Essays on Liquidity Crises and Public Policies

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Diese Dissertation ist aus eigenen Forschungsarbeiten (Kapitel 2 und 5), sowie aus gemeinsamen Arbeiten mit den zu Beginn der Kapitel 3 und 4 genannten Personen entstanden. Das erste Essay wurde in einer früheren Version unter dem Titel "Liquidity and Capital Requirements and the Probability of Bank Failure" als Working Paper des SFB 649 "Ökonomisches Risiko" veröffentlicht. Das dritte Essay wurde ebenfalls als Working Paper des SFB 649 veröffentlicht und wird in Kürze als Working Paper der Bank of Canada erscheinen.

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Zusammenfassung

Die vorliegende Dissertation umfasst vier eigenständige Essays, die sich mit den Auswirkungen verschiedener Politikmaßnahmen zur Eindämmung von Liquiditätskrisen bei Banken auseinandersetzen. Die ersten drei Essays untersuchen das Thema theoretisch, während das vierte Essay sich in analytisch-deskriptiver Weise mit den Politikmaßnahmen der Europäischen Zentralbank (EZB) und der Rolle ihres Zahlungsverkehrssystems Target2 während der gegenwärtigen Krise im Europäischen Währungsraum auseinandersetzt.

Die ersten beiden Essays betrachten insbesondere die Auswirkungen mikroprudenzieller Liquiditätsregulierung auf das Risiko der Zahlungsunfähigkeit von Banken. Das dritte Essay untersucht die Wirkungen staatlicher Garantien für Bankverbindlichkeiten auf die Zahlungsfähigkeit von Banken und die Rückkoppelung, die sich daraus für die Zahlungsfähigkeit des Staates selbst ergibt. Alle drei Studien nutzen die Theorie globaler Spiele, um die Wahrscheinlichkeit einer Krise endogen, als Funktion der politikrelevanten Modellparameter zu bestimmen.

Das vierte Essay untersucht, basierend auf einem stilisierten Bilanzsystem des Bankensystems, die Funktionsweise von Zentralbankmaßnahmen zur Stützung des Bankensektors und die Auswirkungen auf die Bilanzpositionen der Zentralbank. Ferner werden die Konsequenzen analysiert, die sich aus diesen Maßnahmen im Zusammenhang mit der Abwicklung des innereuropäischen Zahlungsverkehrs durch die EZB ergeben. Darauf basierend wird eine kritische Würdigung verschiedener Politikmaßnahmen vorgenommen, welche im Zusammenhang mit der Reduzierung innereuropäischer makroökonomischer Ungleichgewichte und den Ungleichgewichten im Zahlungsverkehrssystem gemacht wurden.

Schlagwörter: Globale Spiele, Finanzkrisen, Bankwesen, Bankenregulierung, Zentralbankwesen, Europäische Zentralbank, Target2

Summary

The present dissertation consists of four self–contained essays concerned with the effects of public policies to contain liquidity crises of banks. The first three essays consider the topic from a theoretical perspective, whereas the fourth one provides an analytical-descriptive study of policy measures of the European Central Bank and the functioning of its payment system Target2 during the recent banking and balance of payments crisis in the euro area.

The first two essays are primarily concerned with the effects of microprudential liquidity regulation on bank illiquidity. The third study considers the impact of government guarantees on the funding situation of a bank and the resulting feedback effect on the funding situation of the government itself. All three essays use the theory of global games in order to derive the likelihood of crises endogenously as a function of the relevant policy parameters.

The last essay uses a stylized system of financial accounts to derive the effects of liquidity support on the central bank's balance sheet and the consequences of such measures with respect to the central bank's payment system. Moreover, on grounds of this framework, a critical assessment of different alternative policy proposals to mitigate euro area internal macroeconomic imbalances and Target2 imbalances is provided.

Keywords: Global Games, Financial Crisis, Banking, Bank Regulation, Central Banking, European Central Bank, Target2

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1 Liquidity Crises and Public Policies: Introduction

1.1 Opening Remarks

Liquidity crises and *public policies* that can be used to address them are the main subject of the four essays collected in this study. The second and third chapter are concerned with *liquidity regulation* and the effects of increasing, e.g. by means of statutory rules, the amount of liquidity held by banks in order to prevent their default. The fourth chapter analyzes *government guarantees* as another means to mitigate liquidity tensions of the banking sector. Finally, using the example of the recent banking and balance of payments crisis in the euro area, the fifth chapter discusses the effects of the European Central Bank's *liquidity support* during the crisis and the role played by its *payment system* TARGET2 in this respect.

1.2 Notions of Liquidity

Liquidity is said to be an "elusive concept" (Tirole, 2011, p. 288), something "easier to recognize than to define" (Crockett, 2011, p. 14). The reason may be, as Cramp (1987, p. 185) remarks, that "[l]iquidity is a highly complex phenomenon" and, as stressed by Tirole (2011), it may in general not be measurable through a single statistic. In particular, liquidity refers to an ability of economic entities or a property of assets and is loosely associated with the notions of 'easiness' or 'flexibility', both being concepts which are difficult to substantiate and which can be measured in a variety of ways. In the present study, the following three notions of liquidity, often used in the economics literature, are important: *funding liquidity*, *market liquidity* and *central* *bank liquidity*.[1]

Following the Basel Committee on Banking Supervision (2008, p. 1), *funding liquidity* may be defined as the ability of a bank to efficiently meet expected and unexpected cash flows. Or, as Strahan (2010, p.112) simplifies it, "funding liquidity involves raising cash on short notice".

Banks traditionally provide funding liquidity to their depositors and customers by issuing deposits and credit lines which can be accessed on short notice and thereby act as a close substitute for legal tender / cash (Strahan, 2010; Gorton and Pennacchi, 1990). The promise to deliver cash on demand thereby exposes banks themselves to funding liquidity risk and makes the management of funding liquidity, i.e. the ability to issue new (retail and wholesale) deposits, bank bonds, different types of equity etc., a key task of the banking business.

Market liquidity, in contrast, refers to the "ability to sell an asset close to its consensus [fundamental] value" (Foucault, Pagano, and Röell, 2013, p. 8). The asset's price that can be obtained immediately without spending time and search costs is the fire–sale price (Benston et al., 1986, p. 43). An asset is therefore considered liquid (in the sense of market liquidity) if the fundamental / consensus value and the immediate or fire–sale price are the same.

Funding and market liquidity can become closely connected in practice: Firstly, funding liquidity is often a precondition for market liquidity. Securities are usually traded on exchanges or trading platforms organized by market makers. To trade securities in large amounts at close–to–fundamental prices, the market maker needs to have sufficient and cheap enough funding liquidity. A deterioration in the market maker's funding liquidity may induce him to widen the bid–ask spread, i.e. the difference between the price he charges a purchaser and the price he pays to a seller of the asset. Larger bid–ask spreads in turn impair the market liquidity of the asset (Foucault, Pagano, and Röell, 2013, p. 9). Secondly, market liquidity may also become a precondition for funding liquidity. Under secured or collateralized credit arrangements, borrowers pledge assets as collateral in order to obtain funding. To protect themselves from changes in the value of the collateral, lenders apply haircuts

[1] See e.g. Brunnermeier (2009), Brunnermeier and Pedersen (2009), Nikolaou (2009), Strahan (2010), Tirole (2011) or Foucault, Pagano, and Röell (2013) (who refer to the latter as monetary liquidity).

or margins which reduce the amount that can be borrowed against the asset. Haircuts are usually lower for assets which are expected to be traded on thicker and more liquid markets, i.e. for assets whose market liquidity is higher. Thirdly, Brunnermeier and Pedersen (2009) show that, in particular during times of financial turmoil, liquidity spirals may emerge through which deteriorations in funding and market liquidity reenforce each other. For example, a decline in asset prices may impair the capital of borrowers and can cause a tightening of lending standards and margins. Higher margins, in turn, impair the funding liquidity of traders. These two effects may induce borrowers to fire–sell assets which pushes prices down and tightens funding condition even further.

However, notwithstanding any strong relationships between market and funding liquidity, Foucault, Pagano, and Röell (2013, p. 10) emphasize that they are entirely different notions and consequently have to be targeted by different policy actions, with security regulation being appropriate to address market liquidity and funding liquidity falling into the realm of banking regulation. Yet, market and funding liquidity are both affected by the policy measures of the central bank.

The central bank is, by law, the monopoly supplier of the economy's legal tender which serves as the ultimate means of settlement for any transaction. While commercial banks' liabilities may also be used in settling transactions, they must be convertible into legal tender at par in order to sustain and protect confidence in them and enable them to serve as money or money–substitutes. Banknotes and coins or reserves held with the central bank, also referred to as *central bank liquidity*, are therefore the most liquid assets and constitute the 'zero–point' on the liquidity scale.

By expanding its balance sheet or by changing its composition, the central bank can exert a strong influence over market and funding liquidity. For example, buying particular types of assets outright may improve their market liquidity by compressing their yield differential relative to more liquid assets.[2] Furthermore, the central bank can stabilize the funding liquidity of banks by increasing its liquidity provision

[2]For example, Beirne et al. (2011) show that the European Central Bank's Covered Bond Purchase Programme between 2009 and 2010 reduced liquidity premia on covered bonds in the euro area; Gagnon et al. (2011, p. 13) point out that the Federal Reserve's program of buying agency debt and mortgage–backed paper markedly improved the market liquidity of these instruments and narrowed the yield difference to US Treasuries.

to those banks facing a withdrawal of deposits through lender of last resort operations. Moreover, central banks usually undertake only collateralized lending operations where the borrowing bank has to provide sufficient adequate collateral to obtain central bank credit. Changes in the collateral framework, either through a reduction in the haircuts applied on eligible assets, or by adding further assets which were previously not eligible, provides central banks with a powerful tool to improve the funding liquidity of banks and the market liquidity of certain asset classes.[3]

1.3 Liquidity Crisis

At the heart of the formal models in this study is a *liquidity mismatch* on a bank's balance sheet which may give rise to its default. The term 'liquidity mismatch' describes a situation where the assets on its balance sheet are, at a particular point in time, less liquid than the bank's liabilities (Brunnermeier, Krishnamurthy, and Gorton, 2013).

As already pointed out, banks provide funding liquidity to their customers by issuing deposit liabilities with the promise to convert them into legal tender / central bank liquidity at relatively short notice. From the bank lenders' point of view, deposits are therefore a liquid asset as long as the bank is able to meet its obligations. Yet, whenever the bank itself holds market–illiquid assets that, at some point in time, cannot generate the liquidity needed to cover any amount of deposit withdrawals, a liquidity mismatch between asset and liability side of the bank's balance sheet emerges.

When faced with a too–large deposit outflow, the bank may try to raise additional funding or sell parts of its assets. But whenever the additional funding that can be raised is not sufficient or whenever the losses from selling assets at low fire–sale prices become too large, the bank may become illiquid and the failure to meet its promise to convert liabilities into legal tender triggers its default. Henceforth, we refer to a situation of deposit outflows that may give rise to the default of the bank because of a liquidity mismatch on its balance sheet as a *liquidity crisis*.

[3] Higher liquidity support and an expanded collateral framework come at the cost of increasing the central bank's risk exposure. This issue is further discussed in chapter 5.

1.4 Liquidity Crisis as a Coordination Failure

According to the view adopted in this study, a liquidity crisis results from a *coordination failure* on the side of bank depositors. This view essentially dates back to the seminal models of Bryant (1980) and Diamond and Dybvig (1983) which can be interpreted as the earliest formalizations of the idea of Merton (1968) that bank defaults are the outcome of a *self–fulfilling prophecy*.

At the heart of this view lies the decision problem of bank depositors who decide whether to withdraw their deposits or to rollover. Importantly, in case the bank's balance sheet exhibits a liquidity mismatch, the decision of a single depositor becomes dependent on the decisions of other depositors: the larger the number of other depositors who decide to withdraw, the higher the incentives for an individual depositor to withdraw as well (and *vice versa* for the decision to rollover). Thereby actions of creditors mutually reenforce each other; such reenforcing actions are termed *strategic complements*.

Table 1.1 shows a typical depositor's payoffs (conditional on the decisions of other depositors) in a stylized decision problem where he faces the choice between rolling over and withdrawing. This decision problem is identical in structure to the respective decision problem in the Diamond–Dybvig model.[4]

At the time of the decision, the depositor holds a claim of one unit of cash against the bank. In case he rolls over and the bank does not default, the claim increases to 1.1 units of cash due to the accrual of interest. If he withdraws and the bank defaults, he cannot recoup his unit claim in total. Default is costly and reduces his claim to 0.8 units of cash. If he rolls over and the bank defaults, he receives nothing since the withdrawing depositors reap the full default value of the bank's assets.

Bank default is exclusively triggered by the total mass of depositors who opt for withdrawing. This reflects the liquidity mismatch on the bank's balance sheet: at the time of the decision, the bank's assets are illiquid and total liquidity generated by assets falls short of the total value of liabilities; if, however, the bank manages the rollover successfully, the assets eventually pay off and the bank is able cover its liabilities in full.

[4] It is assumed here that the total number of depositors is large enough so that the actions of a single depositor have no influence on the overall outcome.

		if other depositors	
		withdraw	rollover
payoff from	withdraw	0.8	1
	rollover	0	1.1

Table 1.1: Decision problem of typical depositor in a stylized Diamond–Dybvig model.

The situation depicted in Table 1.1 is one of strategic complementarities. If a typical depositor believes that all other depositors withdraw, the best he can do is to withdraw as well. This yields at least 0.8 compared with nothing in case he rolls over. In contrast, if he believes that all other depositors decide to rollover, the best he can do is to rollover as well. Otherwise, he would forego interest payments of 0.1 units. Since these considerations are valid for all depositors, the mutually reenforcing behavior gives rise to two (pure strategy) equilibria: one where all depositors withdraw and the bank defaults, and one where all depositors rollover and the bank survives. *Post hoc,* in equilibrium, depositors' initially held beliefs are vindicated by the results of the decisions that they have triggered. Equilibria are brought about by *self–fulfilling beliefs.*

Because the rollover–equilibrium is preferable for depositors (they earn 0.3 units more) as well as for the bank (it does not default), we say that, in case the withdraw–equilibrium obtains, the bank defaults due to a *coordination failure* since depositors failed to coordinate on the preferable equilibrium.

1.5 Public Policies against Liquidity Crises

The formal models contained in the present study are basically concerned with the question how particular public policies can be used to prevent the coordination failure and save the bank from defaulting due to illiquidity. As illustrated by the example in the previous section, the default due to illiquidity is inefficient. Had depositors decided to rollover their claims, the bank would have survived and depositors would have received a higher payment. The default due to illiquidity has to be distinguished from default due to *insolvency*, i.e. a situation where the bank, even if no liquidity shock occurs, would have defaulted. As pointed out by Goodhart (2011), insolvency and illiquidity are frequently indistinguishable in practice. Moreover, the decision of depositors to withdraw is often triggered by a "suspicion of insolvency" (Goodhart, 1999) of the creditor. However, as will be explained in chapter 2, even though it is difficult to keep insolvency and illiquidity apart in reality, the theoretical distinction between these concepts is meaningful since both are affected in different ways by regulatory policies. In any case, the fact that the coordination failure and the resulting default due to illiquidity are inefficient, renders such situations particularly important for policy makers who may want to mitigate economy–wide inefficiencies. In particular, since the funding illiquidity of banks bears the danger of asset fire–sales and liquidity spirals which may exert negative externalities on the economy, the question how to stall bank illiquidity is of paramount importance for policy makers.

Yet, in order to study this issue theoretically, the simple model structure *à la* Diamond and Dybvig (1983) in Table 1.1 has to be altered. While multiple equilibrium models in the tradition of Diamond and Dybvig "have considerable intuitive appeal, since they provide a convenient and economical prop in a narrative of unfolding events" (Morris and Shin, 2001, p. 139), three main points of criticism have been raised against modeling a crisis as the outcome of some arbitrary self–fulfilling beliefs.[5] Firstly, multiple equilibrium models lack an explanation of the determinants and the likelihood of equilibria and thereby fail to explain the shift from one equilibrium to another. Secondly, they fail to take into account the intuitively plausible idea that those banks which hold more illiquid assets and exhibit a greater liquidity mismatch are also more likely to experience a liquidity crisis. Thirdly, they preclude the possibility to derive, by means of comparative statics exercises, explicit policy recommendations of how to prevent the coordination failure.

The major reasons behind the indeterminacy of depositors' beliefs are, according to Morris and Shin (2001, 2003), two particular modeling assumptions: firstly, all economic fundamentals are assumed to be common knowledge among depositors; secondly, in equilibrium, depositors are certain about the the behavior of other de-

[5]See Morris and Shin (2001) for an in–depth discussion.

positors.

To circumvent the problem of indeterminacy of beliefs, yet to preserve the existence of a coordination failure as the root cause of illiquidity, we rely on the *theory of global games* which is due to Carlsson and van Damme (1993).[6] Global games provide a link between the Diamond–Dybvig view of self–fulfilling liquidity crises and the view that depositors' beliefs are triggered by economic fundamentals and news about the bank's health (Gorton, 1985, 1988).

To apply the theory of global games, the typical depositor's decision problem is slightly altered by writing the bank's failure condition in a more explicit way than in Table 1.1. This is shown in Table 1.2, where the payoffs to the depositor remain the same as in Table 1.1 but the bank failure condition is written explicitly in terms of the bank's liquid resources. The bank fails whenever the fraction of withdrawing depositors, denoted by $\lambda \in [0,1]$, exceeds the bank's liquid resources, given by the function $g(\theta)$. The function argument θ is a random variable which is drawn from a commonly know probability distribution and the function $g(\cdot)$ is assumed to be monotonically increasing.

Under the assumption of common knowledge, the range of θ can be classified in a tri–partite fashion according to the equilibria which prevail in the respective intervals. For any θ such that $g(\theta) < 0$, the bank is essentially insolvent (its failure occurs independent of the amount of withdrawals) and a unique equilibrium exists where all depositors withdraw and the bank defaults. Similarly, for θ such that $g(\theta) > 1$, the bank caqn cover a full–blown withdrawal of its deposits without defaulting. A unique equilibrium emerges where all depositors rollover and the bank survives. Yet, for realizations of θ such that $g(\theta)$ lies within the unit interval, the model exhibits again multiple equilibria as in the Diamond–Dybvig model. These equilibria are triggered by self–fulfilling beliefs about the behavior of other depositors. Again, due to common knowledge of the fundamental θ, depositors perfectly coordinate on one or the other equilibrium.

To derive a unique equilibrium, by using the theory of global games, the assumption of common knowledge about θ is abandoned. Instead, depositors receive some

[6] Global games were popularized through the works of Morris and Shin (1998, 2001, 2003). Heinemann, Nagel, and Ockenfels (2004) experimentally corroborate the behavioral predictions of a standard global game of currency crises.

noisy idiosyncratic information about θ which they can use to form beliefs about the information and the behavior of other depositors and about the eventual situation of the bank. Under some additional technical assumptions, it can be shown that the global game exhibits a unique equilibrium in *threshold strategies*: the bank defaults once θ falls below a threshold θ^* and it survives otherwise. Depositors withdraw whenever their information is sufficiently bad and otherwise they rollover.

Thereby, the threshold θ^* becomes a function of the underlying balance sheet and policy parameters. In conjunction with the probability distribution of θ, the *ex ante* likelihood of bank default can be derived by computing the probability that θ lies below θ^*. The dependency of θ^* on the model's parameters then allows to compute the effects of particular policy measures on the likelihood of illiquidity and thereby makes it possible to provide explicit policy recommendations of how to prevent the coordination failure.

		bank	
		failure $\lambda > g(\theta)$	success $\lambda < g(\theta)$
payoff from	withdraw	0.8	1
	rollover	0	1.1

Table 1.2: Decision problem of typical depositor with explicit failure condition.

1.6 Summary of the Study

Chapters two to four contain formal models whose core structure is essentially the one depicted in Table 1.2. Chapters two and three deal with liquidity regulation and the effects of changing, by means of statutory rules, the amount of liquid assets relative to bank deposits in order to mitigate the coordination problem and to prevent bank default. The fourth chapter considers the impact of government guarantees for bank liabilities and their feedback effect on the funding situation of the government itself. Finally, the fifth chapter contains an analytically–descriptive study, rather than a formal model, of central bank interventions and the role of the central bank's payment system during the recent banking and balance of payment crisis in the euro area.

1.6.1 Liquidity Regulation

The second chapter, entitled *Liquidity Requirements - A Double–edged Sword*, builds on the well–known banking model of Rochet and Vives (2004) and provides conditions under which micro–prudential liquidity regulation effectively strengthens a bank's resilience to financial stress. We show that liquidity requirements exert two opposing effects. A *liquidity effect* which reduces the likelihood of default, as well as a *solvency effect* through which the likelihood of default is increased. The former effect occurs because liquid assets can be used to meet deposit withdrawals without incurring fire–sales costs. Hence, a higher amount of liquid assets allows to withstand larger withdrawals at lower costs and thereby reduces the likelihood of default. Yet, the latter effect occurs because liquid assets fetch lower returns on average. Given a fixed face value of debt, the lower average returns induced by the higher amount of liquid assets on the bank's balance sheet have to be compensated by higher returns on the illiquid assets. This in turn raises the likelihood of default. It is then shown that the former effect dominates the latter and liquidity regulation works effectively if and only if the interest rate on bank liabilities is sufficiently low. Moreover, the effectiveness of liquidity requirements can be further improved by enforcing additional equity requirements. Hence, equity requirements constitute a complement to liquidity requirements. Finally, it is shown that liquidity regulation may be more effective for assets with higher expected returns and lower variance, implying that a contingent design of regulatory policies may further improve their effectiveness.

In the third chapter, entitled *Illiquidity Risk and Liquidity Regulation* (joint work with Tijmen Daniels), we go one step beyond the partial equilibrium model in the first chapter. Rather than considering the bank's balance sheet and the interest rate on bank's liabilities as exogenous parameters, we explicitly endogenize the bank's portfolio and borrowing decisions and the interest rate paid on bank liabilities. The bank and its creditors take the likelihood of default (derived as the probability that a coordination failure occurs at a later date) explicitly into account during the initial stage when the investment decisions are made.

We show that whenever bank depositors perfectly observe the bank's actions, it fully internalizes the risks from its portfolio and borrowing choices. As a consequence, illiquidity risk is eliminated because once the bank borrows, it is always inclined to maintain a sufficiently large liquidity buffer to eliminate any coordination failure on the side of its creditors. However, the inefficiency due to the coordination failure is shifted to the initial stage and not fully eliminated once bankruptcy is costly. By fully ensuring itself against illiquidity risk, the bank blows up its debt–to–equity ratio. But since the additional borrowing is costly, the bank refrains from financing investments with low expected return even if the investments have a positive net present value. Yet, liquidity regulation is of no use in this situation because the bank self–insures and liquidity regulation cannot exert any influence on the bank's decision to refrain from funding particular investment projects. We show further that the most effective way to eliminate the coordination failure and the inefficiency due to under–investment is the creation of a central bank facility which promises to intervene with a particular probability. This eliminates the coordination failure completely because it renders the bank sufficiently liquid in expected terms. In equilibrium, the central bank's promise to intervene is sufficient to induce creditors to rollover and the facility is therefore never used.

