u - e_{2Ll}} - \lambda - \mu_z - 0.975\mu_{LR} \stackrel{!}{=} 0,\end{aligned} \tag{A.31}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial u} =& \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot 1.54}{1.3z + 1.54u - e_{2Hh}} + \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot 1.54}{0.3z + 1.54u - e_{2Hl}} \\ &+ \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot 0.25}{1.3z + 0.25u - e_{2Lh}} + \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot 0.25}{0.3z + 0.25u - e_{2Ll}} \\ &- \lambda\left(1 - \left(\frac{0.5 \cdot 1.4497}{1.5}\right)\right) - \mu_u \stackrel{!}{=} 0,\end{aligned} \tag{A.32}$$

$$\frac{\partial \mathcal{L}}{\partial e_{2Hh}} = \frac{0.5 \cdot 0.93 \cdot 0.98 \cdot (-1)}{1.3z + 1.54u - e_{2Hh}} - \lambda\left(-\frac{0.5}{1.5} \cdot 0.9114\right) - \mu_{e_{2Hh}} \stackrel{!}{=} 0, \tag{A.33}$$

$$\frac{\partial \mathcal{L}}{\partial e_{2Hl}} = \frac{0.5 \cdot 0.93 \cdot 0.02 \cdot (-1)}{0.3z + 1.54u - e_{2Hl}} - \lambda\left(-\frac{0.5}{1.5} \cdot 0.0186\right) - \mu_{e_{2Hl}} \stackrel{!}{=} 0, \tag{A.34}$$

$$\frac{\partial \mathcal{L}}{\partial e_{2Lh}} = \frac{0.5 \cdot 0.07 \cdot 0.98 \cdot (-1)}{1.3z + 0.25u - e_{2Lh}} - \lambda\left(-\frac{0.5}{1.5} \cdot 0.0686\right) - \mu_{e_{2Lh}} \stackrel{!}{=} 0, \tag{A.35}$$

$$\frac{\partial \mathcal{L}}{\partial e_{2Ll}} = \frac{0.5 \cdot 0.07 \cdot 0.02 \cdot (-1)}{0.3z + 0.25u - e_{2Ll}} - \lambda\left(-\frac{0.5}{1.5} \cdot 0.0014\right) - \mu_{e_{2Ll}} \stackrel{!}{=} 0, \tag{A.36}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \lambda} =& z + u - 1 - \left[\frac{0.5}{1.5}(1.4497u + 0.9114e_{2Hh} + 0.0186e_{2Hl}\right. \\ &\left. + 0.0686e_{2Lh} + 0.0014e_{2Ll})\right] \stackrel{!}{=} 0.\end{aligned} \tag{A.37}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{LR}} = 0.975z - 0.92 \stackrel{!}{=} 0. \tag{A.38}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_z} = -z \stackrel{!}{=} 0, \tag{A.39}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_u} = -u \stackrel{!}{=} 0, \tag{A.40}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Hh}}} = -e_{2Hh} \stackrel{!}{=} 0, \tag{A.41}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Hl}}} = -e_{2Hl} \stackrel{!}{=} 0, \tag{A.42}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Lh}}} = -e_{2Lh} \stackrel{!}{=} 0, \tag{A.43}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{e_{2Ll}}} = -e_{2Ll} \stackrel{!}{=} 0. \tag{A.44}$$

Considering $x^* = y^* = 0.5z^*$ and $LR^{min} = 0.92 = x + 0.95y$, we obtain that $z^* = 0.9436$ ($\mu^*_{LR} \neq 0$). After testing which non-negativity conditions bind, we derive that the non-negativity conditions for e_{Hh}, e_{Hl}, e_{Ll} and e_{Ll} become binding, i.e. $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} = e^*_{Ll} = 0$ and thus $\mu^*_{e_{2Hh}} = \mu^*_{e_{2Hl}} = \mu^*_{e_{2Lh}} = \mu^*_{e_{2Ll}} \neq 0$. By inserting $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} = e^*_{Ll} = 0$ and $z^* = 0.9436$ in equation (A.37) and solving for u^* we get $u^* = 0.1092$. Solving then for e^*_0 by inserting $e^*_{Hh} = e^*_{Hl} = e^*_{Ll} = e^*_{Ll} = 0$ and $u^* = 0.1092$ in equation (11) we get $e^*_0 = 0.0528$.■

Bibliography

Abad, J. (2018). Breaking the feedback loop: Macroprudential regulation of banks' sovereign exposures. mimeo.

Acharya, V. V. and S. Steffen (2017). The importance of a banking union and fiscal union for a capital markets union. European Economy – Discussion Paper, No. 62, European Commission.

Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. *Quarterly Journal of Economics 84*(3), 488–500.

Allen, F. and E. Carletti (2006). Credit risk transfer and contagion. *Journal of Monetary Economics 53*(1), 89–111.

Allen, F. and D. Gale (2000). Financial contagion. *Journal of Political Economy 108*(1), 1–33.

Bagehot, W. (1873). *Lombard Street: A description of the money market.* New York: Scribner, Armstrong & Company.

Baker, C., C. Cumming, and J. Jagtiani (2017). The impacts of financial regulations: Solvency and liquidity in the post-crisis period. *Journal of Financial Regulation and Complience 25*(3), 253–270.

Banerjee, R. N. and H. Mio (2017). The impact of liquidity regulation on banks. *Journal of Financial Intermediation*, 1–15.

BCBS (2008). Principles for sound liquidity risk management and supervision. Bank for International Settlements.