Finally, a role for liquidity regulation is found in a variant of the model where depositors cannot observe the bank's decisions directly. Although, by observing the equilibrium interest rate, they can infer to the actual decisions of the bank, there exists the potential for equilibria where the bank does not hold cash and pays an illiquidity risk premium. In this situation, liquidity regulation can be effectively used as a coordination device that coordinates creditor's expectation and the bank's behavior on the situation where the bank holds sufficient liquidity and creditors do not demand an illiquidity risk premium.

1.6.2 Government Guarantees

The model presented in chapter four (joint work with Frank Heinemann and Kartik Anand) was inspired by the situation in Ireland during the recent financial turmoil. Ireland was a sound country with good future prospects, yet the Irish government issued an unlimited guarantee to protect its banking sector. This in turn caused a massive increase in its government debt and deficit ratios and forced the Irish government eventually to apply for a bailout program from European facilities and the International Monetary Fund. Chapter four is thus entitled *The 'Celtic Crisis': Guarantees, Transparency and Systemic Liquidity Risk* and it considers the joint effect of government guarantees on bank and sovereign funding risk.

Traditionally, bank liability guarantee schemes have been viewed as rather costless measures to shore up investor confidence and stave off bank runs. The experiences during the recent crisis, most notably in Ireland, have demonstrated that the credibility and effectiveness of these guarantees is crucially intertwined with the sovereign's funding risks. We analyze this issue in a global game model and explore the systemic linkage between the rollover risks of a bank and a government which are connected through the government's guarantee of bank liabilities. Since the model uses two distinct fundamentals for bank and government, something which has not been studied to a great extent in the theory of global games, we first derive the existence and uniqueness of the joint equilibrium and then derive its comparative static properties. We provide an analytical condition for the guarantee's effect to reduce the risk of a bank default and then derive the optimal guarantee numerically. In these numerical exercises, we show how the guarantee's credibility may be improved through policies that promote bank balance sheet transparency. A further implication is that the size of the optimal guarantee increases with the costs of a banking sector default, which suggests that *ex ante*, even the large Irish guarantee could have been optimal. Furthermore, our model also suggests that the high guarantee increases the likelihood of a systemic crisis of bank and sovereign, i.e. the guarantee increases the likelihood of the crisis which Ireland eventually experienced.

1.6.3 Central Bank Liquidity Support

The The fifth chapter *TARGET2 Imbalances – Causes, Consequences and Re–Balancing* studies the effects of central bank liquidity support by examining the measures of the European Central Bank (ECB) and the role of its payment system TARGET2 (T2) during the recent crisis.

As a consequence of the turmoil in euro area financial markets, financial integration in the euro area deteriorated at a rather fast pace. In particular, the interbank market became segmented across national borders and banks in the crisis countries

(Greece, Ireland, Italy, Spain and Portugal) are denied market access. To prevent widespread bank defaults, asset fire–sales of highly market–illiquid assets and the emergence of liquidity spirals, the ECB substituted for the supply and demand side of the interbank market: it strongly raised its liquidity support to the banking sector in crisis countries, while it offered absorbing facilities to the banking sectors in non–crisis countries.

As funding and liquidity outflows from crisis countries were moved via the ECB's payment system T2, the T2 positions on the balance sheets of national central banks began to increase strongly. The chapter provides a detailed analysis of the causes of T2 imbalances, their relationships to the ECB's funding liquidity support measures and discusses whether and under which circumstances T2 imbalances may be reduced. We show, by means of simple balance sheet examples, that a major part of the T2 imbalances is reduced once the Eurosystem switches back to its pre–crisis liquidity allotment mode.

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2 Liquidity Requirements – A Double-Edged Sword

2.1 Introduction

The recent financial crisis was associated with severe liquidity problems in the banking sector. This experience has called the attention of regulators and led them to put more emphasis on issues of bank liquidity risk than was the case before the crisis. In particular, in the course of the latest reform of the Basel accords on banking regulation (Basel III), new liquidity standards have been proposed in order to strengthen international liquidity risk measurement and supervision. Two regulatory standards on bank liquidity have been introduced which shall complement and institutionalize the Basel committee's guidelines for liquidity risk management.[1] These newly introduced liquidity standards are the 'net stable funding ratio' (NSFR) and the 'liquidity coverage ratio' (LCR). The respective objectives of these measures differ but complement each other. While the LCR is designed to enhance banking institutions' resilience to short-term (i.e. thirty days) funding stress, the NSFR shall promote the stability of bank refinancing over a longer period (i.e. up to one year).[2]

The present paper uses the well-known banking model by Rochet and Vives (2004) in order to provide some analytical results on the functioning of short-term liquidity buffers (like the LCR). It discusses whether and under which circumstances they actually serve micro–prudential regulatory objectives and thereby improve an individual bank's resilience in periods of financial stress.

By refining a result of Rochet and Vives (2004, Proposition 3), it is demonstrated that liquidity requirements strengthen a bank's resilience (as measured by its prob-

[1] See Basel Committee on Banking Supervision (2008).
[2] See Basel Committee on Banking Supervision (2010*a*).

ability of default) if and only if the likelihood of a default is already sufficiently low. This result is further translated into a condition that shows that liquidity requirements lower the bank's default probability whenever the interest rate on the bank's liabilities is below a certain threshold. This threshold is strictly increasing in the bank's equity ratio (defined as the ratio of equity to risky investments) which implies that regulatory equity requirements may be complementary to liquidity requirements as they increase the range of interest rates where liquidity requirements are effective. Moreover, the threshold is also increasing in the expected returns of the bank's profitable assets and, for a sufficiently high equity ratio, it is decreasing in the variance of returns.

In general, the reason why liquidity requirements may only work effectively under particular circumstances is the existence of two opposing effects, the *liquidity effect* and the *solvency effect*. The *liquidity effect* arises because it is costly for the bank to use an illiquid asset as a cushion against sudden funding roll–offs. Converting such an asset into cash at short notice involves a loss and thus keeping a larger fraction of the balance sheet in the form of liquid assets allows the bank to withstand larger funding drains without engaging in overly costly fire–sales. This in turn decreases the bank's risk of default due to illiquidity. However the *solvency effect* occurs because liquid assets earn lower returns on average and thus fail to generate the necessary net return which the bank needs to service its interest–bearing deposit liabilities. Given that the bank manages to roll over its debt, the lower returns on liquid assets have to be compensated by sufficiently higher returns on more profitable but less liquid assets in order for the bank to become solvent. This increases the bank's risk of insolvency. Additionally, when creditors realize the higher insolvency risk, their incentive to withdraw their funds may increase, thereby spurring the illiquidity of the bank. The existence of these polar effects implies that the use of liquidity requirements is a 'double–edged sword' and that it is *a priori* not clear whether they can indeed make the bank more resilient against financial stress.

In their original analysis, Rochet and Vives (2004) solely focus on the *liquidity effect* and confirm that it has indeed a mitigating impact on the bank's failure risk if insolvency risk is not affected. However, they implicitly assume a particular balance sheet adjustment in response to changes in the liquidity ratio which suppresses the *solvency effect.* In what follows, we solve Rochet and Vives's model by using a different adjustment mechanism which explicitly takes the dependency of insolvency risk on the balance sheet into account and therefore allows to study the interaction between liquidity and solvency which is focal to regulators.

The chapter is organized as follows. Section 2.2 provides a condensed description of Rochet and Vives's banking model which takes the dependency of insolvency on the balance sheet into account. Section 2.3 contains the relevant comparative statics exercises. Section 2.4 discusses the implications of the results for micro-prudential regulation and Section 2.5 concludes. All mathematical proofs are deferred to the appendix.

2.2 The Rochet-Vives Banking Model

2.2.1 Basic set-up

The model studies a bank that operates at dates $\tau = 0, 1, 2$. At $\tau = 0$, the bank possesses equity E_0 and takes in wholesale deposits D_0. The deposit contract promises a repayment $D > D_0$ independent of whether the funds are withdrawn at $\tau = 1$ or $\tau = 2$.

Deposits are managed by fund managers who decide on behalf of the original depositors at $\tau = 1$ about rolling over or withdrawing the funds. It is assumed that the bank contracts with a large number of *ex ante* identical fund managers. For simplicity, the total size of fund managers is normalized to the unit interval and each fund manager administers an amount D_0. The assumption that decisions on withdrawal are carried out by fund managers instead of fund owners themselves reflects the fact that a major part of the short–term funding base of banks is managed by money market mutual funds or collective investment funds. Experience during the recent crisis has shown that especially this part of bank funding is more volatile and evaporates quicker than the retail and customer deposit base.[3] Hence, the assumption seems

[3]For example, as explained in Shin (2010), the liquidity problems of British bank Northern Rock started with a drain of wholesale deposits and interbank funding rather than with a run on retail deposits. Further anecdotal evidence is provided by Sorkin (2009) who describes how desperately large US investment banks sought to merge with commercial banks that could rely on a stable customer deposit base in order to halt the drains of short-term funding they experienced during the crisis in 2008.

reasonable for the purpose of studying the short–term funding liquidity situation of a large bank that is subject to liquidity regulation.

The modeling of fund managers' payoffs is motivated by the empirical evidence that their remuneration and salary is often indexed to the absolute size of their trusted funds and to their personal reputation rather than to the returns they achieve.[4] It is therefore assumed that fund managers receive a fixed remuneration B in case they succeed in obtaining D. However, when they withdraw early at $\tau = 1$, they incur an additional cost C.[5] In case of bank default, a fund manager who rolled over receives a zero payoff. The optimal decision of fund managers is then to withdraw at $\tau = 1$ whenever the expected payoff from withdrawing exceeds the expected payoff from rolling over. Formally expressed, a typical fund manager $i \in [0, 1]$ withdraws if and only if

$$(B - C) - (1 - P_i)B > 0 \;\Leftrightarrow\; P_i > \gamma := \frac{C}{B},$$

where P_i denotes the probability that fund manager i attaches to the failure of the bank.

The bank invests amount I of its funds into a risky asset and keeps M in cash. Hence, its balance sheet at $\tau = 0$ reads

$$I + M = D_0 + E_0. \tag{2.1}$$

The per–unit return on the risky asset is a normally distributed random variable $\tilde{R}$ with mean $\bar{R}$ and precision α. It pays out the realized return R at $\tau = 2$, but can be sold on a secondary market at $\tau = 1$ only against a fire–sale price $R/(1+\lambda)$, where λ is henceforth referred to as the fire–sale discount rate. Cash holdings, in contrast, fetch a zero net–return at date $\tau = 2$ but they are perfectly liquid and can be used to cover liabilities at both $\tau = 1$ or $\tau = 2$.

[4]See also the explanations in Rochet and Vives (2004) who refer to the studies of Chevalier and Ellison (1997) and Chevalier and Ellison (1999).

[5]The cost C may be viewed as the transaction cost from transferring the withdrawn funds to another bank. Alternatively, one may interpret C as the loss in fund managers' reputation because withdrawing means that they revert their initial investment decision.

2.2.2 Bank failure

The bank can default either due to *insolvency* or due to *illiquidity*. The *ex ante* default risk is then a function of insolvency and illiquidity risk. I consider failure due to insolvency and due to illiquidity in turn.

Insolvency

Let x denote the proportion of deposits withdrawn early. As long as $xD < M$, the bank can cover all withdrawals at $\tau = 1$ out of its cash holdings without resorting to fire–sales of illiquid assets on the secondary market. It can then fail only at $\tau = 2$ due to insolvency. Precisely, it is insolvent whenever

$$R < R_s \equiv \frac{D - M}{I}, \tag{2.2}$$

where R_s is henceforth called the *solvency point*.

Denote the *liquidity ratio* by $m \equiv M/D$ and the *equity ratio* by $e \equiv E_0/I$. These ratios can be interpreted as approximations to regulatory ratios such as the Basel's newly LCR or the equity ratio to which regulatory requirements are applied. Moreover, denote the ratio of debt to assets by $d \equiv D_0/I$ and the interest rate on deposits by $(1+r) \equiv D/D_0$. The solvency point can then be expressed as a function of the ratios m and e and the interest rate on deposits $(1+r)$. To this end, one firstly rewrites the solvency point R_s as

$$R_s = d(1+r)(1-m). \tag{2.3}$$

Secondly, since the initial balance sheet constraint stated in equation (2.1) must hold, it can be used to rewrite d as

$$d = \frac{1-e}{1-(1+r)m}. \tag{2.4}$$

Using equation (2.4) to substitute for d in equation (2.3) yields the solvency point as a function of m, e and r,

$$R_s(m, e, r) = \frac{(1-e)(1+r)(1-m)}{1-(1+r)m}. \tag{2.5}$$

Illiquidity

Absent other sources of refinancing, the bank has to resort to selling illiquid assets on the secondary market whenever its cash holdings are not sufficient to meet early withdrawals, i.e. if $xD > M$. Suppose that the bank has sufficient liquidity (cash plus secondary market liquidity from selling assets) to cover total withdrawals xD at $\tau = 1$. Yet, if $xD > M$ it has to sell illiquid assets. Per unit sold, the bank loses $\lambda R/(1+\lambda)$. Total losses rise with x and may deplete the bank's resources to such an extent that it becomes unable to meet the remaining liabilities $(1-x)D$ at $\tau = 2$. Hence, the bank fails due to illiquidity at $\tau = 2$ if

$$RI - (xD - M)(1+\lambda) < (1-x)D,$$

which can be rewritten as

$$R < R_s + \frac{\lambda(xD - M)}{I}, \tag{2.6}$$

or equivalently, in terms of ratios m and e, as

$$R < R_f(x, m, e, r) \equiv R_s(m, e, r)\left(1 + \lambda\left(\frac{x-m}{1-m}\right)\right). \tag{2.7}$$

Fund managers then base the calculation of their subjective probability of bank default, P_i, on the failure threshold R_f.[6]

2.2.3 Discussion of the model

The model described so far is widely identical to Rochet and Vives's original model. The exception is that we have used the initial balance sheet constraint (2.1) in order to express the solvency point R_s explicitly as a function of the regulatory ratios m and e (see equation (2.5)). Rochet and Vives instead use the balance sheet constraint to substitute out M from equation (2.2) and thereby express the solvency point as a function of e and d.[7] However, in deriving equation (2.7), they again use equation (2.2) to replace I by $(D-M)/R_s$ in equation (2.6), while maintaining that R_s is a function of e. Thereby, Rochet and Vives obtain a failure point R_f which has a similar form as the one displayed in equation (2.7) except that their R_s is independent

[6] The bank may already fail at $\tau = 1$ if withdrawals exceed cash and total secondary market liquidity all at once, i.e. whenever $xD > M + \frac{RI}{1+\lambda}$. The respective condition in terms of R follows from rewriting this inequality as $R < R_s(m, e, r)(1+\lambda)\left(\frac{x-m}{1-m}\right)$. But since failure at $\tau = 1$ implies failure at $\tau = 2$, the latter occurs for a larger range of return realizations R. Therefore it is the threshold R_f that matters to fund managers and in the remainder of the analysis we abstract from failure at $\tau = 1$.

[7] See Rochet and Vives (2004, p. 1124).

of m and only depends on e. Accordingly, in their comparative statics, a change in m does not lead to an adjustment of the solvency point R_s. Yet, changing the liquidity ratio m while keeping the solvency point R_s fixed and satisfying the balance sheet constraint at the same time is only possible if a certain balance sheet adjustment mechanism through either D_0 or E_0 is assumed. This, however, is neither made explicit by Rochet and Vives, nor taken into account in their comparative statics exercises.[8] In contrast, we assume here explicitly that the ratio d endogenously adjusts in response to changes in m, e or r (see equation (2.4)). This mechanism is particularly useful in studying the effects of the ratios m and e which both approximate ratios focal to regulators and in studying the interaction between liquidity and solvency.[9] Moreover, this adjustment mechanism is rather plausible if one believes that banks have less difficulties to raise additional short–term debt than selling new equity, i.e. that a balance sheet adjustment through E_0 is more expensive and less flexible than an adjustment through D_0. As further discussed in Section 2.3, by assuming an explicit balance sheet adjustment mechanism and taking the dependency of R_s on m into account, the implications of the model for prudential regulation differ from the results obtained by Rochet and Vives.

2.2.4 Fund managers' decisions and equilibrium

As can be seen from equation (2.7), the proportion of fund managers who withdraw is a crucial determinant for the default of the bank. Observe that the bank fails at $\tau = 2$ for any $R < R_s$ and it survives for any $R \geq (1+\lambda)R_s = \lim_{x\to 1} R_f$ independent of the fund managers' behavior. Accordingly, all fund managers would withdraw if they knew that $R < R_s$ and they would all roll over if they knew that $R > (1+\lambda)R_s$. However for $R \in [R_s, (1+\lambda)R_s)$ the behavior of each fund manager depends on his individual

[8] To keep the solvency point fixed requires $(\mathrm{d}D - \mathrm{d}M)/(D-M) = \mathrm{d}I/I$. To satisfy the balance sheet constraint requires $\mathrm{d}I + \mathrm{d}M = \mathrm{d}E_0 + \mathrm{d}D_0$. Suppose the liquidity ratio is varied, for example $\mathrm{d}m > 0$. Then we have either $\mathrm{d}M > 0$ or $\mathrm{d}D < 0$. To keep the solvency point fixed and to satisfy the balance sheet constraint then requires changing either D_0 or E_0 in certain proportions (implying that e or d change as well).

[9] There are of course other possible adjustment mechanisms. An earlier version of this paper, König (2010), assumed a constant liability side and varied only the composition of the asset side. This leaves the results qualitatively unchanged.

beliefs about the behavior of the other fund managers, whose behavior in turn involves some belief about the behavior of all others and so on. Under common knowledge of R the model would exhibit multiple equilibria whenever $R \in [R_s, (1+\lambda)R_s)$.[10] Therefore, Rochet and Vives specify the model as an incomplete information game by assuming that fund managers do not have common knowledge of R but instead each fund manager receives an idiosyncratic noisy signal about R. For a typical fund manager $i \in [0,1]$, the signal is given by

$$\tilde{s}_i = \tilde{R} + \varepsilon_i,$$

where ε_i is i.i.d. normally distributed with zero mean and precision β. This structure of the incomplete information model permits the application of Global Game methods for the derivation of a unique equilibrium.[11] The following proposition summarizes the equilibrium of the model.

Proposition 2.1. *There exists a unique Bayesian Nash Equilibrium in symmetric threshold strategies if and only if*

$$\beta \geq \frac{1}{2\pi}\left(\frac{\lambda\alpha(1-e)(1+r)}{1-(1+r)m}\right)^2 \equiv \beta_0.$$

A fund manager withdraws at date $\tau = 1$ whenever he observes $s_i < t^*$ and rolls over otherwise. The bank fails whenever $R < R^*$ and survives otherwise. The tuple (t^*, R^*) simultaneously solves the pair of equations

$$\Phi\left(\sqrt{\alpha+\beta}R^* - \frac{\alpha\bar{R}+\beta t^*}{\sqrt{\alpha+\beta}}\right) = \frac{C}{B} \tag{2.8}$$

and

$$R^* = R_s(m,e,r)\left(1 + \frac{\lambda \max\left\{\Phi(\sqrt{\beta}(t^*-R^*)) - m, 0\right\}}{1-m}\right), \tag{2.9}$$

where $\Phi(\cdot)$ denotes the standard normal cdf.

Proof. See appendix.[12] □

[10] This outcome would be equivalent to the outcome in the well–known model by Diamond and Dybvig (1983). For a discussion of the influence of the assumption of common knowledge on the equilibrium multiplicity see Morris and Shin (2001).

[11] See Morris and Shin (2003) for an extended survey of Global Games.

[12] The proof is similar to Rochet and Vives (2004, pp.48). But as Rochet and Vives' proof is contained in the main body of their text, the proof provided here may be more comprehensive.

2.3 Liquidity and Solvency Effects

This section analyzes the effects of regulatory ratios on the *ex ante* probability of bank default, given by

$$\mathbf{Pr}\left(\tilde{R} \leq R^*\right) = \Phi\left(\sqrt{\alpha}(R^* - \bar{R})\right).$$

Since $\Phi(\cdot)$ is a strictly monotone function, it suffices to study the effects of regulatory ratios on the failure point R^*. One may view the *ex ante* default probability as a measure of the bank's resilience against financial stress. Since the Basel accords identify the strengthening of bank's resilience as a major objective of micro-prudential regulation, the comparative statics properties of R^* with respect to equity and liquidity ratio indicate to which extent regulatory requirements on these ratios may indeed serve the Basel objective.

Proposition 2.2. *i) If $R^* = R_s$, the failure point R^* strictly decreases in the equity ratio e, and it strictly increases in the liquidity ratio m.*

ii) If $R^* > R_s$, the failure point R^* strictly decreases in the equity ratio e, and it strictly decreases in the liquidity ratio m if and only if

$$R^* < (1-e)(1+\lambda). \tag{2.10}$$

Proof. See appendix. □

According to Proposition 2.2, the failure point is always decreasing in the equity ratio. Consequently, requirements on the equity ratio can be used as a regulatory measure to lower the bank's *ex ante* default risk. This is basically a restatement of the respective result by Rochet and Vives (2004, Proposition 3). However, the effects of the liquidity ratio m depend crucially on the underlying parameters of the model. This result stands in marked contrast to the respective result by Rochet and Vives (2004, Proposition 3). They claim that an increase in the liquidity ratio unambiguously lowers the failure point R^*. The reason for these different findings is that Rochet and Vives treat R_s as a fixed parameter and thereby switch off the dependency of R_s on m. But since the balance sheet constraint given by equation (2.1) holds, treating R_s as fixed requires a particular endogenous adjustment of e or d in response to a change in the liquidity ratio m. As pointed out in section 2.2.3, Rochet and Vives do not further specify this adjustment mechanism. Moreover, by treating R_s as fixed, Rochet and Vives suppress an important effect which is otherwise present if one allows for an endogenous response of R_s. We call this the *solvency effect.* And as shown in Proposition 2.2, the *solvency effect* may hamper the effectiveness of liquidity requirements in mitigating the bank's total default risk.

To better appreciate the intuition behind the *solvency effect*, note that, from equations (2.8) and (2.9), the failure point R^* and the switching signal t^* depend positively on the solvency point R_s.[13] Moreover, the solvency point R_s is strictly increasing in the liquidity ratio m. The reason is that a higher liquidity ratio is tantamount to a higher level of non–interest–bearing assets relative to interest–bearing liabilities. And since the balance sheet constraint (2.1) binds, the adjustment via the ratio d (see equation (2.4)) implies that a higher liquidity ratio m leads to a higher level of deposits relative to investments in profitable assets. Consequently, the bank needs higher net returns in order to service its deposit liabilities, i.e. it must generate a higher rate of return on its profitable asset in order to become solvent. This is the *solvency effect.* Whenever $R^* = R_s$ only the *solvency effect* is present and consequently the liquidity ratio m cannot be used to effectively lower the bank's default risk. However, if $R^* > R_s$, and an otherwise solvent bank may fail due to illiquidity, a change in the liquidity ratio m is associated with a second effect which works in the opposite direction and which we may call the *liquidity effect.* To understand the intuition behind the *liquidity effect*, recall that illiquidity is governed by the depletion of the bank's assets due to fire–sales to meet withdrawals at date $\tau = 1$. Hence, if the bank keeps a higher liquidity ratio m, the depletion of its illiquid, but profitable assets through fire–sales is less strong and the bank is less exposed to illiquidity. Therefore, the *liquidity effect* has a decreasing impact on the failure point R^*.

[13]One may view this dependency as a formal restatement of Charles Goodhart's notion that illiquidity implies "(...) at least a whiff of suspicion of insolvency" (1999, p. 346). If the insolvency risk increases (i.e. R_s increases), fund managers become more "suspicious" and attach a higher likelihood to the event that the bank fails. This increases the switching point t^* and therefore the failure point R^*.

2.4 Implications for Prudential Regulation

2.4.1 Equity requirements and asset properties

In sum, the effect of the liquidity ratio – and the possibility for prudential regulation to use liquidity requirements as a measure to strengthen the bank's resilience – crucially depend on whether the *liquidity* or the *solvency effect* dominates. Equation (2.10) is only partially useful as a condition for the dominance of the liquidity effect, since its left hand side still involves R^* which depends on exogenous parameters, including the liquidity ratio itself. However, the relative impact of the *solvency effect* is basically driven by the level of interest rates on deposit liabilities. To see this, suppose that $r = 0$. The face value of the bank's debt at dates $\tau = 1$ and $\tau = 2$ equals the amount of initially obtained deposits. No interest-bearing investment is needed and the bank may simply store its deposits in cash to acquit total obligations. Only the *liquidity effect* is present and the failure point strictly decreases in m. But if $r > 0$, the face value of debt exceeds the value of initial deposits. Per unit of deposits held, the bank needs to obtain net returns of at least r to become able to service its debt, which, however, is not possible by resorting only to non–interest bearing cash holdings. *A fortiori*, with increasing r, the ability of the bank to cover withdrawals by holding cash weakens, while the solvency point increases. The following Corollary states this formally and translates condition (2.10) into a condition in terms of interest rates.

Corollary 2.1. *If $R^* > R_s$, then the failure point R^* decreases in the liquidity ratio m if and only if*

$$r < r^m := \frac{\lambda(1-\Phi(\omega))}{1+\lambda\Phi(\omega)} \tag{2.11}$$

where $\omega := \frac{\alpha}{\sqrt{\beta}}((1+\lambda)(1-e)-\bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)$.

Proof. See appendix. □

Corollary 2.1 reveals that liquidity requirements may work effectively once the interest rate on deposits is below the threshold value r^m. The following Proposition provides some important properties of r^m.

Proposition 2.3. *Suppose that $\beta \in [\beta_0, \infty)$ and $\alpha > 0$, then the critical threshold r^m*

(i) *strictly increases in the equity ratio e;*

(ii) *strictly increases in the* ex ante *expected asset returns $\bar{R}$;*

(iii) *strictly increases in the precision of asset returns if and only if $e > \hat{e}$, where $\hat{e} := 1 - \frac{\bar{R} + \frac{\Phi^{-1}(\gamma)}{2\sqrt{\alpha+\beta}}}{1+\lambda}$.*

Proof. See appendix. □

According to Proposition 2.3 (i), a sufficiently high equity requirement can help to restore the effectiveness of liquidity requirements for any given level of interest rates r. This provides a further rationale for the use of equity requirements beyond the usual justification that they are to be used to control the riskiness of banks' asset portfolios. If a prudential regulator wants to use liquidity requirements as a control tool, he would be well advised to additionally implement a sufficiently high equity requirement which ensures that liquidity requirements work effectively at the given level of interest rates. In this sense, equity requirements can be considered complementary to liquidity requirements.

Proposition 2.3 (ii) and (iii) analyze the effects of the properties of the profitable assets on the threshold r^m. According to Proposition 2.3 (ii), an *ex ante* higher expected return on the profitable assets increases the range of interest rates where liquidity requirements may be effective. A higher $\bar{R}$ implies that the distribution of asset returns is shifted upwards. In expected terms it becomes therefore easier for the bank to generate the returns needed to offset the solvency effect.

In order to gain the intuition behind Proposition 2.3 (iii), let us first consider an additional comparative statics result about R^* which was first proved by Metz (2002) in the context of a Global Game of currency attacks which exhibits a similar structure as the model by Rochet and Vives.

Corollary 2.2. *A marginal increase in the precision of asset returns α decreases the probability of default if and only if*

$$R^* < \bar{R} + \Phi^{-1}(\gamma)/2\sqrt{\alpha+\beta}. \tag{2.12}$$

Proof. See appendix. □

Metz (2002) provides a detailed, graphical explanation of the effects of changing α on the default point, so we can shorten the explanation here and refer the reader interested in more details to her paper. However, to gain the intuition behind condition (2.12), note that R^* is strictly decreasing in $\bar{R}$, while the right–hand side of (2.12) is strictly increasing in $\bar{R}$. This implies that there exists a critical value $\bar{R}_\alpha$ such that for $\bar{R} > \bar{R}_\alpha$, an increase in α decreases the default point R^*. Now consider a fund manager who calculates the probability of default conditional on his signal observation. The conditionally expected return is a weighted sum of signal and prior expected return. Therefore if the prior expected return $\bar{R}$ is rather large (above $\bar{R}_\alpha$) and α increases, the fund manager attaches a larger weight to rather favorable publicly available information. This in turn implies that he attaches a lower probability to the default event and is more likely to roll over. The critical signal t^* decreases and so does the default point R^*.

Coming back to the explanation of Proposition 2.3 (iii), observe that from Proposition 2.2 follows that r^m is the value of r that sets $R^* = (1-e)(1+\lambda)$. Substituting $\hat{e}$ from Proposition 2.3 into the latter yields

$$R^* = (1-\hat{e})(1+\lambda) = \bar{R} + \frac{\Phi^{-1}(\gamma)}{2\sqrt{\alpha+\beta}}.$$

Since R^* is strictly decreasing in e, an equity level $e > \hat{e}$ ensures that for $r \leq r^m$, the critical value R^* will necessarily come to lie below $\bar{R} + \Phi^{-1}(\gamma)/2\sqrt{\alpha+\beta}$. But from Corollary 2.2 follows that this is exactly the threshold that needs to be passed such that an increase in the precision α leads to a decrease of the default point R^*. Now suppose that $r = r^m$ and $e \geq \hat{e}$. Then a marginal increase in α decreases R^*, which in turn slackens constraint (2.10). This allows to marginally increase r without violating condition (2.10). Hence, the range of interest rates where liquidity requirements work effectively becomes larger.

Summing this exercise up, the effectiveness of liquidity requirements in strengthening the bank's resilience depends crucially on the level of deposit interest rates being below the bound r^m. If one regards the range of interest rates $(0, r^m]$ as a measure for the potential effectiveness of liquidity requirements, one may conclude that their effectiveness is enhanced through a higher level of equity and whenever the bank's asset side contains assets with relatively high expected returns and low variance. The latter property again requires the equity ratio to be set sufficiently high. *Mutatis mutandis*, whenever expected rates of return decrease or the variance of assets increases during times of financial stress, the effectiveness of liquidity requirements may become impaired. This in turn would require making the liquidity requirement dependent on the business cycle in a similar way as has been recently proposed for capital requirements.[14]

2.4.2 Back-of-the-Envelope Example

The question arises whether the *solvency effect* is only a theoretical artifact and whether it is actually quantitatively relevant. Vives (2011, p. 10), for example, believes that for typical financial intermediaries, the parameter values are usually such that the *liquidity effect* dominates. Vives is certainly right in that the question whether or not liquidity requirements are effective in strengthening the resilience of banks is ultimately an empirical question. However, we believe that this should not *a priori* preclude any analysis that points out to the potential *in*effectiveness of such measures. Moreover, we also do not share Vives' view that parameters for a typical financial intermediary are usually such that no *solvency effect* can occur. To illustrate this point, consider a rather simple back–of–the–envelope calculation for the special case of the Global Game solution which obtains when the precision of private signals becomes sufficiently large (alternatively, if the precision of asset returns becomes sufficiently small).

Corollary 2.3. *For $\beta \to \infty$ (alternatively for $\alpha \to 0$), the default point R^* tends to*

$$R_0^* = R_s(m,e,r) + \frac{\lambda(1-e)(1+r)\max\{1-\gamma-m,0\}}{1-m(1+r)}. \tag{2.13}$$

Moreover, if $R_0^* > R_s$, then the liquidity effect dominates the solvency effect if and only if

$$r \leq r_0^m \equiv \frac{\lambda\gamma}{1+\lambda(1-\gamma)} \tag{2.14}$$

Proof. See appendix. □

[14] See e.g. Basel Committee on Banking Supervision (2010*b*).

As detailed below, it is straightforward to come up with empirical counterparts for parameters λ and r. Yet, it is more difficult to find empirical counterparts for γ, the ratio of C to B. Therefore, for given values λ and r, what is the lowest value of γ such that condition (2.14) holds and liquidity requirements lower the default probability? Rewriting condition (2.14) in terms of γ provides the answer. The *liquidity effect* dominates the *solvency effect* if and only if

$$\gamma \geq \underline{\gamma} \equiv \frac{r(1+\lambda)}{\lambda(1+r)}. \tag{2.15}$$

One may interpret the fraction $(1+\lambda)/\lambda$ on the right hand side of (2.15) as the inverse of the haircut h which the bank faces when it tries to convert the risky asset into cash at date $\tau = 1$.[15] The following Table 2.1 shows $\underline{\gamma}$ (expressed in percent) for different combinations of interest rates and haircuts. Values above 100% are printed in italics in order to emphasize that such values can never be attained in the model due to the assumption that $C < B$. Hence, in these cases, liquidity requirements can never work to strengthen the resilience of the bank.

		Haircut $h = \lambda/(1+\lambda)$				
		1%	**6.5%**	**10%**	**15%**	**25%**
	1%	99	15.23	9.09	6.6	3.96
Interest	**2%**	*196*	30.17	19.6	13.07	7.84
Rate r	**3%**	*291*	44.8	29.13	19.41	11.65
	7.5%	*698*	*107*	69.76	31.75	27.9
	10%	*909*	*140*	90.90	60.60	36.36

Table 2.1: Lower bound of γ, calculated as $\underline{\gamma} = \frac{r}{h(1+r)}$. Liquidity requirements lower the probability of default for $\gamma > \underline{\gamma}$. Values of $\underline{\gamma}$ are depicted for different combinations of interest rate r and haircut h, all values expressed in percent.

To interpret the values in Table 2.1, recall that γ measures a fund manager's cost of early withdrawals as a fraction of the benefit B. This is also the probability that a fund

[15]Per unit of the asset, the bank can obtain $R/(1+\lambda)$. The unit value of the asset is R, so the haircut can be calculated as $R(1-h) = R/(1+\lambda)$. Solving for h yields $h = \lambda/(1+\lambda)$.

manager with signal $s_i = t^*$ attaches to the event that the bank defaults. For example, for a haircut of 6.5%,[16] and an interest rate of 2%, γ has to exceed already 30% for liquidity requirements to work effectively. If $B - C$ is interpreted as fund managers' transaction costs, values of γ above 10% can be considered quite high since transaction costs in money markets and markets for wholesale deposits are usually rather low. One may therefore conclude that it becomes difficult to apply liquidity requirements for combinations of low interest rates and relatively low haircuts. During times of financial turmoil, however, when the haircuts on bank assets may suddenly increase, liquidity requirements may become more effective than during normal times. But it can also be seen from Table 2.1 that the *solvency effect* quickly gains importance with increasing interest rates and even when the asset is highly illiquid at a haircut of 25%, interest rates above 7.5% may require values of γ above 30% to ensure that the liquidity effect dominates. This simple exercise clearly demonstrates that the *solvency effect* should not be dismissed as a solely theoretical property. When applying liquidity requirements, regulators may therefore focus on the whole set of balance–sheet–relevant parameters, including also properties of the assets on the regulated banks' balance sheets, and the haircuts applied to these assets in the markets or at the central bank's window.

2.5 Conclusion

The paper provided the solution to the well–known Rochet–Vives model under the assumption of a particular balance sheet adjustment mechanism that allows to study the interactions between equity and liquidity requirements. It has been demonstrated that liquidity requirements, like the Basel's newly proposed LCR, can be effectively used to strengthen the resilience of a bank if and only if the interest rates on deposits are sufficiently low. The model points to several important aspects in the design of regulatory liquidity standards. Firstly, besides strengthening the bank's ability to withstand sudden funding roll–offs, liquidity requirements may have a direct impact on the solvency of the bank. Secondly, as the implications of this finding are partly based on the adjustment mechanism presumed, a successful use of

[16] This is the haircut that the ECB applies to triple–A–rated ABS and covered bonds with residual maturity of one year (ECB, 2011).

liquidity regulation requires that regulators understand how banks in practice react to higher liquidity standards. If the mechanism employed in the paper indeed constitutes a correct description of banks' reaction, then the effectiveness of liquidity requirements (as measured by the range of interest rates where they lower the likelihood of bank default) may be improved by enacting a sufficiently large equity requirement. Thirdly, since the effectiveness of liquidity requirements depends on the properties of banks' assets, which in turn may be influenced by exogenous economic events, effectiveness of regulation may be improved by specifying contingent liquidity standards which take these dependencies into account.

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Appendix

Proof of Proposition 2.1. We first introduce some language. A *strategy* for a typical fund manager i is defined as a complete plan of action that specifies for each signal s_i whether the manager rolls over or withdraws. Formally, a strategy is defined as a mapping $t_i : \mathbb{R} \to \{\text{withdraw, roll over}\}$. Strategies are called *symmetric* if $t_i(\cdot) = t(\cdot)$ for all i. A strategy is called a *threshold strategy* if there exists a critical value t_i^* such that a fund manager withdraws for all signals $s_i < t_i^*$ and rolls over otherwise. A *symmetric threshold strategy* is a threshold strategy where all fund managers use the same critical value t^*. A *strategy profile* **t** is a sequence that specifies a strategy for each fund manager $i \in [0,1]$, formally, $\mathbf{t} = \langle t_i | i \in [0,1] \rangle$. Finally, a strategy profile $\mathbf{t}^*$ constitutes an equilibrium if no fund manager i finds it profitable to deviate from the strategy t_i^* specified by the profile $\mathbf{t}^*$ to a different strategy t_i'. A *threshold equilibrium* is an equilibrium where $\mathbf{t}^*$ contains only threshold strategies.

As all fund managers are identical, we can restrict ourselves to symmetric strategies without loss of generality. For notational simplicity, we can then write t for both, the strategy and the strategy profile.

The proof proceeds in two steps. In the first step, we show that if fund managers use symmetric threshold strategies, then there exists a unique threshold equilibrium if

$$\beta \geq \frac{1}{2\pi}\left(\frac{\lambda\alpha(1-e)(1+r)}{1-(1+r)m}\right)^2 \equiv \beta_0.$$

In the second step we show that there are no equilibria where fund managers use strategies other than threshold strategies. Taken together, the two steps state that there exists a unique equilibrium and that it is a threshold equilibrium.

1. *Unique threshold equilibrium*
   Suppose fund managers use symmetric threshold strategies around the critical value t. Since there exists a continuum of fund managers and since their private signals are i.i.d., the probability that a single manager observes a signal below the threshold t is, by the law of large numbers, equal to the proportion of managers with a signal below t. Given R, we can thus express the fraction of fund managers who withdraw as

$$x(t,R) = \mathbf{Pr}\left(\tilde{R} + \varepsilon < t | R\right) = \Phi\left(\sqrt{\beta}(t-R)\right).$$

   The failure point $R_f(t)$ is then implicitly defined as

$$R_f - R_s(m,e,r) - \frac{\lambda(1+r)(1-e)\max\left\{\Phi\left(\sqrt{\beta}(t-R_f)\right) - m, 0\right\}}{1-m(1+r)} = 0. \tag{A2.1}$$

   Application of the implicit function theorem yields

$$\frac{\mathrm{d}R_F}{\mathrm{d}t} = \begin{cases} 0, & \text{if } t \leq t_0 \equiv R_s + \Phi^{-1}(m)/\sqrt{\beta} \\ \dfrac{\frac{\lambda(1-e)(1+r)}{1-m(1+r)}\phi\left(\sqrt{\beta}(t-R)\right)\sqrt{\beta}}{1+\frac{\lambda(1-e)(1+r)}{1-m(1+r)}\phi\left(\sqrt{\beta}(t-R)\right)\sqrt{\beta}} > 0, & \text{otherwise.} \end{cases} \tag{A2.2}$$

Since the maximum of $\phi(\cdot)$ is $1/\sqrt{2\pi}$, dR_F/dt has a well–defined upper bound,

$$\frac{\mathrm{d}R_F}{\mathrm{d}t} \leq \frac{1}{\frac{1-m(1+r)}{\lambda(1+r)(1-e)}\sqrt{\frac{2\pi}{\beta}}+1}. \tag{A2.3}$$

Recall that a typical fund manager i withdraws if and only if

$$P_i > \gamma,$$

where P_i denotes the probability he attaches to the event of bank default. Now consider a typical fund manager who observes the signal s and who knows that other fund managers are using the strategy around the threshold t. The subjective probability he attaches to the event of a bank default is given by

$$P(s,\, t) \equiv \mathbf{Pr}\left(\tilde{R} < R_f(t)\big|\, s\right) = \Phi\left(\sqrt{\alpha+\beta}\left(R_f(t) - \frac{\alpha\bar{R}+\beta s}{\alpha+\beta}\right)\right).$$

One can readily observe that $P(s,\, t)$ is strictly decreasing in s and weakly increasing in t.

The strategy around the threshold $t = t^*$ constitutes a symmetric equilibrium in threshold strategies if and only if

$$P(t^*,\, t^*) = \gamma. \tag{A2.4}$$

t^* is indeed a symmetric threshold equilibrium because if $s < t^*$, then $P(s,\, t^*) > P(t^*,\, t^*) = \gamma$, implying that a typical fund manager with a signal $s < t^*$ withdraws. Conversely, if $s > t^*$, a typical fund manager rolls over because $P(s,\, t^*) < P(t^*,\, t^*) = \gamma$.

The symmetric threshold equilibrium exists, because

$$\lim_{t^*\to\infty} P(t^*,\, t^*) = 0 < \gamma$$

and

$$\lim_{t^*\to-\infty} P(t^*,\, t^*) = 1 > \gamma.$$

By the intermediate value theorem, there exists at least one t^* where equation (A2.4) holds.

The symmetric threshold equilibrium is unique if and only if t^* is the unique solution to equation (A2.4). To show this, it suffices to show that $P(t^*,\, t^*)$ is strictly decreasing in t^*.

Suppose first that $t \leq t_0$, then the failure point R_f is independent of t and is equal to $R_s(m,\, e,\, r)$. It follows from equation (A2.1) that for any $t \leq t_0$, $P(t,\, t)$ is strictly decreasing in t.

Now suppose that $t > t_0$. Using, equation (A2.2), the total derivative of $P(t,\, t)$ can be calculated as

$$\frac{\mathrm{d}P(t,\, t)}{\mathrm{d}t} = \phi\left(\sqrt{\alpha+\beta}\left(R_f(t) - \frac{\alpha\bar{R}+\beta t}{\alpha+\beta}\right)\right) \times \left(\sqrt{\alpha+\beta}\frac{\mathrm{d}R_f}{\mathrm{d}t} - \frac{\beta}{\sqrt{\alpha+\beta}}\right).$$

Hence, $\mathrm{d}P(t,\, t)/\mathrm{d}t < 0$ for all $t > t_0$ if and only if

$$\sqrt{\alpha+\beta}\frac{\mathrm{d}R_f}{\mathrm{d}t} < \frac{\beta}{\sqrt{\alpha+\beta}}.$$

By using the upper bound on R_f from (A2.3), a sufficient condition for the threshold equilibrium to be unique is therefore

$$\beta \geq \beta_0 \equiv \frac{1}{2\pi}\left(\frac{\lambda\alpha(1-e)(1+r)}{1-(1+r)m}\right)^2.$$

2. *No other Equilibria*

We can write a typical fund manager's best reply to the threshold strategy t as $t' = \xi(t)$, where $\xi(t)$ is implicitly defined by

$$U(t', t) \equiv P(t', t) - \gamma = 0.$$

The typical manager withdraws whenever $U > 0$ and rolls over otherwise. Consider the sequence $\langle \underline{t}_n | = 0, 1, ...\rangle$ which is recursively defined by $\underline{t}_n = \xi(\underline{t}_{n-1})$ with $\underline{t}_0 = -\infty$ as starting point. This sequence is (weakly) increasing. A fund manager who believes all others to roll over will want to withdraw always if $s \in (-\infty, \underline{t}_1) = (-\infty, \xi(-\infty))$.

Yet, if other fund managers withdraw, they will *at least* withdraw for $s < \underline{t}_1$, hence rolling over is strictly dominated for all $s < \underline{t}_1$. Given that no fund manager uses strictly dominated strategies, the iteration process continues further until the fixed point of the best reply function $\xi(.)$ is reached.

The sequence $\langle \underline{t}_n | = 0, 1, ...\rangle$ is bounded because $U > 0$ for all

$$t > t^- \equiv (\alpha+\beta)(1+\lambda)R_s - \alpha\bar{R} - \sqrt{\alpha+\beta}\,\Phi^{-1}(\gamma),$$

where $t^- < \infty$. This entails that the sequence converges to a limit $\underline{t}$.

Since continuity preserves limits, it follows that

$$\underline{t} = \lim_{n\to\infty} \underline{t}_n = \lim_{n\to\infty} \xi(\underline{t}_{n-1}) = \xi(\lim_{n\to\infty} \underline{t}_{n-1}) = \xi(\underline{t}),$$

i.e. the limit of the sequence is a fixed point of the best reply function and thus constitutes an equilibrium. By duality, one can construct a sequence $\langle \bar{t}_n | n = 0, 1, 2...\rangle$ that starts from above at $\bar{t}_0 = \infty$. This sequence is (weakly) decreasing. By duality, it generates another fixed point $\bar{t}$. To the left of $\underline{t}$, *withdrawing* is the dominant action, while to the right of $\bar{t}$, *rolling over* is the dominant action.