BCBS (2010). Basel III: International framework for liquidity risk measurment, standards and monitoring. Bank for International Settlements.

BCBS (2013). Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools. Bank for International Settlements.

BCBS (2014). Basel III: The Net Stable Funding Ratio. Bank for International Settlements.

BCBS (2017). The regulatory treatment of sovereign exposures. Discussion paper, Bank for International Settlements.

Bonner, C. (2012). Liquidity regulation, funding costs and corporate lending. DNB Working Paper, No. 361, De Nederlandsche Bank.

Bonner, C. (2016). Preferential regulatory treatment and banks' demand for government bonds. *Journal of Money, Credit and Banking 48*(6), 1195–1221.

Bonner, C., I. van Lelyveld, and R. Zymek (2015). Banks' liquidity buffers and the role of liquidity regulation. *Journal of Financial Services Research 48*(3), 215–234.

Brunnermeier, M. K., L. Garicano, P. R. Lane, M. Pagano, R. Reis, T. Santos, D. Thesmar, S. Van Nieuwerburgh, and D. Vayanos (2016). The sovereign-bank diabolic loop and ESBies. *The American Economic Review 106*(5), 508–512.

Buschmann, C. and C. Schmaltz (2017). Sovereign collateral as a trojan horse: Why do we need an LCR+. *Journal of Financial Stability 33*, 311–330.

Calomiris, C. W., F. Heider, and M. Hoerova (2015). A theory of bank liquidity requirements. Columbia Business School Research Paper, No. 14–39, Columbia Business School.

Corsetti, G., K. Kuester, A. Meier, and G. J. Müller (2013). Sovereign risk, fiscal policy, and macroeconomic stability. *The Economic Journal 123*(566), 99–132.

Covi, G. and U. Eydam (2018). End of the sovereign-bank doom loop in the European Union? The bank recovery and resolution directive. *Journal of Evolutionary Economics*, 1–26.

De Haan, L. and J. W. van den End (2013). Bank liquidity, the maturity ladder, and regulation. *Journal of Banking & Finance 37*(10), 3930–3950.

DeYoung, R. and K. Y. Jang (2016). Do banks actively manage their liquidity? *Journal of Banking & Finance 66*, 143–161.

Diamond, D. W. and P. H. Dybvig (1983). Bank runs, deposit insurance, and liquidity. *Journal of Political Economy 91*(3), 401–419.

Diamond, D. W. and A. K. Kashyap (2016). Liquidity requirements, liquidity choice, and financial stability. In J. B. Taylor and H. Uhlig (Eds.), *Handbook of Macroeconomics, Volume 2*, pp. 2263–2303. Amsterdam: Elsevier.

Duijm, P. and P. Wierts (2014). The effects of liquidity regulation on bank assets and liabilities. Tinbergen Institute Discussion Paper, No. 14–018/IV/DSF72, Tinbergen Institute.

Farhi, E. and J. Tirole (2012). Collective moral hazard, maturity mismatch, and systemic bailouts. *The American Economic Review 102*(1), 60–93.

Farhi, E. and J. Tirole (2018). Deadly embrace: Sovereign and financial balance sheets doom loops. *The Review of Economic Studies 85*(3), 1781–1823.

Gobat, J., M. Yanase, and J. F. Maloney (2014). The Net Stable Funding Ratio: Impact and issues for consideration. IMF Working Paper, No. 14/106, International Monetary Fund.

Hartlage, A. W. (2012). The Basel III Liquidity Coverage Ratio and financial stability. *Michigan Law Review 111*(3), 453–483.

Hong, H., J.-Z. Huang, and D. Wu (2014). The information content of Basel III liquidity risk measures. *Journal of Financial Stability 15*, 91–111.

King, M. R. (2013). The Basel III Net Stable Funding Ratio and bank net interest margins. *Journal of Banking & Finance 37*(11), 4144–4156.

König, P. J. (2015). Liquidity requirements: A double-edged sword. *International Journal of Central Banking 11*(4), 129–168.

Lallour, A. and H. Mio (2016). Do we need a stable funding ratio? Banks' funding in the global financial crisis. Staff Working Paper, No. 602, Bank of England.

Malherbe, F. (2014). Self-fulfilling liquidity dry-ups. *The Journal of Finance 69*(2), 947–970.

Neyer, U. and A. Sterzel (2017). Capital requirements for government bonds – Implications for bank behaviour and financial stability. DICE Discussion Paper, No. 275, Heinrich-Heine-Universität Düsseldorf.

Perotti, E. C. and J. Suarez (2011). A Pigovian approach to liquidity regulation. DNB Working Paper, No. 291, De Nederlandsche Bank.

Ratnovski, L. (2009). Bank liquidity regulation and the lender of last resort. *Journal of Financial Intermediation 18*(4), 541–558.

Ratnovski, L. (2013). Liquidity and transparency in bank risk management. *Journal of Financial Intermediation 22*(3), 422–439.

Scalia, A., S. Longoni, and T. Rosolin (2013). The Net Stable Funding Ratio and banks' participation in monetary policy operations: Some evidence for the euro area. Occasional Paper, No. 195, Banca D'Italia.

Eidesstattliche Erklärung

Ich, André Sterzel, versichere an Eides statt, dass die vorliegende Dissertation von mir selbstständig und ohne unzulässige fremde Hilfe unter Beachtung der “Grundsätze zur Sicherung guter wissenschaftlicher Praxis an der Heinrich-Heine-Universität Düsseldorf” erstellt worden ist.

Köln, 17. Juni 2019

Ort, Datum

Unterschrift