However, we know already from the first step above that if $\beta > \beta_0$, then the best reply function has a unique fixed point. Hence, for $\beta > \beta_0$,

$$\underline{t} = t^* = \bar{t},$$

and there cannot be any equilibria other than the equilibrium in symmetric threshold strategies.[17]

[17] It may be the case that the sequence from below converges after only one step. This occurs if $\xi'(\underline{t}_1) = 0$. In this case, the failure point is given by R_s and the fund managers' switching point is given

To summarize, from step 1. follows that the threshold equilibrium is unique if $\beta > \beta_0$. From step 2. follows that all other equilibria except the unique threshold equilibrium can be ruled out by using iteration of strictly dominated strategies.

□

Proof of Proposition 2.2. (i) If $R^* = R_s$, the failure point is given explicitly by equation (2.5) as

$$R_s(m, e, r) = \frac{(1-e)(1-m)(1+r)}{1-m(1+r)}.$$

It is straightforward to compute

$$\frac{\partial R_s}{\partial e} = -\frac{(1-m)(1+r)}{1-m(1+r)} < 0$$

and

$$\frac{\partial R_s}{\partial m} = \frac{(1+r)r}{(1-m(1+r))^2} > 0.$$

This proves (i).

(ii) If $R^* > R_s$, the failure point is given by the solution to the implicit function

$$\begin{aligned}\psi(R^*, m, e, r) :=& (1-m(1+r))R^* - (1-e)(1+r)(1-m) + \lambda(1-e)(1+r)m \\ &- \lambda(1-e)(1+r)\Phi\left(\frac{\alpha}{\sqrt{\beta}}(R^* - \bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right) = 0. \end{aligned} \tag{A2.5}$$

Equation (A2.5) is derived by solving equation (2.8) for fund manager's critical threshold,

$$t^* = \frac{\alpha+\beta}{\beta}R^* - \frac{\alpha}{\beta}\bar{R} - \sqrt{\alpha+\beta}\Phi^{-1}(\gamma),$$

and inserting this into equation (2.9).

Moreover, if $\beta \geq \beta_0$, i.e. if equilibrium is unique, then

$$\frac{\partial\psi(R^*, m, e, r)}{\partial R} = (1-m(1+r)) - \frac{\alpha\lambda(1-e)(1+r)}{\sqrt{\beta}}\phi\left(\frac{\alpha}{\sqrt{\beta}}(R^* - \bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right) > 0.$$

Hence, for $z \in \{m, e\}$, by the implicit function theorem,

$$\frac{\partial R^*}{\partial z} < 0 \Leftrightarrow -\frac{\frac{\partial\psi}{\partial z}}{\frac{\partial\psi}{\partial R}} < 0 \Leftrightarrow \frac{\partial\psi}{\partial z} > 0. \tag{A2.6}$$

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by

$$\underline{t} = \beta^{-1}\left((\alpha+\beta)R_s - \alpha\bar{R} - \sqrt{\alpha+\beta}\Phi^{-1}(\gamma)\right).$$

The condition for this to occur is

$$\alpha(R_s - \bar{R}) \leq \sqrt{\alpha+\beta}\Phi^{-1}(\gamma) + \sqrt{\beta}\Phi^{-1}(m).$$

Hence, we can calculate the partial derivative with respect to e as

$$\frac{\partial\psi(R^*, m, e, r)}{\partial e} = (1+r)(1-m) + \lambda(1+r)\left(\Phi\left(\frac{\alpha}{\sqrt{\beta}}(R^* - \bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right) - m\right) > 0,$$

and by equation (A2.6) it follows that $\frac{\partial R^*}{\partial e} < 0$.

For the liquidity ratio, one can compute

$$\begin{aligned}&\frac{\partial\psi(R^*, m, e, r)}{\partial m} \lesseqgtr 0\\ \Leftrightarrow\ & -(1+r)R^* + (1-e)(1+r) + \lambda(1-e)(1+r) \lesseqgtr 0\\ \Leftrightarrow\ & R^* \gtreqless (1-e)(1+\lambda).\end{aligned}$$

Using equation (A2.6), it follows that $\frac{\partial R^*}{\partial m} < 0$ if and only if $R^* < (1-e)(1+\lambda)$. This proves (ii). □

Proof of Corollary 2.1. From Proposition 2.2 follows that if $R^* > R_s$, then $\partial R^*/\partial m < 0$ if and only if

$$R^* < (1+\lambda)(1-e).$$

Evaluating $\psi(R^*, m, r, e) = 0$ at $R^* = (1+\lambda)(1-e)$ gives

$$\begin{aligned}\psi((1+\lambda)(1-e), m, r, e) =&\lambda\left(1-\Phi\left(\frac{\alpha}{\sqrt{\beta}}((1-e)(1+\lambda)-\bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right)\right)\\ &- r\left(1+\lambda\Phi\left(\frac{\alpha}{\sqrt{\beta}}((1-e)(1+\lambda)-\bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right)\right) = 0.\end{aligned}$$

Solving the latter for r yields

$$r^m = \frac{\lambda(1-\Phi(\omega))}{1+\lambda\Phi(\omega)},$$

with $\omega := \frac{\alpha}{\sqrt{\beta}}((1+\lambda)(1-e)-\bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)$.

Moreover, from

$$\frac{\partial\psi}{\partial r} = -mR^* - (1-e)(1-m) - \lambda(1-e)\left(\Phi\left(\frac{\alpha}{\sqrt{\beta}}((1-e)(1+\lambda)-\bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right) - m\right) < 0$$

and equation (A2.6) follows that $\frac{\partial R^*}{\partial r} > 0$. Therefore, it can be concluded that $R^* > (1+\lambda)(1-e)$ for any $r > r^m$ and vice versa. □

Proof of Proposition 2.3. The derivative of r^m with respect to any parameter $z \in \{e, \bar{R}, \alpha\}$ is given by

$$\frac{\partial r^m}{\partial z} = \frac{\partial r^m}{\partial \omega} \times \frac{\partial \omega}{\partial z}.$$

Observe first that

$$\frac{\partial r^m}{\partial \omega} = -\frac{\lambda(1+\lambda)\phi(\omega)}{(1+\lambda\Phi(\omega))^2} < 0.$$

The proof of (i)-(iii) follows immediately by combining the latter with

$$\frac{\partial \omega}{\partial e} = -\frac{\alpha(1+\lambda)}{\sqrt{\beta}} < 0,$$

$$\frac{\partial \omega}{\partial \bar{R}} = -\frac{\alpha}{\sqrt{\beta}} < 0,$$

or

$$\frac{\partial \omega}{\partial \alpha} = \frac{(1+\lambda)(1-e) - \bar{R} - \frac{\Phi^{-1}(\gamma)}{2\sqrt{\alpha+\beta}}}{\sqrt{\beta}} \gtrless 0 \Leftrightarrow e \lesseqgtr \hat{e} := 1 - \frac{\bar{R} + \frac{\Phi^{-1}(\gamma)}{2\sqrt{\alpha+\beta}}}{1+\lambda},$$

and by taking into account that the latter are non-zero if and only if $\beta \in [\beta_0, \infty)$ and $\alpha > 0$.

□

Proof of Corollary 2.2. The derivative of ψ with respect to α is given by

$$\frac{\partial \psi}{\partial \alpha} = -\lambda(1-e)(1+r) \times \phi\left(\frac{\alpha}{\sqrt{\beta}}(R^* - \bar{R}) - \sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}(\gamma)\right) \times \left(\frac{R^* - \bar{R}}{\sqrt{\beta}} - \frac{1}{2}\sqrt{\frac{\beta}{\alpha+\beta}}\Phi^{-1}(\gamma)\beta^{-1}\right).$$

For R^* to decrease in α, the latter has to be positive, which occurs if and only if

$$R^* < \bar{R} + \frac{1}{2}\sqrt{\frac{1}{\alpha+\beta}}\Phi^{-1}(\gamma).$$

□

Proof of Corollary 2.3. Taking the limit $\beta \to \infty$ (or $\alpha \to 0$) of $\psi(\cdot)$ in equation (A2.5) immediately yields equation (2.13) after solving for the critical R^*.

Equation (2.14) can be either obtained by taking the limit of $\beta \to \infty$ (or $\alpha \to 0$) in equation (2.11) or by taking the derivative of R_0^* with respect to m.

□

3 Illiquidity Risk and Liquidity Regulation

(written in collaboration with Tijmen R. Daniëls)

3.1 Introduction

There seems to be widespread agreement by policy makers and regulators that liquidity regulation is important and useful. In its latest revision of the regulatory standards for banks (Basel III), the Basel Committee on Banking Supervision introduced, for the first time, explicit regulation on bank liquidity. The initiative for the new regulatory standards was largely motivated by severe liquidity problems and funding tensions experienced by banks during the recent financial turmoil.[1] Under the new regulatory framework, banks are required to meet certain minimal standards for liquidity and are thus obliged to hold at least a certain fraction of their balance sheet in the form of liquid assets.[2] Regulators praised the new rules as, a "very significant achievement" (Mervyn King, governor of the Bank of England) which will help to "significantly reduce the probability and severity of banking crises in the future" (Nout Wellink, then–chairman of the Basel committee).[3]

Yet, what was absent when the liquidity standards were agreed upon by the regulators was an analytical framework that (a) revealed under which circumstances *liquidity underinsurance* occurs, so that liquidity regulation is necessarily required; (b)

[1]The new liquidity regulation is set out in Basel Committee on Banking Supervision (2009). It is intended to strengthen the (non–compulsory) guiding principles for liquidity of banks described in Basel Committee on Banking Supervision (2008).

[2]The regulatory rules are implemented in the form of two ratios, the *liquidity coverage ratio* (LCR) and the *net stable funding ratio* (NSFR). The former should tackle short–term liquidity problems, whereas the latter should enhance long–term, structural liquidity of banks.

[3]The quote by governor King is published on *http://www.bis.org/publ/bcbs238.htm.* The quote by chairman Wellink is published on *http://www.bis.org/publ/bcbs188.htm.*

provided guidance as to whether liquidity regulation in such situations would indeed be the most efficient way to solve the funding problems and mitigate potential inefficiencies stemming from underinsurance, and (c) described how liquidity regulation interacts with other regulatory measures and the liquidity provision undertaken by the central bank.

In this chapter, we contribute to the literature on liquidity regulation by addressing the aforementioned points in a stylized model of banking in the presence of illiquidity risk. Technically, we model illiquidity risk as the result of a *coordination problem* among creditors. In certain circumstances, creditors fail to coordinate on the socially optimal equilibrium of extending funding. Therefore, in our model, banks' reliance on wholesale funding markets creates an inefficiency. We solve our model by using the global game methods of Carlsson and van Damme (1993) and Morris and Shin (2003). Global games are a well–established modeling technique to take account of the strategic uncertainty that arises from the possibility of mis–coordination in financial markets. Our model differs from the standard global game models of illiquidity problems, e.g. Morris and Shin (2001), Rochet and Vives (2004), or Morris and Shin (2010) in that we do not look exclusively at the partial equilibrium effects of the bank's balance sheet parameters on the coordination problem in times of stress. We also study the *ex ante* effects that emerge when investors and banks take these partial effects structurally into account in their respective investment decisions. For instance, while larger liquidity buffers decrease the likelihood of liquidity stress, in our model they also depress the return on investment, which influences the investment decisions of the bank in the first place.

Within this framework, we prove three results on bank liquidity crises. To start with, we focus on the case where banks and markets fully internalize the bank's risk of illiquidity. We show that in this case, even in the absence of liquidity regulation, banks fully self–insure against the risk of becoming illiquid by holding a sufficiently large stock of liquid assets. Hence, in this setting, liquidity regulation is not necessary. Secondly, however, we show that self–insurance can also lead to inefficiencies. In particular, in order to insure against illiquidity, banks blow up their balance sheets by loading up on liquid assets. This induces a larger–than–necessary dead–weight loss on the economy in case the bank defaults and bankruptcy is costly. Because this reduces the recovery value of the bank's assets in case of default, these costs are entirely borne by the creditors. Hence, creditors need to be compensated for these losses in 'good' states where the bank survives, which can be achieved solely by reducing the payout to equity owners. This, however, implies that there are investment projects with positive net present value which are no longer financed. Whenever the expected return from investment projects is not sufficiently large, owners may instruct the bank to refrain from additional borrowing and to invest only equity so that owners can reap all profits in the good states. We further show that this inefficiency can be eliminated completely if the central bank commits to intervene with a sufficiently high probability in a liquidity crisis. In this case, the need for self–insurance vanishes. Yet again, due to the possibility of central bank intervention, there is no role for liquidity regulation.[4]

Thirdly, we study a variant of our model that recognizes that banks and markets may fail to internalize the risk of illiquidity. In reality, one important source of market failure stems from the opacity of bank balance sheets. Due to high fluctuations in liquidity needs, coupled with the low frequency and low granularity of bank reporting, it may be the case that banks cannot credibly commit to hold large liquidity buffers. In this variant of our model, creditors demand an interest rate conditional on their beliefs about the bank's portfolio choice, while banks respond to the interest rates demanded by creditors by adjusting their portfolio optimally. In equilibrium, actual choices and beliefs are mutually consistent so that creditors infer the bank's actual holdings of liquidity from observing the equilibrium interest rate even if they do not directly observe the bank's actions. This variant of our model gives rise to multiple equilibria. There are equilibria where the bank may fail to hold sufficient liquidity. For example, if creditors believe that the bank will not hold any liquidity, they ask for an illiquidity risk premium, which makes it too costly for the bank to hold liquid assets. The bank will prefer to accept the illiquidity risk and thereby vindicate creditors' initial beliefs. Furthermore, the inefficiencies associated with the risk of illiquidity are amplified. Due to the higher interest rates demanded from the bank, a wider range of investments with positive net present value projects are no longer

[4] In practice, central banks are reluctant to commit to specific emergency facilities in advance in order to avoid moral hazard (ECB, 2006, pp. 171).

financed to the full extent. Conversely, there are equilibria where creditors believe that the bank self–insures against illiquidity risk which prompts them to ask for a lower interest rate. This renders it cheaper to build up the liquidity buffer and the bank indeed considers it optimal to insure against illiquidity risk.

In this variant of the model, we obtain a role for liquidity regulation. A sufficiently large liquidity requirement can restore the outcome that was obtained under a transparent balance sheet where the bank self–insured. The requirement acts as a selection device that coordinates creditors' expectations and bank actions on the equilibrium with low interest rates, sufficiently high liquidity buffers and no inefficient illiquidity default.

Notably, the occurrence of the different equilibria can also be influenced by the bank's equity requirement. Generically, when the equity requirement is large, the bank tends to self–insure against illiquidity risk. The reason is that a large equity requirement constrains the bank's ability to take on debt. But with less debt, the liquidity buffer that needs to be kept to mitigate illiquidity risk is smaller and hence it is less costly to hold it. From this perspective, higher equity requirements are another way of enforcing the bank to maintain liquidity buffers. Liquidity and equity requirements can be seen as substitutes. Finally, also in the presence of opaque balance sheets, emergency liquidity provided by the central bank can eliminate the illiquidity risk and the associated inefficiency. Yet again, such intervention renders liquidity regulation superfluous.

3.2 Related Literature

Our model is, in particular, related to two strands of the banking literature. Firstly, we view bank illiquidity as the the outcome of a *coordination failure* among creditors. This viewpoint largely originated with the well–known banking model of Diamond and Dybvig (1983). The Diamond–Dybvig model exhibits multiple equilibria (at the rollover stage): In one equilibrium, only those depositors with a true need for liquidity withdraw. In the other equilibrium all depositors withdraw because even those who are not subject to a liquidity shock expect everyone to withdraw. This belief implies that withdrawing becomes a best response for all depositors. Hence, in the former equilibrium, the bank survives and can continue its long–term asset until it pays off. In the latter, the bank fails due to illiquidity. Equilibria are self–fulfilling in that decisions of depositors who do not face a liquidity shock are brought about by particular beliefs which are eventually vindicated by the consequences of their decisions. In this respect, the Diamond–Dybvig model constitutes the first formalization of the idea by Merton (1968) that bank failures can be interpreted as *self–fulfilling prophecies*.

While the Diamond–Dybvig model is a *"workhorse of banking research"* (Prescott, 2010, p. 1), it is vulnerable to the critique that its multiplicity of equilibria is associated with an indeterminacy of depositors' beliefs at the rollover–stage (Morris and Shin, 2001). The *theory of global games*, which originated with Carlsson and van Damme (1993) and which was popularized, in particular, by the works of Morris and Shin[5] provides a selection device for multiple equilibrium models and allows to express the likelihood of one or the other equilibrium in terms of the underlying parameters of the model. Global games have become an important modeling device for bank runs and related phenomena since the effects of policy–relevant parameters on the likelihood of a crisis can be derived in a straightforward way. Examples are Goldstein and Pauzner (2005), who derive the global game selection for the Diamond–Dybvig model, Rochet and Vives (2004) whose model allows to distinguish between insolvency and illiquidity or Morris and Shin (2010) who introduce a time–varying fundamental into a model similar to the Rochet–Vives model. The latter two papers stress that liquidity regulation is effective as it increases the likelihood that the bank does not become illiquid. König (2010), however, refines the results of Rochet and Vives and points out that their comparative statics analysis fails to take the bank's balance sheet constraint properly into account. When doing this, liquidity requirements exert two opposing effects, a *liquidity effect* which indeed decreases, and a *solvency effect* which increases the likelihood of a default. The latter occurs because liquid assets earn lower returns on average and, given fixed interest rates on bank's liabilities, the average returns on profitable assets have to increase in order to make good the lower returns on liquid assets, thereby ceteris paribus increasing the proability of default.

In the same vein, we also rely in our model on the global game selection and use

[5] See e.g. Morris and Shin (1998, 2001, 2003, 2004, 2010).

it as a tool to model the probability of illiquidity in terms of the bank's balance sheet parameters. In contrast to the above mentioned papers, our analysis goes one step further in that we use the resulting closed–form expression of the probability of illiquidity in the *ex ante* stage where the bank determines its balance sheet structure. Similar exercises have been performed recently by Szkup (2013) or Eisenbach (2013) with respect to the choice of debt maturity. The trade–off studied in their models is between short–term debt (which is cheap but can be withdrawn) and long–term debt (which is more expensive but stable), while the liquidity of the borrowing entity's asset portfolio is not endogenously chosen.

In our model, we assume that only short–term debt is available, but we study the endogenous determination of a bank's portfolio composition. The trade–off is between assets which are costly to hold due to low returns but which can be used to reduce illiquidity risk, and profitable but illiquid assets which raise the likelihood of becoming illiquid. To our knowledge, our model is the first that derives a bank's portfolio composition consisting of liquid and illiquid assets by taking into account the endogenous illiquidity risk derived from the global game selection.

As mentioned above, a variant of our model also exhibits multiple equilibria when we assume that the bank's choices are not directly observable. However, in contrast to multiplicity that occurs at the rollover stage, for example in the Diamond–Dybvig model, the multiplicity in our model occurs at the initial stage when the bank makes its borrowing and investment decisions. The main difference between the two situations is, we assume a market exists at the initial stage which aggregates creditors' information, a feature that is lacking at the stage when agents decide whether to withdraw or to rollover their loans. Cannot the initial stage be embedded into a global game as well? One problem here is that a market price may act as a public signal restoring common knowledge among agents and destroying the uniqueness results (Atkeson, 2001). Werning and Angeletos (2006) introduce an endogenous price as a public signal into an otherwise standard coordination game. They show that even in the absence of common knowledge, multiple equilibria obtain under certain conditions on the market's information aggregation process. Similarly, Tsyvinski, Mukherji, and Hellwig (2006) study a rational expectations currency crisis model with endogenously determined interest rates and conclude that the equilibrium uniqueness results of global games do not hold in market–based models of currency crises. In the light of these results, we abstain from embedding our initial market game into a global game framework as we do not expect to obtain a unique equilibrium in an unambiguous way. Rather, we assume that the market aggregates information and we allow for multiple equilibria depending on the prevailing set of market participants' beliefs. The resulting choice of liquidity can then be interpreted as an *institutional feature* of the bank in normal times. The corresponding economic equilibria are the outcome of a stable social convention between bank and market participants which emerges during normal times, thereby becoming a focal point (Mas-Colell, Whinston, and Green, 1995, pp. 248). This interpretation is meaningful with respect to the *ex ante* perspective; it would be less meaningful with respect to the rollover stage where a liquidity *crisis*, i.e. a sudden change of the underlying behavior of creditors is modeled. We emphasize that in this setting regulatory standards on bank liquidity can act as a selection device and coordinate expectations on the particular equilibrium where the bank, even in the absence of the regulatory standards, would fully self–insure against illiqudity risk.

Secondly, our model is also closely related to the literature on bank reserve management. This literature dates back to Edgeworth (1888) who was the first to model the choice between liquid reserves and earning assets, treating it as an inventory optimization problem with stochastic demand (Baltensperger, 1980). Reserves may help to buffer exogenous random liquidity shocks, but they earn lower returns. Earning assets are profitable but can be used to meet deposit outflows only by incurring an additional cost. Edgeworth's approach was taken up and refined by Orr and Mellon (1961). Poole (1968) or recently Quiros and Mendizabal (2006) use a similar approach to model the optimal holdings of central bank liquidity over a reserve maintenance period. While the bank in our model solves a similar trade–off between liquidity and profitability, the major difference to the models in the reserve management tradition is that we endogenize, by virtue of the global game approach, the liquidity shock at the rollover stage and relate it explicitly to a coordination problem and not only to a particular random liquidity shock. Moreover, we also take the effect of the bank's choices on the interest rate into account, which is usually ignored in the reserve management literature.

Our model thereby connects two distinct strands of the banking literature: the view that illiquidity is the outcome of a coordination failure and the reserve management literature which provides optimality conditions for the problem of how to select a portfolio that is immune to illiquidity default.

3.3 Benchmark Model

We start by considering a benchmark model of a bank's borrowing and portfolio choice without illiquidity risk and where the bank fully internalizes the risks associated with its choices. The former rests on the assumption that creditors cannot withdraw their funding before the bank's assets pay off, whereas for the latter, we assume that creditors can observe the bank's choices when making their lending decisions so that the bank's choices are reflected in the interest rate it pays on its debt.[6] This benchmark provides a natural starting point which allows us to understand the effects of *illiquidity risk* (introduced in section 4) and a *non–transparent / unobservable balance sheet* (section 5) on the bank's decisions and their respective implications for prudential regulation, in particular liquidity regulation (section 6).

3.3.1 Basic set–up

The model studies a bank that operates for three periods, $t \in \{0, 1, 2\}$. The bank is financed by equity to the amount e and can raise additional funds at date 0 by borrowing from wholesale creditors. The amount borrowed is denoted by s and the gross interest rate that the bank pays at date 2 for funds borrowed at date 0 is denoted r_s.

The bank can invest borrowed funds and its equity into a risk–free asset with gross interest rate equal to unity. The amount invested into the risk–free asset is denoted by m. Alternatively, the bank can invest into a risky project. The stochastic per-unit return on this asset is given by

$$\tilde{R} = \begin{cases} R & \text{with probability } q \\ 0 & \text{with probability } 1 - q. \end{cases}$$

[6] An alternative assumption would be that the bank can credibly commit to a particular balance sheet structure.

We assume that the expected return satisfies

$$\mathbf{E}(\tilde{R}) = qR \geq 1, \tag{3.1}$$

so that investment in the risky project is efficient. The amount invested into the risky asset is denoted by y.

Moreover, the safe asset is perfectly liquid as the bank can convert one unit held in the form of the safe asset into one unit of liquidity at its own discretion at either date 1 or date 2 (essentially the asset is like a storing technology or cash). In contrast, the risky asset is illiquid as its payoffs accrue at date 2 and it does not generate any liquidity at date 1 (this assumption is weakened in section 4, when we introduce illiquidity risk).

According to equation (3.1), the risky asset pays out nothing at date 2 with probability $(1-q)$. In this case, the bank's sole source of revenues are its liquid assets of amount m. We distinguish between two cases. Firstly, if the bank has enough liquid assets to pay off its debt, i.e. if $m > r_s s$, then it redeems its liabilities and passes the remains on to the equity owners. Secondly, whenever $m < r_s s$, the bank declares bankruptcy and is closed by the regulator. In this case, creditors receive a *pro–rata* share of the recovery value of the bank. The recovery value is given by the value of the remaining assets less bankruptcy costs, e.g. legal fees or administration costs, which we assume to be a constant fraction of the value of the remaining assets. Thus, we can express the recovery value as νm, where $\nu \in [0, 1]$.

With converse probability q, the risky asset generates the high return R at date 2. The bank then uses the proceeds from the risky and the safe asset holdings to pay off its liabilities and distributes the remaining proceeds among its equity owners. In this state of the world, the bank never defaults.

Finally, the bank is subject to equity regulation. The regulator requires it to hold at least $\beta \in (0,1)$ units of equity per unit invested into the risky asset,

$$e \geq \beta y. \tag{3.2}$$

No equity requirement is imposed on holdings of the safe asset and the bank can hold as much liquid assets as it desires without facing any constraint.

3.3.2 Optimal borrowing and portfolio choice

We now turn to the derivation of the bank's choices of y, m and s under the two benchmark assumptions of no illiquidity risk and full transparency of the bank's balance sheet. We may therefore assume that creditors who lend to the bank at date 0 can claim principal and interest of their credit only at date 2. The assumption of full balance sheet transparency implies that the interest rate paid to creditors, r_s, reflects the bank's choices and the associated risks are therefore internalized by the bank.

The balance sheet identity

$$y + m = s + e, \tag{3.3}$$

always holds. Since its equity e is predetermined, the bank can choose only two out of the three variables y, m and s, with the remaining variable being automatically determined as a residual. We find it convenient to think of the bank's optimization problem as a three–stage process, reflecting the division of labor between specialists in different divisions of a banking corporation. In the first stage, the bank's board decides whether to invest borrowed funds at all or whether solely equity is invested. During the second stage, the investment decision on y is made, while at the third stage, the liquidity management decision, i.e. the choice of m, is carried out.

The bank thereby maximizes its profit function

$$\Pi(y, m, s) = q\left(Ry + m - r_s s\right) + (1-q)\max\{m - r_s s, 0\}. \tag{3.4}$$

subject to the balance sheet identity (3.3) and an interest rate parity condition for wholesale creditors (investor participation condition)

$$q r_s + (1-q)\mathbf{1}_{[m - r_s s > 0]} r_s + (1-q)\left(1 - \mathbf{1}_{[m - r_s s > 0]}\right)\frac{\nu m}{s} \geq 1, \tag{3.5}$$

where we made use of the indicator function

$$\mathbf{1}_{[z>0]} = \begin{cases} 1 & \text{if } z > 0, \\ 0 & \text{if } z < 0. \end{cases}$$

Creditors' only outside option is the risk–free asset, as they do not have access to the risky project in which the bank can invest (see right hand side of equation (3.5)). Furthermore, we also assume that financial markets are sufficiently thick and there exists a sufficiently large number of wholesale creditors who compete the interest rate down to the point where the interest parity condition holds with equality. In addition, the choices of the bank have to be sufficiently attractive for its equity owners. Their participation constraint is given by

$$\Pi(y, m, s) - e \geq qRe - e. \tag{3.6}$$

The intuition behind equation (3.6) is as follows. Since debt is senior to equity, the interest payments on debt may become too high and dilute the equity owners' payoffs; as the equity owners can always demand that only their equity stakes are invested into the risky asset and thus instruct to refrain from additional borrowing, the bank's expected profit must be at least as large as $qRe - e$ which is the expected profit from investing only equity riskily.

The following Proposition summarizes the bank's choices of y, m and s.

Proposition 3.1. *The bank borrows* $s^* = \frac{1-\beta}{\beta}e$*. It invests borrowed funds and equity completely into the risky asset,* $y^* = s^* + e = e/\beta$*, and does not invest into the safe asset,* $m^* = 0$*. The interest rate is given by* $r_s^* = 1/q$*.*

Proof. See appendix. □

Proposition 3.1 states a natural benchmark against which we will compare the outcomes that obtain when illiquidity risk and balance sheet opaqueness are introduced. The intuition behind Proposition 3.1 is straightforward. Firstly, as the risky asset provides, in expected terms, a higher return than the safe asset, the bank finds it optimal to borrow in order to invest as much into the risky asset as its equity allows. Secondly, the interest rate r_s^* perfectly reflects the bank's risk taking and, given the non–zero default probability of the bank, exceeds unity. This implies that the bank also refrains from holding some of the safe and liquid assets. The only property that makes the latter desirable is its liquidity at all dates. However, in the absence of illiquidity risk, the bank has no incentive to divert some borrowed funds to obtain an asset that yields a lower payoff (1 per unit) than it costs to borrow the funds to acquire the asset (r_s per unit).

3.4 Model with Illiquidity Risk

We continue to assume that creditors can observe the bank's choices at date 0 and therefore condition their interest rate on them. However, in contrast to the benchmark model in the previous section, we now assume that wholesale debt can be withdrawn early at date 1. This creates a liquidity mismatch on the bank's balance sheet and therefore induces a reason for the bank to hold some liquid assets in order to buffer against potential withdrawals which may occur at date 1.

3.4.1 Illiquidity as coordination failure

We model illiquidity as the outcome of a coordination game between the creditors at date 1. We solve this game by resorting to the theory of global games which allows us to express the probability that the bank will become illiquid at date 1 in terms of the balance sheet variables y, m and s. At date 0, the bank takes this probability into account when it carries out its portfolio and borrowing choices. Since its choices affect the likelihood of experiencing a run, illiquidity risk becomes endogenous. In order to obtain tractable analytical solutions, we model the rollover decision in the style of Rochet and Vives (2004) or König (2010).

Wholesale debt is managed by *ex ante* identical risk–neutral fund managers each administering one unit of cash. Managers decide on behalf of the original fund owners at date 0 whether to lend to the bank or whether to invest into the risk–free asset. A manager's decision to lend to the bank depends on whether the bank offers a sufficiently large interest rate such that the expected return from lending out his client's funds is at least as high as the risk–free outside option. Furthermore, at date 1, fund managers decide whether to withdraw or to rollover the trusted funds. The decision at date 1 depends on fund managers' personal benefits. In case they withdraw, they earn a base wage C. Withdrawing is the safe action for a fund manager. If fund managers rollover and the bank succeeds, they obtain the base wage plus a bonus payment. The sum of base wage and bonus payment is denoted by $B > C$. If, however, fund managers rollover and the bank fails they are held liable for having made a bad decision and receive no compensation (even if the original creditors may become entitled to a fraction of the bank's recovery value). Fund managers adopt the following simple behavioral rule: Given their assessment of the bank's default probability, they roll over whenever their expected personal benefit from continuing to lend is at least as large as the base wage.[7]

With respect to the information possessed by fund managers, we assume that all managers have the same information at date 0; as market participants, fund managers' information is essentially ground out by the market which perfectly coordinates fund managers' actions such that they behave like a single representative agent at date 0. However, when deciding about withdrawing or not at date 1, no such coordinating mechanism exists. Each fund manager then forms his expectations about the bank's failure based on his private information and his beliefs about the information and the likely behavior of other fund managers. This in turn may give rise to a coordination failure once managers withdraw their funding because they believe that too many withdrawals occur that drive the bank into illiquidity. The resulting withdrawals may indeed cause the illiquidity of the bank thus vindicating managers' initially held beliefs.

It is important to note that the failure of the bank due to illiquidity is always inefficient. The bank does not default because an underlying change in the investment fundamentals occurs, which induces creditors to revise their solvency assessment and thus to withdraw. While it will be shown below that the solvency probability q enters the decision of fund managers, no change in fund managers' assessments of the solvency occurs between dates 0 and 1. Rather, the actual reason for withdrawing is the "reverberant doubt" (Hofstadter, 1985, p. 752) that the bank may become illiquid because too many withdrawals occur, which may eventually render withdrawing the preferred action.

Finally, we are more specific about the illiquidity of the risky asset. In particular,

[7] The assumption that wholesale debt is managed by fund managers is mainly made for the sake of analytical tractability. However, the assumption is also reflective of the reality in financial and money markets where large banking corporations refinance their asset inventories by borrowing from money market funds and mutual investment funds which administer a considerable part of the overall volume of deposits. The idea of modeling illiquidity risk in this way is due to Rochet and Vives (2004). They further justify the assumption of introducing a risk–insensitive and exogenous compensation of fund managers by referring to empirical evidence. For example, Chevalier and Ellison (1997, 1999) found that fund managers' personal returns are determined by the volume of funds administered rather than by the actual returns they achieve.

we assume that to meet any withdrawals at date 1, the bank cannot only use its liquid assets m, but it can obtain θy units of liquidity against the risky asset, where $\theta \sim U[0,1]$. Here, we find it convenient to think of the additional interim liquidity as obtained through a secured borrowing or repo arrangement with margin given by $(1-\theta)$. In addition, if we let the sum of interest rate and per–unit transaction costs in these borrowing operations be equal to the interest rate r_s, the bank's date 2 liabilities remain unchanged.[8]

The bank defaults at date 1 due to illiquidity whenever the withdrawals exceed its available liquidity. Formally, denoting by $n \in [0,1]$ the fraction of fund managers who withdraw, the bank becomes illiquid if and only if

$$ns > m + \theta y. \tag{3.7}$$

Equation (3.7) illustrates that the bank is likely to become illiquid once too many withdrawals occur. However, if all fund managers roll over, the bank can continue until date 2 (where it survives with probability q). This suggests that there may exist multiple equilibria of the coordination game between fund managers and illiquidity can therefore be interpreted as the result of a coordination failure.

In order to derive the unique equilibrium of fund managers' coordination game, we resort to global game techniques.[9] To this end, we assume that fund managers only imperfectly observe the margin $(1-\theta)$. Shortly before deciding whether to withdraw or not, each fund manager receives some noisy information about θ. The information is modeled as a signal

$$x_i = \theta + \varepsilon_i, \quad \text{where } \varepsilon_i \overset{i.i.d.}{\sim} U[-\varepsilon, \varepsilon].$$

A fund manager's decision at date 1 can then be described by a strategy

$$\sigma_i : x_i \mapsto a_i, \quad \text{where } a_i \in \{\text{withdraw, roll over}\},$$

[8]See Morris and Shin (2010) or He and Xiong (2012) for the use similar assumptions when the focus of the analysis is on illiquidity problems.

[9]Global games are a tool to select a unique equilibrium in a game with multiple equilibria. The selection technique captures the idea that some equilibria are more robust to strategic uncertainty than others. Of note, in the context of our model, a stronger equilibrium selection technique also applies: the selected equilibrium is the unique equilibirum robust to incomplete information in the sense of Kajii and Morris (1997). This also means that the equilibrium survives in a much wider range of other settings with strategic uncertainty beyond those generated by global games.

that associates with each signal either the decision to withdraw or the decision to roll over. Fund managers' strategies are said to be *symmetric* if $\sigma_i(\cdot) = \sigma(\cdot)$ for each i. Furthermore, a strategy of fund manager i is called *threshold strategy* if it prescribes to withdraw for any signal x_i below some threshold value $\hat{x}_i$, while it prescribes to roll over for any signal above $\hat{x}_i$. A threshold strategy is symmetric if $\hat{x}_i = \hat{x}$ for all i.

In what follows we restrict attention to symmetric threshold strategies. As stated in Proposition 3.2 below, the resulting *threshold equilibrium* is unique.[10]

We now turn to the derivation of the unique threshold equilibrium. To this end, suppose that fund managers use the threshold strategy around $\hat{x}$. By the law of large numbers, the fraction of fund managers with a signal below $\hat{x}$ is given by $\mathbf{Pr}(x_i \le \hat{x}|\theta)$. Therefore, the bank fails whenever $\theta < \hat{\theta}$, where

$$\hat{\theta} = \min\left\{\theta \in [0,1] \,\middle|\, \mathbf{Pr}(x_i \le \hat{x}|\theta) \cdot s \le m + \theta y\right\}. \tag{3.8}$$

We henceforth refer to $\hat{\theta}$ as the *default point* of the bank.

Given the default point, we can derive a typical fund manager's decision at date 1. He withdraws if and only if his expected payoff from withdrawing exceeds the expected payoff from rolling over, where his expectation is based upon his signal observation x_i and his knowledge of the default point. The expected payoff from withdrawing is given by the base wage C, whereas the expected payoff from rolling over becomes $\mathbf{Pr}\left(\theta > \hat{\theta} \middle| x_i\right) \cdot q \cdot B$. The expected payoff from rolling over is weakly increasing in x_i, meaning that a fund manager who receives more favorable information about the bank's liquidity situation considers rolling over to be more preferable because he knows that the bank can cover more withdrawals from given liquid resources. According to the definition of a threshold strategy, a fund manager observing a signal equal to the threshold signal $\hat{x}$ has to be indifferent between rolling

[10] Under some mild additional assumption, there are also no other equilibria in non–threshold strategies. This requires essentially to enlarge the support of θ into negative terrain. A sufficient assumption would be $\theta \sim U[-\gamma/(1-\gamma/q), 1]$. This suffices to ensure that there exist *upper* and *lower dominance regions* where one or the other action of creditors is strictly dominant. By using iterated deletion of strictly dominated strategies, one can then easily show that there are no other equilibria, see e.g. Morris and Shin (2003). The only change to the remaining model would be that the probability of illiquidity, which is derived below, would have to be normalized by $1 + \gamma/(1-\gamma/q)$ instead of just by 1.

over and withdrawing. Thus, the threshold signal $\hat{x}$ is given by

$$\hat{x} = \min\left\{x_i \in [-\varepsilon, 1+\varepsilon] \middle| \mathbf{Pr}\left(\theta > \hat{\theta} \middle| x_i\right) qB \geq C\right\}. \tag{3.9}$$

In order for the bank to be able to borrow at all, we must additionally assume

$$\frac{C}{B} \equiv \gamma < q. \tag{3.10}$$

If equation (3.10) failed to hold, fund managers would always opt for withdrawing at date 1 because the expected payoff from rolling over would be smaller than the expected payoff from withdrawing for any realization of θ. But since fund managers would be aware of this already at date 0, they would be (weakly) better off by not lending to the bank at all.

The threshold equilibrium can thus be summarized by the tuple $(\hat{x}, \hat{\theta})$ which simultaneously satisfies equations (3.8) and (3.9). The following Proposition provides the closed form solution for the limit case with vanishing signal noise, the so–called *global game solution* (Heinemann, Nagel, and Ockenfels, 2004, p. 1586).

Proposition 3.2. *If fund managers use threshold strategies, the unique default point of the bank is given by*

$$\hat{\theta} = \hat{\theta}(y, m, s) = \begin{cases} \frac{\frac{\gamma}{q}s - m}{y}, & \text{if } m < \frac{\gamma}{q}s \\ 0, & \text{if } m \geq \frac{\gamma}{q}s. \end{cases} \tag{3.11}$$

In the limit, for $\varepsilon \to 0$, all fund managers withdraw whenever $\theta < \hat{\theta}$ and they all roll over whenever $\theta \geq \hat{\theta}$.

Proof. See appendix. □

From the assumption that θ is uniformly distributed on the unit interval, we can calculate the *ex ante* probability that the bank becomes illiquid as

$$\mathbf{Pr}\left(\theta < \hat{\theta}\right) = \hat{\theta}.$$

As explicitly stated in Proposition 3.2, the default point, and thus the risk of illiquidity, are a function of the bank's choice variables and can therefore be directly influenced by the bank. This induces a trade–off between illiquidity risk and profitability. As will become clear from the subsequent discussion, when the balance sheet identity is taken into account, larger holdings of the liquid asset will reduce the illiquidity risk. This *liquidity effect* (König, 2010), however, comes at the cost of reducing the bank's profits because the liquid assets are costly to hold, yielding a return lower than the interest costs expended on the funds that are needed to acquire the assets. In the following section we turn to the analysis of how the bank is going to choose its portfolio and borrowings at date 0 optimally when it faces the threat of defaulting due to illiquidity at date 1.

3.4.2 Optimal borrowing and portfolio choice

When the bank is subject to illiquidity risk, its profit function at date 0 becomes

$$\Pi(y, m, s) = q(1-\hat{\theta})\left(Ry + m - r_s s\right) + (1-q)\max\{m - r_s s, 0\}. \tag{3.12}$$

Similar to the optimization problem in the benchmark model, the bank chooses y, m and s to maximize the profit function (3.12) subject to the balance sheet identity (3.3), the equity requirement (3.2), the participation constraint for equity (3.6), the default point defined in equation (3.11) and the following interest parity condition (which replaces equation (3.5)),

$$(1-q)\mathbf{1}_{[m>r_s s]} r_s + (1-q)(1-\hat{\theta})(1-\mathbf{1}_{[m>r_s s]})\frac{vm}{s} + \hat{\theta}(1-\mathbf{1}_{[m>s]})\frac{vm}{s} + q(1-\hat{\theta})r_s = 1. \tag{3.13}$$

The first term in equation (3.13) refers to the case where the risky asset generates a zero return, yet the revenues from the bank's liquid assets are sufficiently large to redeem principal and interest of its debt. The second term refers to the opposite case where the risky asset does not pay out anything and the liquid assets do not suffice to pay off the liabilities. In this case, the bank is closed and the creditors have to establish their claims at the bankruptcy court. Each creditor then receives a share v/s of the remaining assets. The third term covers the case of a run where the bank does not hold sufficient liquidity to redeem the principal on its debt. Accordingly, it declares bankruptcy and is closed by the regulator. Again, creditors only receive a a fraction v/s of the recovery value. The fourth term, finally, covers the case where the bank is not run and the risky asset pays out the high return, in which case the bank redeems interest and principal on its debt.[11]

In the optimization problem, we replace s from the balance sheet identity by $y + m - e$ and let the bank choose y and m. Given an unconstrained access to funding at date 0, the amount of debt needed to sustain the bank's optimal choices of y and m is then determined residually.

The bank's optimal choices in the presence of illiquidity risk are provided in the following Proposition.

Proposition 3.3. *i) Whenever the expected return qR of the risky asset satisfies*

$$qR \geq \frac{q(1-\gamma)-(1-q)\nu\gamma}{q-\gamma} \geq 1, \tag{3.14}$$

then the bank borrows

$$s^* = \frac{1-\beta}{\beta}\frac{1}{1-\gamma/q}e.$$

The asset side of its balance sheet is given by

$$y^* = \frac{e}{\beta} \qquad \text{and} \qquad m^* = \frac{1-\beta}{\beta}\frac{\gamma/q}{1-\gamma/q}e.$$

Thereby the bank sets $\hat{\theta}^* = \hat{\theta}(y^*, m^*, s^*) = 0$ and perfectly insures itself against illiquidity risk. The interest rate is given by

$$r_s^* = \frac{1-\frac{\nu\gamma(1-q)}{q}}{q}$$

which satisfies $1 < r_s^* \leq q^{-1}$.

ii) Whenever the expected return satisfies

$$qR \in \left[1, \frac{q(1-\gamma)-(1-q)\nu\gamma}{q-\gamma}\right],$$

then the bank does not borrow at all, it does not hold any cash and only invests its equity into the risky asset.

[11] In general, one would need to include the creditor's cost of delegating the management of the funds to the fund manager, i.e. C in case of early withdrawal and B in case of successful rollover. However, as only the ratio $\gamma = C/B$ matters for the analysis, we can plausibly assume that the costs of managing a unit of cash are small, $C \approx B \approx 0$, so that they disappear from the interest parity condition, while the ratio C/B is still well–defined.

Proof. See appendix. □

To gain the intuition behind Proposition 3.3, recall that the liquidity mismatch can lead to the illiquidity and default of the bank at date 1. This is inefficient because the success probability of the risky project has not changed, yet the default destroys the bank's ability to continue the project until date 2. How does the bank cope with this inefficiency? For projects that satisfy condition (3.14), the bank invests the same amount riskily that it would have invested in the absence of illiquidity risk. Yet, it increases its debt–to–equity ratio and lengthens its balance sheet in order to build up a liquidity buffer to self–insure against illiquidity risk. The liquidity buffer exerts two beneficial and one detrimental effect. The former consist of a *risk–reduction* and a *price effect*. The risk–reduction effect occurs because the optimal liquidity holdings of amount $\gamma s/q$ completely eliminate illiquidity risk by driving $\hat{\theta}$ down to zero (cf. equation (3.11)). Thereby, the total default risk of the bank is pushed towards its level in the benchmark model. The price effect occurs, since building up the liquidity buffer is tantamount to building up a positive recovery value to which creditors, in contrast to the benchmark model, can resort in case the risky project ends up in the bad state at date 2 and the bank defaults. This in turn reduces the interest rate that the bank has to pay on its debt. The two beneficial effects come at the cost of a larger amount borrowed, i.e. a higher debt–to–equity ratio (compared to the benchmark model), which is needed to build up the liquidity buffer in the first place, a detrimental *quantity effect*.

Condition (3.14) thus suggests that the inefficiency is shifted from date 1 to date 0 when the bank undertakes its portfolio and borrowing decisions: The condition implies that there may exist projects with positive net present value which are not financed to the same extent as in the benchmark model, i.e. projects whose expected return qR is above unity, but which fail to satisfy condition (3.14). Essentially, by investing only its equity in such cases, the bank underinvests compared to the benchmark model. To understand why this happens, suppose the bank finances the project to the full extent possible (given the constraint due to the equity requirement β) and in addition builds up a liquidity buffer. By virtue of the buffer, illiquidity risk is eliminated and the risk level in the benchmark model is restored. Moreover, in expected terms, creditors receive the value of their outside option which equals the unit payment from the safe asset. However, *ex post*, whenever the bad state occurs, the risky asset does not generate any returns and the bank fails. Creditors can take recourse to the safe and liquid assets in the recovery pool. On the one hand, compared to the benchmark model, this constitutes an improvement because the safe assets were not available to creditors in case of default beforehand. However, on the other hand, the safe assets lose some of their value as bankruptcy is costly. Hence, the additional creditors that lend to the bank so that the liquidity pool could have been built up would have been better off if they had invested into their outside option instead. By comparing the gains from providing a recovery pool to the 'old' creditors and the losses of the 'new' creditors from not having invested into the safe asset, it becomes evident that bankruptcy costs cause a loss for the creditors as a whole. The gains for the 'old' creditors are given by

$$\underbrace{\frac{1-\beta}{\beta}e}_{\text{benchmark debt level}} \times \underbrace{\frac{\nu m^*}{s^*}}_{\text{recovery share}},$$

whereas the losses for the additional 'new' creditors are

$$\underbrace{\left(s^* - \frac{1-\beta}{\beta}e\right)}_{\text{additional debt}} \times \underbrace{\left(1 - \frac{\nu m^*}{s^*}\right)}_{\text{relative loss due to bankruptcy}},$$

where s^* and m^* refer to the debt level and the liquidity holdings provided in Proposition 3.3. Subtracting the latter from the former yields an expression for the creditors' losses in the bad state compared to the benchmark model,

$$\frac{(1-\beta)e}{\beta} \times \frac{\gamma/q}{1-\gamma/q}(\nu - 1) < 0.$$

It can be seen that the loss arises only if the bankruptcy costs are positive, i.e. $\nu < 1$. Since creditors' *ex ante* expected return is the same as in the benchmark model, they need to be compensated for the loss in the bad state by receiving a higher share of the proceeds from the assets in the good state. Therefore, the payouts to equity owners have to be reduced in the good state. This explains why there may be projects that would have been undertaken in the benchmark model, but which do not satisfy condition (3.14) and accordingly the bank invests only its equity into these projects: The gains to equity owners from investing less (only equity) but receiving a larger share in the good state exceed the lower return on equity on the larger investments made possible by additional borrowing. The inefficiency due to the early (illiquidity) default is shifted from the rollover stage at date 1 to the borrowing choice of the bank at date 0. By insuring itself against illiquidity risk, the bank dilutes its equity owners' returns in the good state in order to make up the losses that creditors incur in the bad state due to bankruptcy costs. Hence, the inefficiency essentially stems from the simultaneous occurrence of illiquidity risk and bankruptcy costs. It is straightforward to show that whenever $\nu = 1$ (no bankruptcy costs) or $\gamma = 0$ (no illiquidity risk), condition (3.14) collapses to

$$qR \geq 1,$$

which is the condition required for borrowing in the benchmark model and which is satisfied by assumption.

It is obvious from Proposition 3.3 that liquidity regulation cannot improve this outcome. It is unnecessary to force the bank to obey a regulatory liquidity standard, because it fully insures against illiquidity risk out of its own accord. Moreover, liquidity regulation cannot eliminate the resulting inefficiency that is essentially created by the fact that bankruptcy is costly. What other ways are there to eliminate the illiquidity inefficiency?

3.4.3 Central bank intervention

The main reason behind the distortion described in Proposition 3.3 lies in the fact that the bank builds up a liquidity buffer to mitigate illiquidity risk whose value is pushed below face value at date 2 due to the existence of positive bankruptcy costs.

This is unavoidable because the bank cannot create the liquidity that it needs to mitigate illiquidity risk by itself, it has to borrow and it has to pay for it. In contrast, a central bank is endowed with the monopoly power to create legal tender and therefore it can create additional liquidity once this is needed. Therefore, suppose that a central bank exists in our model which offers an emergency liquidity facility at date 1. The bank can apply for liquidity assistance in case it is subject to a run. The central bank, however, grants liquidity assistance only with probability δ. Fund managers are aware of the possibility of central bank assistance. The assistance probability enters their expected payoff difference,

$$u^{\delta}(\theta) = \big(1-(1-\delta)p(\theta)\big)\, qB - C \;=\; \min\left\{\delta + (1-\delta)\frac{m+\theta(s+e-m)}{s}, 1\right\} qB - C. \quad (3.15)$$

Solving $u^{\delta}(\theta) = 0$ for the default point yields

$$\hat{\theta}^{\delta} = \begin{cases} \frac{\frac{\bar{\gamma}(\delta)}{q}s-m}{(s+e-m)} & \text{if } m < \frac{\bar{\gamma}(\delta)}{q}s \\ 0 & \text{if } m \geq \frac{\bar{\gamma}(\delta)}{q}s \end{cases} \quad (3.16)$$

where

$$\bar{\gamma}(\delta) \equiv \frac{\gamma - q\delta}{(1-\delta)} \qquad \text{with} \qquad \frac{\mathrm{d}\bar{\gamma}(\delta)}{\mathrm{d}\delta} < 0.$$

The bank's profit function and the interest rate parity condition in the presence of possible central bank intervention are given by

$$\Pi(y,m,s) = (1-\hat{\theta}^{\delta}(1-\delta))q\left(Ry + m - r_s s\right) + (1-q)\max\{m - r_s s, 0\}, \quad (3.17)$$

and

$$(1-q)\mathbf{1}_{[m>r_s s]} r_s + (1-q)(1-\hat{\theta}^{\delta}(1-\delta))(1-\mathbf{1}_{[m>r_s s]})\frac{vm}{s} \quad (3.18)$$

$$+\hat{\theta}^{\delta}(1-\delta)(1-\mathbf{1}_{[m>s]})\frac{vm}{s} + q(1-\hat{\theta}^{\delta}(1-\delta))r_s = 1. \quad (3.19)$$

The following Proposition shows how the bank chooses its borrowing and portfolio allocation in the presence of probabilistic emergency liquidity assistance by the central bank.

Proposition 3.4. *When the central bank provides emergency liquidity support at date* 1 *with probability* δ*, the bank borrows*

$$s^* = \frac{1-\beta}{\beta}\frac{1}{1-\bar{\gamma}(\delta)/q}e.$$

once the expected return on the risky project satisfies

$$qR \geq \frac{q(1-\bar{\gamma}(\delta)) - (1-q)v\bar{\gamma}(\delta)}{q-\bar{\gamma}(\delta)}, \quad (3.20)$$

The asset side of its balance sheet becomes

$$y^* = \frac{e}{\beta} \qquad \textit{and} \qquad m^* = \frac{1-\beta}{\beta}\frac{\bar{\gamma}(\delta)/q}{1-\bar{\gamma}(\delta)/q}e.$$

Thereby the bank sets $\hat{\theta} = 0$ *and perfectly insures itself against illiquidity risk. The interest rate is given by*

$$r_s^* = \frac{1 - \frac{v\bar{\gamma}(\delta)(1-q)}{q}}{q}$$

which satisfies $1 < r_s^* < q^{-1}$.

However, whenever the expected return satisfies

$$qR \in \left[1, \frac{q(1-\bar{\gamma}(\delta)) - (1-q)v\bar{\gamma}(\delta)}{q - \bar{\gamma}(\delta)}\right],$$

then the bank does not borrow at all, it does not hold any cash and only invests its equity into the risky asset.

Proof. Follows from the proof of Proposition 3.3 by replacing γ with $\bar{\gamma}(\delta)$. □

The central bank can completely eliminate the distortion by committing to a sufficiently high intervention probability ex ante.

Corollary 3.1. *By committing to the intervention probability*

$$\bar{\delta} \equiv \frac{\gamma}{q},$$

the central bank can fully remove illiquidity risk and inefficient investment decisions at date 0.

By intervening with probability $\bar{\delta}$, the central bank restores the outcome that was described in Proposition 3.1. This will lead to *higher* interest rates for the bank compared to the situation without central bank intervention in Proposition 3.3, yet the total interest costs for the bank will be lower and converge to the level from the benchmark model. This results from the fact that the bank reduces its liquidity buffer in response to the central bank's possible intervention. Since the liquid assets were the only assets to which creditors could resort at date 2 in case the bad state occurred, the lower liquidity buffer / recovery value implies that the interest rate must rise to meet creditors' interest rate parity condition. However, the overall debt burden for the bank is lower so that equity owners will prefer funding the risky project to the extent possible.[12]

[12]This can also be seen by taking the derivative of $\frac{q(1-\bar{\gamma}(\delta))-(1-q)v\bar{\gamma}(\delta)}{q-\bar{\gamma}(\delta)}$ with respect to δ. Since this decreases in δ, a higher intervention probability implies that the bank undertakes a larger range of positive net present values by using borrowed funds as well.

In practice, central banks are reluctant to provide facilities that completely eliminate illiquidity risk. The national central banks in the euro area can provide *emergency liquidity assistance* (ELA) to banks that otherwise have no eligible collateral, under a so–called *constructive ambiguity* approach. In our model, the probabilistic central bank intervention can be interpreted as akin to ELA provision, with the constructive ambiguity approach being reflected by the fact that the probability $\bar{\delta}$ is below unity. Even though central banks in practice may not fully eliminate illiquidity risk out of moral hazard concerns (an issue which is outside the scope of our model), we may argue that they are at least interested in eliminating illiquidity risk stemming from a coordination failure and the associated inefficiecies, as is reflected in the following quote from ECB (2006, p. 172),

> "One of the specific tools available to central banks in a crisis situation is the provision of emergency liquidity assistance (ELA) to individual banks. (...) This support may be warranted to *ease an institution's liquidity strains*, as well as to *prevent any potential systemic effects*, or (...) *disruption of the smooth functioning of payment and settlement systems* [emph. added]. However, the importance of ELA should not be overemphasized. Central bank support should not be seen as a primary means of ensuring financial stability, since it bears the risk of moral hazard. Furthermore, ELA rarely needs to be provided, and is thus less significant than other elements of the financial safety net, which have increased in importance in the management of crises."

Moreover, it should be noted that banks in practice are also reluctant to apply for central bank emergency facilities – e.g. ELA in the euro area or the US Federal Reserve's discount window – because of the stigma associated with it. Central banks in general neither publish whether liquidity assistance was approved nor any information about the recipients and the terms associated with it. Yet, market participants are usually able to figure out rather quickly that an emergency loan has been granted and which bank has received it. Since recourse to emergency facilities signals that neither market financing nor regular central bank funding is available for the respective bank, it conveys to the market not only the information that the bank faces strong liquidity tensions but may also create doubts about the solvency of the bank.

This may increase pressure on the bank whenever creditors withdraw because of the belief that the bank is insolvent, an issue which is outside the scope of the present model.

3.5 Model with Illiquidity Risk and Non–Transparent Balance Sheet

The previous section described a rather benign world. In particular, the assumption that creditors can directly react to the bank's balance sheet entails that the bank's choices and thus the risk inherent in its portfolio are properly reflected in the price of debt. This implies that it is optimal for the bank to fully ensure against illiquidity risk once it considers it profitable to borrow.

The inefficiency that arises from the combination of illiquidity risk and bankruptcy cost can be eliminated by the central bank through the provision of an emergency liquidity facility. Even if the central bank only commits to intervene with a certain probability, it obviates the creditor coordination problem and the illiquidity risk at date 1 without ever having to actually use its facility.

In this section, we abstain from the assumption that the bank's choices of y, m and s are directly observable by fund managers at date 0. This reflects the fact that bank balance sheets are rather opaque in practice and are usually published only with a quarterly frequency. Hence, wholesale lenders in financial and money markets cannot make their lending decisions contingent on the actual decisions of the bank. Rather, they use past balance sheet data or soft information (e.g. rumors among traders) in order to form beliefs about the bank's borrowing and investment behavior.

3.5.1 Notion of equilibrium

Instead of directly observing the bank's choices of y, m and s at date 0, fund managers / creditors form (identical) beliefs at date 0 about the bank's choices of y, m and s. The interest rate parity condition, which is no longer treated as a simple constraint in the bank's maximization problem, then yields the interest rate that the bank is charged conditional on the 'market's beliefs'. Denoting beliefs by y^e, m^e and s^e, the resulting *rational expectations equilibrium* at date 0 is defined as follows.

Definition. *A* **rational expectations equilibrium** *of the bank's borrowing and portfolio problem at date* 0 *is*

- *a triplet* $(y^{**}(r_s), m^{**}(r_s), s^{**}(r_s))$ *which, for a given interst rate* r_s*, maximizes the bank's profit function provided in equation* (3.12) *subject to the balance sheet constraint* (3.3)*, the default point defined in equation* (3.16)*, the equity requirement* (3.2) *and the equity owners' participation constraint* (3.6)*;*

- *a triplet of market beliefs* (y^e, m^e, s^e) *that yields an interest rate*

$$r_s = r_s(y^e, m^e, s^e)$$

  satisfying the interest rate parity condition (3.18)*;*

- *equilibrium–consistency of beliefs about* y*,* m *and* s*, i.e. fund managers' beliefs about equilibrium choices are consistent with the actual equilibrium choices of the bank. This may be expressed as a fixpoint of the map*

$$r_s = r_s(y^{**}(r_s), m^{**}(r_s), s^{**}(r_s)).$$

By virtue of rational expectations, in equilibrium, the fund managers again 'know' the bank's choices since they know the interest rate stated in their lending contracts as well as the bank's best reply functions. Knowledge of both enables them to 'calculate' the resulting optimal choices of the bank. As a consequence, the withdrawal game at date 1, which takes place after the date 0 equilibrium values are determined remains unaltered. Fund managers receive signals about θ and, given their knowledge about the equilibrium choices of the bank, decide whether to roll over or not. The bank's default point corresponds to the default point stated in Proposition 3.2 evaluated at the date–0–equilibrium values m^{**}, y^{**} and s^{**}. If fund managers decide to roll over, the bank continues until date 2 where its project is either successful with probability q, or defaults with converse probability. Otherwise, if they decide to withdraw, the bank fails due to illiquidity at date 1.

Since the equilibrium at the rollover stage still applies in the present variant of the model, we can immediately turn to the derivation of the equilibrium at date 0.

3.5.2 Derivation of date 0 equilibrium choices

We begin to derive the date 0 equilibrium by studying the bank's portfolio choice for a given interest rate r_s under the assumption that the bank borrows. Whether the bank will indeed borrow depends on the comparison between the expected returns from borrowing and not borrowing. We consider this issue in the subsequent section.

Firstly, we consider the bank's choice of liquidity holdings in line with our informal illustration of the bank's maximization problem as a three–stage process above. Similar to our findings in the previous section, the bank will never choose to hold liquidity in excess of what it needs to eliminate the illiquidity risk. However, in contrast to the previous section, it will not always be optimal to choose a liquidity buffer sufficiently large to fully obviate the risk of illiquidity.

Lemma 3.1. *If the bank borrows, its liquidity choice can be described by the function*

$$\hat{m}^{**} : (y, r_s) \mapsto m \in \left[0, \frac{\gamma(y-e)}{(q-\gamma)}\right]. \tag{3.21}$$

Proof. See appendix. □

Albeit the bank's choice of m may now be different and, at times, become more involved, its choice of y, in case it decides to borrow, is not altered compared to the model in the previous section.

Lemma 3.2. *If the bank borrows, then it always invests the maximal possible amount into the risky asset,*

$$y^{**} = \frac{e}{\beta}. \tag{3.22}$$

Proof. See appendix. □

Lemma 3.2 is quite helpful in reducing the complexity of the bank's portfolio problem. Suppose that the bank borrows, by Lemma 3.2, we must have $y^{**} = e/\beta$. Moreover, since the bank never holds liquidity when it does not borrow, we can use equation (3.21) to write the bank's liquidity choice as

$$\hat{m}^{**}(e/\beta, r_s) \equiv m^{**}(r_s).$$

The bank's optimal portfolio in response to the interest rate r_s demanded by creditors can therefore be characterized solely in terms of the optimal choice of m. As $m^{**}(r_s)$

strictly decreases in r_s and since the optimal m^{**} must be in the interval $[0, \frac{\gamma(1-\beta)e}{\beta(q-\gamma)}]$, we can characterize the bank's best reply function as follows.

Lemma 3.3. *There exist critical values $\underline{r}$ and $\overline{r}$, such that $\underline{r} < \overline{r}$ and*

$$m^{**}(r_s) = \begin{cases} 0 & \text{if } r_s \geq \overline{r} \\ \mu(r_s) & \text{if } r_s \in (\underline{r}, \overline{r}) \\ \frac{\gamma(1-\beta)}{\beta(q-\gamma)} & \text{if } r_s \leq \underline{r}, \end{cases} \tag{3.23}$$

where $\mu(r_s)$ is a continuous and strictly decreasing function.

Proof. See appendix. □

Secondly, consider the interest rate demanded by fund managers on behalf of creditors. Given beliefs y^e and m^e, we obtain the interest rate $r_s(y^e, m^e)$ from the interest rate parity condition (3.13). Using the fact that the fund managers know that the bank always invests $y^{**} = e/\beta$ whenever it decides to borrow, we can express the interest rate solely in terms of m^e,

$$r_s(e/\beta, m^e) \equiv r_s(m^e).$$

Lemma 3.4. *Given the belief m^e, the interest rate demanded by creditors is given by*

$$r_s(m^e) = \frac{1 - \frac{\nu m^e}{(1-\beta)e/\beta + m^e}}{q(1-\hat{\theta})} + \frac{\nu m^e}{(1-\beta)e/\beta + m^e}, \tag{3.24}$$

which is strictly decreasing in m^e.

Proof. See appendix. □

For future reference, we note that the interest rate becomes maximal whenever it is expected that the bank does not hold any liquid assets at all, i.e. if $m^e = 0$,

$$r_s(0) = \frac{1}{q - (1-\beta)\gamma},$$

while it is smallest whenever it is believed that the bank insures itself against illiquidity risk, i.e. if $m^e = (1-\beta)\gamma/\beta(q-\gamma)$,

$$r_s\left(\frac{\gamma(1-\beta)}{\beta(q-\gamma)}\right) = \frac{1 - \frac{\nu\gamma(1-q)}{q}}{q}.$$

In equilibrium, the market belief m^e and the bank's actual choice m^{**} have to be mutually consistent. The equilibrium can be characterized as a fixpoint of the composite function $r_s \circ m^{**}$,

$$r_s^{**} = m^{**}(r_s^{**}).$$

The following Proposition provides the resulting equilibrium values r^{**} and m^{**} under the assumption that the bank indeed borrows.

Proposition 3.5. *Suppose the bank considers it profitable to borrow. There exist threshold values $\underline{R}$ and $\overline{R}$ such that*

i) whenever

$$qR \geq \underline{R},$$

an equilibrium exists where the bank fully self–insures against illiquidity risk, thus

$$m^{**} = \frac{(1-\beta)\gamma}{\beta(q-\gamma)} \quad \text{and} \quad r_s^{**} = \frac{1 - \frac{\nu\gamma(1-q)}{q}}{q};$$

ii) whenever

$$qR \leq \overline{R},$$

an equilibrium exists where the bank does not hold cash, thus

$$m^{**} = 0 \quad \text{and} \quad r_s^{**} = \frac{1}{q-(1-\beta)\gamma};$$

iii) whenever $\underline{R} \neq \overline{R}$ and

$$qR \in \left(\min\{\underline{R}, \overline{R}\}, \max\{\underline{R}, \overline{R}\}\right)$$

an equilibrium exists where the bank partially insures itself against illiquidity risk, $m^{**} \in \left(0, (1-\beta)\gamma/\beta(q-\gamma)\right)$. The interest rate $r_s^{**} = r_s(m^{**})$ can be obtained from equation (3.24).

Proof. See appendix. □

It can already be gauged from the previous Proposition that the model exhibits regions of multiple equilibria, i.e. situations where the bank may either fully self–insure, partially insure or not insure at all, depending on the interest rate demanded by creditors.

Corollary 3.2. *There may be multiple equilibria whenever*

$$\underline{R} < \overline{R} \quad and \quad qR \in \left(\underline{R}, \overline{R}\right).$$

However, if $\overline{R} < \underline{R}$, the equilibria are unique.

Proof. Follows immediately from Proposition 3.5. □

3.5.3 The bank's borrowing decision

In the previous section, we determined the bank's portfolio choice and the interest rate under the assumption that the bank does borrow. This, however, requires that the expected profits from the respective choices exceed the profits that the bank could obtain by just investing its equity. We now turn to the comparison of the equity owner's profits under these two investment strategies. Similar to Proposition 3.3, we state the conditions under which the bank does borrow in terms of the expected return qR.

Proposition 3.6. *There exist threshold values $\{\hat{R}_s, \hat{R}_p, \hat{R}_n\}$ which are ordered, $1 \leq \hat{R}_s < \hat{R}_p \leq \hat{R}_n$, such that*

i) *whenever $qR \leq \hat{R}_s$, the bank refrains from borrowing and invests only equity;*

ii) *whenever $qR \in [\hat{R}_s, \hat{R}_p]$, borrowing and fully self–insuring against illiquidity risk is more profitable than just investing equity;*

iii) *whenever $qR \in [\hat{R}_p, \hat{R}_n]$, borrowing and fully self–insuring as well as borrowing and partially insuring against illiquidity risk are more profitable than just investing equity;*

iv) *whenever $qR \geq \hat{R}_n$, borrowing is generally more profitable than just investing equity, even when the bank does not insure against illiquidity risk.*

Proof. See appendix. □

3.5.4 Characterization of equilibria

Proposition 3.5 provides threshold values that divide the range of expected returns into distinct regions where different equilibria, i.e. different portfolio choices and interest rates, *can* occur. Yet, whether these equilibria *do* indeed occur, depends on whether the bank considers it more profitable to borrow than to just invest its equity, i.e. it depends on the threshold values provided in Proposition 3.6.

We provide a graphical characterization of the different equilibrium regions by plotting them in β–Rq–space, i.e. the space of equity requirement and expected returns. To this end, note that the thresholds $\underline{R}$ and $\overline{R}$ (from Proposition 3.5) are both strictly decreasing functions of the equity requirement β,

$$\underline{R} = \underline{R}(\beta) \quad \text{with } \underline{R}'(\beta) = -\frac{\left(1-\gamma-\frac{\nu\gamma(1-q)}{q}\right)}{1-\gamma/q} < 0$$

and

$$\overline{R} = \overline{R}(\beta) \quad \text{with } \overline{R}'(\beta) = -\frac{q(q-\gamma)}{q-(1-\beta)\gamma} - \gamma < 0.$$

By corollary 3.2, there may be regions with multiple equilibria for some β if and only if $\underline{R}(\beta) < \overline{R}(\beta)$. The following Lemma provides a condition in terms of β such that the curve $\underline{R}(\beta)$ lies below the curve $\overline{R}(\beta)$.

Proposition 3.7. $\underline{R}(\beta) \leq \overline{R}(\beta)$ *if and only if*

$$\beta^2 + \left(\phi - 1\right)\beta + \psi \geq 0, \tag{3.25}$$

where $\phi \equiv \frac{2\gamma(\tau+\gamma)-q\tau}{\gamma(1-\tau)}$, $\psi \equiv \frac{2(\gamma+\tau)(q-\gamma)}{\gamma(1-\tau)}$ *and* $\tau \equiv \frac{\nu\gamma(1-q)}{q} \in (0,1)$.

Proof. See appendix. □

Since the equity requirement β lies in the unit interval, and since ψ and $\phi+\psi$ are both positive,[13] it follows from equation (3.25) that at the boundaries, i.e. at $\beta = 0$ and $\beta = 1$, we have $\underline{R} < \overline{R}$ and therefore there may be multiple equilibria. If, in addition, $\phi > 1$, then condition (3.25) holds for all values of β in [0, 1] and for all possible equity requirements, there may be multiple equilibria.

[13]Using the definitions of ϕ and ψ, it is straightforward to calculate $\phi+\psi = \frac{2q(\gamma+\tau/2)}{\gamma(1-\tau)} > 0$.

Moreover, whenever the equation has complex roots, then again, there may be multiple equilibria, since no (real) root exists in the interval (0, 1).

However, if $\phi \in (-1, 1)$, then one may find parameter combinations where the parabola described by equation (3.25) cuts the abscissa twice (one time from above and one time from below) or may become tangent to it.

Finally, if $\phi < -1$, then the parabola cuts the abscissa outside the unit interval and thus $\underline{R} < \overline{R}$ for any $\beta \in [0,1]$. The following corollary summarizes the details.

Corollary 3.3. *i) If* $|\phi| > 1$*, then* $\underline{R} < \overline{R}$ *for all* $\beta \in [0, 1]$.

ii) If $\phi \in (-1, 1)$*, then equation* (3.25) *possesses two real roots in* $[0, 1]$ *if and only if* $\frac{(1-\phi)^2}{4} > \psi$.

Proof. See appendix. □

Figure 3.1 shows an example for the equilibrium regions in β–Rq–space.[14] Consider Panel (a) first. It depicts only the threshold values from Proposition 3.6 which separate the regions where it is most profitable to invest only equity (denoted by EI), where it is more profitable to borrow and to self–insure (denoted FI), where borrowing and full as well as partial insurance is more profitable than just investing equity (denoted PI) and finally where borrowing with or without insuring against illiquidity risk is more profitable than just investing equity (denoted by NI). Note that the critical threshold values $\hat{R}_s$ and $\hat{R}_n$ are *independent* of β, while the critical threshold $\hat{R}_p$ may depend either positively or negatively on β. Since it is of no material importance for the analysis which sign $\partial\hat{R}_p/\partial\beta$ takes on, we proceed under the assumption that $\hat{R}_p$ is increasing in β.

Next, consider Panel (b). There we inserted the curves $\underline{R}$ and $\overline{R}$ under the assumption that no switching in the curves occurs, for example in the case $\phi > 1$. For the sake of simplicity, also $\overline{R}$ is drawn as a straight line. It follows from Proposition (3.5) that to the left of $\overline{R}$, the bank may choose $m^{**} = 0$ in equilibrium. Moreover, for any points which also lie to the left of $\underline{R}$ and below $\hat{R}_n$, there is no equilibrium where the

[14]Corollary A3.4 in the appendix provides some relationships between the thresholds from Proposition 3.5 and those from Proposition 3.6 which are used in the diagram. We abstained from providing further examples of diagrams with different characteristics of the curves. Given the discussion above, these are straightforward to draw and yield no additional economic insight.

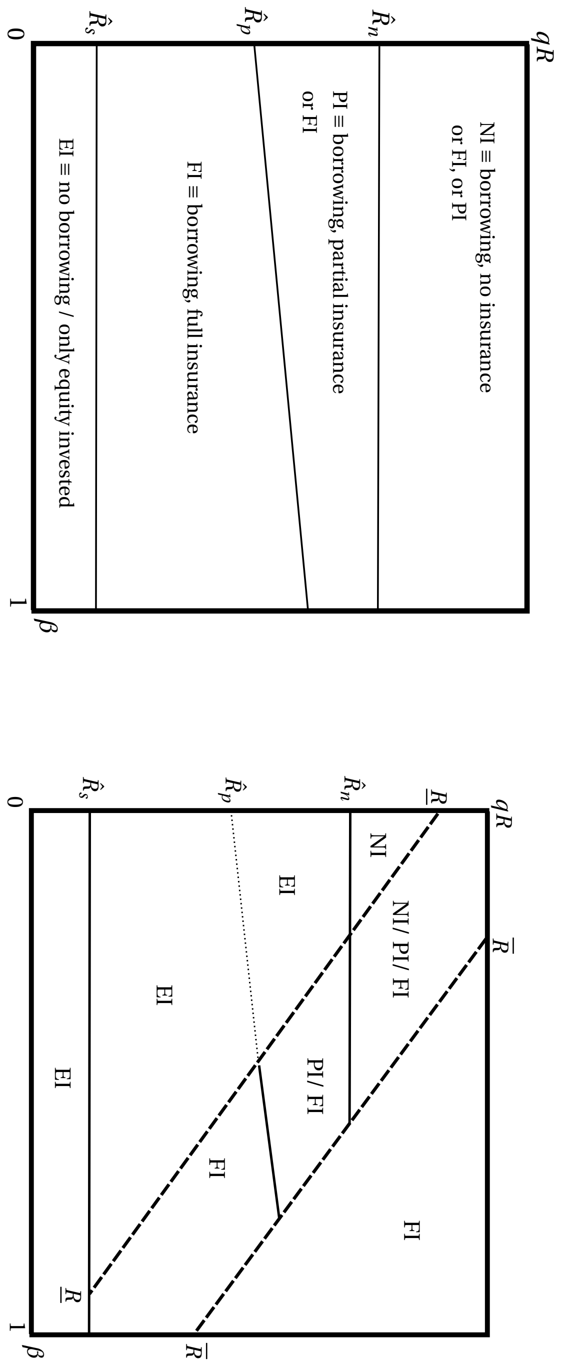
bank considers it profitable to borrow. Hence, in this region it will invest only its equity. However, if the expected return becomes sufficiently large and lies above $\hat{R}_n$, the bank considers it more profitable to borrow than to just invest its equity, even if it does not self–insure. Now consider points between the the curves $\underline{R}$ and $\overline{R}$. In this region, according to Proposition 3.5, multiple equilibria may exist. Yet, which equilibria actually occur depends on the profitability of the respective investment strategies. As creditors know the equity requirements β and the expected return qR, they also know which possible investment strategies are profitable for the bank. Between $\hat{R}_s$ and $\hat{R}_p$, the only profitable strategy is to fully self–insure and to borrow, hence creditors demand a low interest rate in this region and the bank builds up the liquidity buffer. If the expected return increases further above $\hat{R}_p$, also a partially–insuring buffer becomes profitable and once creditors believe that the bank would not fully insure, they would raise the interest rate, which, in the associated equilibrium, would indeed induce the bank to lower its liquid asset holdings. Above $\hat{R}_n$, it may even be profitable to abstain from holding any liquidity at all and whenever creditors believe the bank to incur illiquidity risk by not holding a buffer, they demand a high interest rate which makes the creation of the buffer too costly for the bank. Finally, for any points to the right of $\overline{R}$, only full insurance is an equilibrium and since this is also profitable in the whole region, the bank indeed self–insures and borrows. To summarize, the regions where the bank may actually default due to illiquidity are the regions above $\hat{R}_n$ and to the left of $\overline{R}$ as well as the region between $\hat{R}_p$ and $\hat{R}_n$ between $\underline{R}$ and $\overline{R}$. In all other regions, the bank either foregoes additional borrowing and underinvests as it only uses its equity, or borrows and eliminates illiquidity risk completely.

3.6 Policy Implications

By using the diagrammatic representation of the equilibrium regions in Figure 3.1, we can revisite the implications for different policy measures that may improve on the respective outcomes, i.e. that may help to eliminate illiquidity risk or to eliminate the inefficiency from underinvestment.

a) *Liquidity regulation.* In contrast to our previous results, liquidity regulation may now become useful whenever the combinations of β and qR are to the

Figure 3.1: Equilibria without switching of $\underline{R}$ and $\overline{R}$



Panel (a): Profitability regions in qR–β–space.

Panel (b): Equilibrium regions in qR–β–space.

right of $\underline{R}$. In such situations, forcing the bank to maintain a liquidity buffer, i.e. by adding the constraint $m \geq m^{\text{regulation}}$ to its maximization problem, provides a signal to creditors that ample liquidity is available and induces them to lower the interest rate. This in turn prompts the bank to borrow and build a liquidity buffer in order to eliminate illiquidity risk. The ratio of liquidity to short–term debt, sufficient to set $\hat{\theta} = 0$, is given by γ/q which is strictly smaller than unity.

Recall that the LCR–buffer required under the new Basel III regulatory standards would force the bank to keep a ratio of liquid assets to short–term debt of at least unity. In the present model, this would be suboptimal as it requires the bank to overinsure. What's more, this may induce the bank to refrain from additional borrowing because, as can be seen from the proof of Proposition 3.1 in the appendix, the bank would find it more profitable to invest only equity. Hence, a liquidity requirement *à la* LCR would indeed eliminate illiquidity risk, but mainly because it induces the bank to abstain from borrowing which makes holding a liquidity buffer redundant.

b) *Equity requirement.* So far, the only function of the equity requirement β was to ensure that the bank's balance sheet does not explode, given that we have assumed the expected payoffs from the risky asset to be linearly increasing in the amount invested. However, as can be seen from Figure 3.1, there may be an additional role for β. If β is rather small, the bank can take on a lot of debt and in this case it becomes rather expensive to insure against illiquidity risk. Therefore, in the presence of illiquidity risk, the bank either refrains from borrowing (investing only equity) or it borrows but does not hold any liquidity at all. If, however, β is sufficiently large, the bank cannot borrow that much and it may find maintenance of liquidity not prohibitively expensive so that it reduces illiquidity risk on its own accords. For example, a sufficiently large equity requirement that leads the bank to always maintain a liquidity buffer is given by any $\beta \geq \overline{\beta}$, where $\overline{\beta}$ solves $qR = \overline{R}$, i.e.

$$\overline{\beta} = 2 - \frac{q(R-1)(1-\gamma/q)}{1-\gamma-\nu\gamma(1-q)/q}.$$

An equity requirement of this order of magnitude ensures that all combinations of qR and β are always above the curve $\overline{R}$ where the bank always borrows and fully self–insures. Hence, equity and liquidity requirements are substitutes as the respective equity requirement makes the imposition of a liquidity requirement unnecessary. However, it has to be noted that although the equity requirement induces the bank to self–insure, it also limits investment in the risky asset. Hence, the inefficiency induced by illiquidity risk cannot be eliminated (in full).

c) *Emergency liquidity assistance by the central bank.* As pointed out in section 4.3, the most effective way to eliminate illiquidity risk is by having the central bank committing to intervene with a sufficiently high probability. The same logic applies also when the bank's balance sheet is not directly observable. The central bank's committment attacks the root cause of the problem. It essentially ensures creditors that the bank cannot become illiquid and thereby eliminates the strategic uncertainty that gave rise to the coordination problem in the first place.

   This is reminiscient of the *Bagehotian doctrine* that the central bank should in advance commit to emergency liquidity assistance in order to stall a banking panic,

   > "[i]f it is *known* [emph. added] that the Bank of England is freely advancing (...) the alarm of the solvent (...) bankers will be stayed", (Bagehot, 1873, p. 198)

   because

   > "[i]f possible, that alarm is best met by enabling those persons to pay their creditors to the very moment. For this purpose *only a little money is wanted* [emph. added]. If that alarm is not so met, it aggravates into a panic (...)." (Bagehot, 1873, p. 53)

3.7 Conclusion

In the present chapter, we have developed a stylized model of banking in the presence of illiquidity risk. We modeled illiquidity risk as the outcome of a coordination failure among creditors. Using techniques from the theory of global games, we solved for the unique threshold equilibrium and were thereby able to derive a closed–form expression for illiquidity risk in terms of the underlying balance sheet parameters. We then went on to solve for the bank's optimal borrowing and portfolio decision in order to provide insights into the following points (raised in the introduction): (a) under which circumstances does liquidity 'underinsurance' occur, so that liquidity regulation is necessarily required; (b) whether liquidity regulation in such situations would indeed be the most efficient way to solve the funding problems and mitigate potential inefficiencies stemming from underinsurance, and (c) how liquidity regulation interacts with other regulatory measures and the liquidity provision undertaken by the central bank.

With respect to (a), we found that whenever the bank's creditors can directly observe its choices, the bank always maintains a liquidity buffer and fully eliminates illiquidity risk. However, this may not be true whenever the borrowing and portfolio choices by the bank are not directly observable. In the latter case, there may be, under certain parameter combinations, a role for liquidity requirements. These then serve as a coordination device that signal to creditors the availability of sufficient liquidity, which in turn leads them to lower their interest rate, which makes borrowing and maintaining the liquidity buffer indeed the most profitable option for the bank. However, with respect to points (b) and (c), eliminating the illiquidity risk by keeping a liquidity buffer does not implement the efficient benchmark in case that bankruptcy is costly, since there may be investment projects with positive net present value which are not financed to the full extent but only by investing equity. The inefficiency due to illiquidity was 'shifted' from date 1 to date 0. We then pointed out that the commitment of the central bank to intervene with a certain probability can fully eliminate the strategic uncertainty among fund managers and leads them to rollover in any case. As a consequence, the bank would not need to keep a liquidity buffer and would invest in all projects with positive net present value. Hence, illiquidity risk due to a coordination failure and the associated inefficiency can be eliminated without ever using the respective central bank facilities. Moreover, this holds in both cases, either when the bank's choices were directly observable or not. In the latter case, a substitute for liquidity regulation was found to be a sufficiently large equity requirement which induces the bank to borrow and self–insure.

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Appendix

Proof of Proposition 3.1. In the first step we show that for any given y, the bank never holds liquidity. In the second step we show that if the bank borrows, it finds it optimal to invest as much into the risky asset its equity allows. The borrowed amount is thereby determined as the balance sheet residual. Finally we check that this choice is strictly better than to invest equity only.

First note that if the bank decides not to borrow, then it does not keep any liquidity. In the absence of borrowing, its profits would be given by $qR(e-m)+m$ which is decreasing in m due to equation (3.1). Next, suppose that the bank borrows and keeps liquidity m' so as to redeem its debt even in the bad state, $m' > r_s s'$. The latter inequality implies from equation (3.5) $r_s = 1$. In this case, the bank would be better off by not borrowing at all because

$$\begin{aligned}
&\Pi(e,0,0) \geq \Pi(y',m',s') \\
\Leftrightarrow\ & qRe \geq qRy' + m' - s' \\
\Leftrightarrow\ & qRe \geq qRy' + m' - (y' + m' - e) \\
\Leftrightarrow\ & qRe - e \geq qRy' - y',
\end{aligned}$$

where the last line is a consequence of equation (3.1) and, since $r_s = 1$,

$$m' > r_s s' \Leftrightarrow m' > (y' + m' - e) \Leftrightarrow e > y'.$$

Hence, if the bank borrows then its liquidity holdings must satisfy $m < r_s s$. We can write the interest rate in this case as

$$r_s = \frac{1-(1-q)\frac{vm}{s}}{q}.$$

Plugging the interest rate and the balance sheet identity into the profit function yields expected profits,

$$\Pi(y,m,y+m-e) = qRy + qm + (1-q)vm - (y+m-e).$$

The derivative with respect to m is given by

$$q + (1-q)v - 1 < 0.$$

Hence, profits are decreasing in m for any given y and the optimal choice becomes $m^* = 0$.

Next, observe that due to equation (3.1), profits are increasing in y. Therefore, the bank's optimal choice (if it borrows) is given by $y^* = e/\beta$. This implies that the bank borrows $s^* = y^* - e = (1-\beta)e/\beta$.

Finally, it is straightforward to check that because of equation (3.1), the bank never prefers to just invest its equity compared with investing y^* and borrowing s^*,

$$\Pi(y^*, 0, s^*) \geq \Pi(e, 0, 0) \Leftrightarrow qR \geq 1.$$

□

Proof of Proposition 3.2. We show that for any given parameter combination, there exists exactly one pair $(\hat{x}, \hat{\theta})$ that satisfies equations (3.8) and (3.9) simultaneously.

Suppose first that $\hat{\theta} \in (0, 1)$. Since $\mathbf{Pr}\left(\theta > \hat{\theta} \middle| x_i\right)$ is continuously increasing in x_i and as $\gamma/q < 1$, equation (3.9) implies that there exists a unique $\hat{x} \in [\hat{\theta} \pm \varepsilon]$ such that

$$\frac{\hat{x} - \hat{\theta} + \varepsilon}{2\varepsilon} = \gamma/q. \tag{A3.1}$$

In turn, this implies that $\mathbf{Pr}(x_i < \hat{x}|\theta) \equiv \hat{p} \in (0, 1)$. To see this, suppose towards a contradiction that $\hat{p} = 1$, which requires $\hat{x} = 1 + \varepsilon$ and implies, from equation (3.8), $\hat{\theta} = \frac{y-e}{y} \in (0, 1)$. Yet, we just showed that for $\hat{\theta} \in (0, 1)$, $\hat{x}$ is given by equation (A3.1), i.e.

$$\hat{x} = \frac{y - e}{y} - \varepsilon + 2\varepsilon\gamma/q.$$

But the latter is strictly smaller than $1 + \varepsilon$, thus a contradiction.

Moreover, if $\hat{p} = 0$, then by equation (3.8), $\hat{\theta} = 0$, which contradicts the assumption that $\hat{\theta} \in (0, 1)$. Therefore $\hat{p} \in (0, 1)$.

Then, from equation (3.8),

$$\frac{\hat{x} - \hat{\theta} + \varepsilon}{2\varepsilon} s = m + \hat{\theta} y,$$

which we can solve for

$$\hat{\theta} = \frac{\frac{\gamma}{q} s - m}{y},$$

which satisfies the assumption that $\hat{\theta} \in (0, 1)$ if and only if $m < \frac{\gamma}{q} s$. The corresponding $\hat{x}$ for this case can be obtained from equation (A3.1). If the converse holds, $m \geq \frac{\gamma}{q} s$, then $\hat{\theta} = 0$. To see this, note that the inequality in equation (3.8) is in this case satisfied for all $\theta \in [0, 1]$. Thus, we must have $\hat{\theta} = 0$. The corresponding $\hat{x}$ is given by $-\varepsilon$.

□

Proof of Proposition 3.3. We proceeds as in the proof of Proposition 3.1. First we derive optimal liquidity holdings for given investment levels y. Then we consider the choice of y. Taken together, the two steps give three candidate tuples of choices (y^*, m^*) which we compare with each other to obtain under which conditions they are indeed optimal. The amount borrowed is again determined as the balance sheet residual.

Firstly, note that the only reason for the bank to keep liquidity is to mitigate liquidity risk. By the same argument as in the proof of Proposition 3.1, the bank would not keep any liquidity at all if it were not borrowing at all, i.e. $s^* = 0 \Rightarrow m^* = 0$.

Next, suppose that the bank borrows and that it keeps liquidity $m' \geq r_s s$. As $r_s \geq 1 \geq \gamma/q$, this implies that $\hat{\theta} = 0$. Again, along the lines of the proof of Proposition 3.1, we can conclude that this allocation is always dominated by not borrowing at all. Thus, if the bank does borrow and holds liquidity, we must have $m^* < r_s s^*$. From equation (3.13), we write the interest rate as

$$r_s = \frac{1 - \frac{vm}{s}\left(1 - q(1 - \hat{\theta})\right)}{q(1 - \hat{\theta})}.$$

Substituting the latter and the balance sheet constraint into the profit function (3.12) yields

$$\Pi(y,m,y+m-e) = q(1-\hat{\theta})\left(Ry+m\right)-(y+m-e)+\nu m\left(1-q(1-\hat{\theta})\right).$$

By taking the balance sheet constraint into account and substituting $s = y+m-e$, we can write the default point as

$$\hat{\theta}(m,\,y) = \begin{cases} \frac{\frac{\gamma}{q}(y-e)-(1-\frac{\gamma}{q})m}{y} & \text{if } m < \frac{\gamma(y-e)}{q-\gamma}, \\ 0 & \text{if } m > \frac{\gamma(y-e)}{q-\gamma}. \end{cases}$$

The default point is continuous but not everywhere differentiable since the derivatives with respect to m and y are not defined at the point $m = \frac{\gamma(y-e)}{q-\gamma}$. The derivative with respect to m is given by

$$\hat{\theta}_m = \begin{cases} -\frac{1-\frac{\gamma}{q}}{y} & \text{if } m < \frac{\gamma(y-e)}{q-\gamma}, \\ 0 & \text{if } m \geq \frac{\gamma(y-e)}{q-\gamma}. \end{cases}$$

The derivative of the profit function with respect to m can be written as

$$\Pi_m = q(1-\hat{\theta}) - q\hat{\theta}_m\left(Ry+m\right)-1+\nu\left(1-q(1-\hat{\theta})\right)+\nu q m\hat{\theta}_m,$$

which is negative for any $m \geq \frac{\gamma(y-e)}{q-\gamma}$,

$$\Pi_m = (1-q)(\nu-1) < 0.$$

As the profit function is decreasing in m for $m > \frac{\gamma(y-e)}{q-\gamma}$, any optimal choice m^* must therefore lie in the interval $[0, \frac{\gamma(y-e)}{q-\gamma}]$.

For $m \in [0, \frac{\gamma(y-e)}{q-\gamma}]$, the profit function is convex in m,

$$\Pi_{mm} = -2q\frac{\partial\hat{\theta}}{\partial m}(1-\nu) > 0,$$

where we have used that $\hat{\theta}_{mm} = 0$.

For any given investment choice y, the bank will thus either choose $m^* = 0$ or $m^* = \frac{\gamma(y-e)}{q-\gamma}$.

Secondly, the default point is increasing and concave in y for $m \in [0, \frac{\gamma(y-e)}{q-\gamma}]$,

$$\hat{\theta}_y = \begin{cases} \frac{\frac{\gamma}{q}e+(1-\frac{\gamma}{q})m}{y^2} & \text{if } m < \frac{\gamma(y-e)}{q-\gamma}, \\ 0 & \text{if } m > \frac{\gamma(y-e)}{q-\gamma}, \end{cases}$$

and

$$\hat{\theta}_{yy} = \begin{cases} -\frac{2\hat{\theta}_y}{y} & \text{if } m < \frac{\gamma(y-e)}{q-\gamma}, \\ 0 & \text{if } m > \frac{\gamma(y-e)}{q-\gamma}. \end{cases}$$

Concavity of $\hat{\theta}$ in y causes the profit function to become convex in y for any m,

$$\Pi_{yy} = 2\hat{\theta}_y(1-\nu)q\frac{m}{y} \geq 0.$$

This implies that the bank choose the corner points. Either it abstains from additional borrowing and only invests equity, $y^* = e$ or it chooses the maximal amount that its equity requirement allows, $y^* = e/\beta$.

Taken together, we obtain the following tuples of candidate choices ($y^* = e$, $m^* = 0$), ($y^* = e/\beta$, $m^* = 0$) and ($y^* = e/\beta$, $m^* = \frac{\gamma(y^*-e)}{q-\gamma}$).

Thirdly, we mutually compare the three candidate tuples. Observe that ($y^* = e$, $m^* = 0$) leads to a higher profit than ($y^* = e/\beta$, $m^* = 0$) if and only if

$$\Pi(e, 0, 0) > \Pi\left(\frac{e}{\beta}, 0, \frac{1-\beta}{\beta}e\right),$$

which is equivalent to

$$qR < \frac{1}{1-\frac{\gamma}{q}}. \tag{A3.2}$$

Furthermore, the bank prefers ($y^* = e/\beta$, $m^* = \frac{\gamma(y^*-e)}{q-\gamma}$) over ($y^* = e/\beta$, $m^* = 0$) if and only if

$$\Pi\left(\frac{e}{\beta}, \frac{\frac{\gamma}{q}(1-\beta)e}{\beta(1-\frac{\gamma}{q})}, \frac{(1-\beta)e}{\beta(1-\frac{\gamma}{q})}\right) > \Pi\left(\frac{e}{\beta}, 0, \frac{1-\beta}{\beta}e\right),$$

which is equivalent to

$$qR > \frac{(1-\nu)(1-q)}{1-\frac{\gamma}{q}}. \tag{A3.3}$$

Since $(1-\nu)(1-q) < 1$, the right–hand side of equation (A3.2) is strictly larger than the right–hand side of (A3.3). This implies that we can rule out ($y^* = e/\beta$, $m^* = 0$), i.e. the bank never borrows without also keeping a positive liquidity balance. We finally check under which condition it prefers to borrow and to keep a liquidity buffer by comparing ($y^* = e$, $m^* = 0$) with ($y^* = e/\beta$, $m^* = \frac{\gamma(y^*-e)}{q-\gamma}$).

$$\Pi\left(\frac{e}{\beta}, \frac{\frac{\gamma}{q}(1-\beta)e}{\beta(1-\frac{\gamma}{q})}, \frac{(1-\beta)e}{\beta(1-\frac{\gamma}{q})}\right) \geq \Pi(e, 0, 0)$$

which is equivalent to

$$qR \geq \frac{q(1-\gamma)-(1-q)\nu\gamma}{q-\gamma}.$$

Taken together, the bank prefers to just invest its equity whenever $qR < \frac{q(1-\gamma)-(1-q)\nu\gamma}{q-\gamma}$ and it borrows and keeps a positive liquidity balance once the reverse inequality holds. Since

$$\frac{q(1-\gamma)-(1-q)\nu\gamma}{q-\gamma} \geq 1,$$

there are projects with positive NPV, i.e. $qR \geq 1$ which are only financed by equity and not to the full extent possible. □

Proof of Lemma 3.1. The proof is as follows. First, Claim A3.1 shows that we can restrict ourselves to values $m \leq \frac{\gamma(y-e)}{q-\gamma}$. Secondly, Claim A3.2 shows that the profit function is concave in m over the relevant interval, implying that there may exist an interior solution. Finally, we use these claims to derive the function $\hat{m}^{**}$.

Claim A3.1. *The bank does not keep liquidity in excess of* $\frac{\gamma(y-e)}{q-\gamma}$.

Proof of Claim A3.1. We use the balance sheet constraint to substitute out $s = y+m-e$ from the profit function. For a given interest rate r_s, the profit function can then be written as

$$\Pi(y,m,y+m-e) = q(1-\hat{\theta})\left(Ry+m-r_s(y+m-e)\right) + (1-q)\max\{m-r_s(y+m-e),0\}.$$

The derivative with respect to m is given by

$$\Pi_m = q(1-\hat{\theta})(1-r_s) - \hat{\theta}_m q\left(Ry+m-r_s(y+m-e)\right) + (1-q)(1-r_s)\mathbf{1}_{[m>r_s(y+m-e)]}.$$

For any $m > \frac{\gamma(y-e)}{q-\gamma}$, we have

$$\Pi_m = q(1-r_s) + (1-q)(1-r_s)\mathbf{1}_{[m>r_s(y+m-e)]} \leq 0$$

since r_s is bounded below by 1. This implies that the bank will never keep liquidity in excess of $\frac{\gamma(y-e)}{q-\gamma}$.

□

Claim A3.2. *The profit function is concave in m for* $m \in \left[0, \frac{\gamma(y-e)}{q-\gamma}\right]$.

Proof of Claim A3.2. By virtue of Claim A3.1, we can restrict attention to the interval $\left[0, \frac{\gamma(y-e)}{q-\gamma}\right]$. The second derivative of the profit function with respect to m is given by

$$\Pi_{mm} = -2q(1-r_s)\hat{\theta}_m - \hat{\theta}_{mm} q\left(Ry+m-r_s(y+m-e)\right),$$

which, by using $\hat{\theta}_{mm} = 0$ (see proof of Proposition 3.3), simplifies to

$$\Pi_{mm} = -2q(1-r_s)\hat{\theta}_m \leq 0,$$

since $r_s \geq 1$. □

Since Π is concave in m over the relevant range, the optimum may be an interior point.[15] Clearly, if the bank chooses an optimal level of liquidity holdings $m^{**} \in \left(0, \frac{\gamma(y-e)}{q-\gamma}\right)$, then m^{**} solves $\Pi_m = 0$. concretely, the solution to $\Pi_m = 0$ is given by

$$\mu(y, r_s) = \frac{1}{2}\left(\left(\frac{R-r_s}{r_s-1} - 1\right)y + \frac{r_s e}{r_s-1} - \frac{\gamma e}{q-\gamma}\right). \tag{A3.4}$$

The function describing the bank's optimal liquidity holdings can then be written as

$$\hat{m}^{**}(y, r_s) = \begin{cases} 0, & \text{if } \mu(y, r_s) \leq 0 \\ \mu(y, r_s), & \text{if } \mu(y, r_s) \in \left(0, \frac{\gamma(y-e)}{q-\gamma}\right) \\ \frac{\gamma(y-e)}{q-\gamma}, & \text{if } \mu(y, r_s) \geq \frac{\gamma(y-e)}{q-\gamma} \end{cases} \tag{A3.5}$$

□

[15] Note that the profit function is no longer convex as r_s is not substituted out anymore.

Proof of Lemma 3.2. We prove the Lemma by firstly deriving a condition for the profit function to be convex in y in Claim A3.3. Secondly, we use this condition to show that for any possible choice of m^{**} (provided in equation (A3.5)), the profit function is convex for any $y \in (e, e/\beta)$. This implies that no point in the interval $(e, e/\beta)$ can constitute a maximum. Thus, the only candidates for the optimal y^{**} are either e (in which case the bank would not borrow at all) or e/β (in which case the bank would borrow at much as its equity allows).

Claim A3.3. *The profit function is convex in y if and only if*

$$\frac{r_s}{r_s-1}e > m.$$

It is concave if the reverse inequality holds.

Proof of Claim A3.3. The first derivative of the profit function with respect to y is given by

$$\Pi_y = -q\hat{\theta}_y(Ry+m-r_s(y+m-e)) + (1-\hat{\theta})q(R-r_s), \tag{A3.6}$$

and the second derivative with respect to y is then given by

$$\Pi_{yy} = -2\hat{\theta}_y q(R-r_s) - \hat{\theta}_{yy} q\left(Ry+m-r_s(y+m-e)\right).$$

From the proof of Proposition 3.4 we have for $m \in [0, \frac{\gamma(y-e)}{q-\gamma}]$,

$$\hat{\theta}_{yy} = -\frac{2\hat{\theta}_y}{y},$$

which we can use to write

$$\begin{aligned}\Pi_{yy} &= -2\hat{\theta}_y q(R-r_s) + \frac{2\hat{\theta}_y q}{y}\left(Ry+m-r_s(y+m-e)\right)\\ &= -2\hat{\theta}_y q(R-r_s) + 2\hat{\theta}_y q(R-r_s) + \frac{2\hat{\theta}_y q}{y}(m-r_s(m-e))\\ &= \frac{2\hat{\theta}_y q}{y}(m(1-r_s)+r_s e).\end{aligned}$$

Since $\hat{\theta}_y > 0$, the latter implies

$$\Pi_{yy} \gtreqless 0 \Leftrightarrow \frac{r_s e}{r_s-1} \gtreqless m.$$

□

Using the condition provided in Claim A3.3, we now show that the profit function is convex for all $y \in (e, e/\beta)$ given any choice of m^{**}.

Suppose first that the bank chooses to hold no liquidity, $m^{**} = 0$. Since $e > 0$, it follows from Claim A3.3 that the profit function is convex in y, so no $y^{**} \in (e, \frac{e}{\beta})$ can constitute a profit maximum.

Next, consider the case where the bank chooses the maximal liquidity buffer $m^{max} = \frac{\gamma(y-e)}{q-\gamma}$. We evaluate the derivative of the profit function at m^{max}. Observe that

$$\lim_{m \nearrow m^{max}} \hat{\theta}_y = \frac{\gamma}{qy} \quad \text{and} \quad \lim_{m \nearrow m^{max}} (1-\hat{\theta}) = 1.$$

As the profit function is not differentiable at $m = m^{max}$, we evaluate Π_y by taking the limit from below,

$$\lim_{m \nearrow m^{max}} \Pi_y = (q-\gamma)(R-r_s) - \frac{\gamma}{y}\left(er_s - (r_s-1)m^{max}\right).$$

Clearly, if the latter is strictly positive, then the bank never chooses an interior investment $y^{**} \in (e, e/\beta)$. Since $q > \gamma$ and $R \geq r_s$, the derivative is strictly positive if $m^{max} > \frac{r_s e}{r_s-1}$. If the reverse inequality holds, there may be an interior point y that solves $\Pi_y = 0$. However, by Lemma A3.3, the inequality $m^{max} < \frac{r_s e}{r_s-1}$ implies that the profit function is convex and the respective interior point could not constitute a maximum.

Finally, we turn to the case where the bank keeps a liquidity buffer $\mu(y) \leq m^{max}$. From Lemma 3.1, we have

$$\mu(y) = \frac{1}{2}\left(\left(\frac{R-r_s}{r_s-1} - 1\right)y + \frac{r_s e}{r_s-1} - \frac{\gamma e}{q-\gamma}\right).$$

Moreover, by using the explicit expressions for $\hat{\theta}$ and $\hat{\theta}_y$ from the proof of Proposition 3.3, we can write the first–order necessary condition for y as

$$\Pi_y = (q-\gamma)(R-r_s)y^2 - (\gamma e + (q-\gamma)m)(r_s e - (r_s-1)m) = 0. \tag{A3.7}$$

We evaluate Π_y at $m = \mu(y)$.

To this end, observe that we can write

$$\gamma e + (q-\gamma)\mu(y) = \frac{(q-\gamma)}{2}\left(\left(\frac{R-r_s}{r_s-1} - 1\right)y + \frac{r_s e}{r_s-1} + \frac{\gamma e}{q-\gamma}\right), \tag{A3.8}$$

and

$$r_s e - (r_s-1)\mu(y) = \frac{(r_s-1)}{2}\left(\frac{r_s e}{r_s-1} + \frac{\gamma e}{q-\gamma} - \left(\frac{R-r_s}{r_s-1} - 1\right)y\right). \tag{A3.9}$$

By using equations (A3.8) and (A3.9), we obtain

$$\begin{aligned}
&\left(\gamma e + (q-\gamma)\mu(y)\right)\left(r_s e - (r_s-1)\mu(y)\right) \\
&= \frac{(q-\gamma)(r_s-1)}{4}\left(\left(\frac{R-r_s}{r_s-1} - 1\right)y + \frac{r_s e}{r_s-1} + \frac{\gamma e}{q-\gamma}\right) \\
&\times \left(\frac{r_s e}{r_s-1} + \frac{\gamma e}{q-\gamma} - \left(\frac{R-r_s}{r_s-1} - 1\right)y\right) \\
&= \frac{(q-\gamma)(r_s-1)}{4}\left[\left(\frac{r_s e}{r_s-1} + \frac{\gamma e}{q-\gamma}\right)^2 - \left(\frac{R-r_s}{r_s-1} - 1\right)^2 y^2\right].
\end{aligned} \tag{A3.10}$$

Plugging equation (A3.10) into (A3.7) yields

$$(q-\gamma)(R-r_s)y^2 = \frac{(q-\gamma)(r_s-1)}{4}\left[\left(\frac{r_s e}{r_s-1} + \frac{\gamma e}{q-\gamma}\right)^2 - \left(\frac{R-r_s}{r_s-1} - 1\right)^2 y^2\right].$$

Rearranging yields

$$\left(\frac{(R-r_s)}{r_s-1}+\frac{1}{4}\left(\frac{R-r_s}{r_s-1}-1\right)^2\right)y^2=\frac{1}{4}\left(\frac{r_se}{r_s-1}+\frac{\gamma e}{q-\gamma}\right)^2.$$

By using the fact that $a+\frac{(a-1)^2}{4}=\frac{(a+1)^2}{4}$, we can simplify the left–hand side and rewrite the latter equation as

$$\frac{1}{4}\left(\frac{R-1}{r_s-1}\right)^2 y^2=\frac{1}{4}\left(\frac{r_se}{r_s-1}+\frac{\gamma e}{q-\gamma}\right)^2.$$

Since $y>0$, we can disregard the negative root and obtain, after collecting terms and simplifying,

$$y_l=\frac{r_s-\frac{\gamma}{q}}{(1-\frac{\gamma}{q})(R-1)}e.$$

We are now going to show that $\mu(y_l)<\frac{r_se}{r_s-1}$. By Claim A3.3, this implies that the profit function is convex in y at the point $(\mu,\, y_l)$ and thus y_l cannot constitute a maximum.

$$\begin{aligned}
&\mu(y_l) < \frac{r_se}{r_s-1}\\
\Leftrightarrow\ &\frac{1}{2}\left(\left(\frac{R-r_s}{r_s-1}-1\right)y-\frac{\gamma e}{q-\gamma}\right) < \frac{1}{2}\frac{r_se}{r_s-1}\\
\Leftrightarrow\ &\frac{1}{2}\left(\left(\frac{R-r_s}{r_s-1}-1\right)y-\frac{\gamma e}{q-\gamma}-\frac{r_se}{r_s-1}\right) < 0.
\end{aligned}\tag{A3.11}$$

We distinguish between two cases. Firstly, suppose that $R-r_s<r_s-1$. It can be easily verified that inequality (A3.11) is satisfied for any y. Secondly, suppose that $R-r_s>r_s-1$ and substitute y_l for y into (A3.11). This gives

$$\begin{aligned}
&\left(\frac{R-r_s}{r_s-1}-1\right)y_l < \left(\frac{\gamma}{q-\gamma}+\frac{r_s}{r_s-1}\right)e\\
\Leftrightarrow\ &\frac{r_s-\frac{\gamma}{q}}{(1-\frac{\gamma}{q})(R-1)}e < \frac{r_s-\frac{\gamma}{q}}{(1-\frac{\gamma}{q})(r_s-1)}\frac{(r_s-1)}{R-2r_s+1}e\\
\Leftrightarrow\ &\frac{1}{R-1} < \frac{1}{R-2r_s+1}\\
\Leftrightarrow\ &1 < r_s.
\end{aligned}$$

The latter is satisfied since r_s is bounded below by unity. Hence, when evaluated at $(\mu,\, y_l)$, the profit function is convex in y and therefore y_l cannot constitute a maximum. We have thus established that for any possible liquidity buffer m^{**}, the bank will never choose any $y\in(e, e/\beta)$. The bank either chooses $y^{**}=e$ and does not borrow at all, or it borrows and invests $y^{**}=e/\beta$. □

Proof of Lemma 3.3. It follows from Lemma 3.2 that if the bank borrows, then it invests $y^{**}=e/\beta$. From Lemma 3.1 follows

$$m^{**}(r_s)\equiv\hat{m}^{**}(e/\beta,\, r_s)=\begin{cases}0, & \text{if } \mu(e/\beta,\, r_s)\le 0,\\ \mu(e/\beta,\, r_s), & \text{if } \mu(e\beta,\, r_s)\in\left(0,\, \frac{\gamma(y-e)}{q-\gamma}\right),\\ \frac{\gamma(1-\beta)e}{\beta(q-\gamma)}, & \text{if } \mu(e\beta,\, r_s)\ge\frac{\gamma(1-\beta)e}{\beta(q-\gamma)}.\end{cases}$$

Observe that $\mu(r_s)$ is strictly decreasing in r_s,

$$\mu'(r_s) = \frac{e}{2}\left(\frac{\frac{(1-R)}{\beta}-1}{(r_s-1)^2}\right) < 0.$$

Hence, there exist $\overline{r}$ such that

$$\mu(r_s) \leq 0 \quad \forall\, r_s \geq \overline{r},$$

and $\underline{r}$ such that

$$\mu(r_s) \geq \frac{(1-\beta)\gamma}{\beta(q-\gamma)} \quad \forall\, r_s \leq \underline{r}.$$

We can explicitly calculate

$$\underline{r} = \frac{(q-\gamma)(R+1)+\gamma(2-\beta)}{q(2-\beta)}$$

and

$$\overline{r} = \frac{(q-\gamma)(R+1)+\beta\gamma}{(q-\gamma)(2-\beta)+\beta\gamma}.$$

Note that $\underline{r} < \overline{r} \Leftrightarrow (R+1) > 2-\beta$, which is satisfied since $R > 1$ and $\beta \in [0, 1]$. □

Proof of Lemma 3.4. By Claim A3.1, we can rule out cases where $m^e > \frac{\gamma(y^e-e)}{q-\gamma}$. We can thus solve equation (3.13) for r_s and use Lemma 3.2 to replace y^e by e/β and the balance sheet constraint to substitute out s by $y^e + m^e - e$. The interest rate demanded by creditors can then be written in terms of m^e as

$$r_s(m^e) = \frac{1-\frac{\nu m^e}{(1-\beta)e/\beta+m^e}}{q(1-\hat{\theta})} + \frac{\nu m^e}{(1-\beta)e/\beta+m^e}. \tag{A3.12}$$

r_s is decreasing in m^e. Note that

$$\frac{\partial}{\partial m^e}\left(\frac{\nu m^e}{(1-\beta)e/\beta+m^e}\right) = \frac{\nu(1-\beta)e/\beta}{((1-\beta)e/\beta+m^e)^2} > 0,$$

and $-\hat{\theta}_{m^e} > 0$. Thus,

$$\frac{\mathrm{d}r_s}{\mathrm{d}m^e} = \left(1-\frac{1}{q(1-\hat{\theta})}\right)\frac{\nu(1-\beta)e/\beta}{((1-\beta)e/\beta+m^e)^2} + \frac{(1-\frac{\nu m^e}{(1-\beta)e/\beta+m^e})\hat{\theta}_{m^e}}{(q(1-\hat{\theta}))^2} < 0.$$

□

Proof of Proposition 3.5. The threshold values $\underline{R}$ and $\overline{R}$ are derived by intersecting best reply functions of bank and creditors. From Lemma 3.3, we have that the bank keeps no liquidity if and only if $r_s \geq \overline{r}$. Using the creditors' interest rate from equation (A3.12), we have

$$r_s(0) = \frac{1}{q-(1-\beta)\gamma} \geq \frac{(q-\gamma)(R+1)+\beta\gamma}{(q-\gamma)(2-\beta)+\beta\gamma} = \overline{r},$$

which is equivalent to

$$qR \leq \frac{1}{1-\gamma/q}\left(2-\frac{\beta q}{q-(1-\beta)\gamma}-\beta\gamma\right) - q \equiv \overline{R}.$$

Similarly, the bank keeps maximum liquidity whenever $r_s \le \underline{r}$. Using the creditors' interest rate, we can write this as

$$r_s\left(\frac{(1-\beta)\gamma}{\beta(q-\gamma)}\right) = \frac{1-\frac{v\gamma(1-q)}{q}}{q} \le \frac{(q-\gamma)(R+1)+\gamma(2-\beta)}{q(2-\beta)} = \underline{r}.$$

Or, rewritten as condition in terms of qR, this is equivalent to

$$qR \ge \frac{(2-\beta)\left(1-\gamma-\frac{v\gamma(1-q)}{q}\right)}{1-\gamma/q} - q \equiv \underline{R}.$$

To show existence of the intermediate equilibrium with partial insurance, suppose that $\underline{R} < \overline{R}$ and consider $qR \in (\underline{R}, \overline{R})$. As $qR < \overline{R}$,

$$\lim_{m^e \to 0} r_s(m^e) = (q-(1-\beta)\gamma)^{-1} \ge \overline{r}$$

and since $\underline{R} < qR$,

$$\lim_{m^e \to \frac{\gamma(1-\beta)e}{q-\gamma}} r_s(m^e) = \frac{1-\frac{v\gamma(1-q)}{q}}{q} \le \underline{r}.$$

Moreover, we have

$$\lim_{r_s \to \overline{r}} \mu(r_s) = 0,$$

and

$$\lim_{r_s \to \underline{r}} m^{**}(r_s) = \frac{(1-\beta)\gamma e}{(q-\gamma)}.$$

Since $r_s(m^e)$ and $m^{**}(r_s)$ are continuous functions, by the intermediate value theorem, there exists at least one fixed point $\hat{m} \in (0, \frac{(1-\beta)\gamma e}{(q-\gamma)})$ such that $\hat{m} = m^{**}(r_s(\hat{m}))$.

Now suppose that $\overline{R} < \underline{R}$. For any $qR \in (\overline{R}, \underline{R})$ we have

$$\lim_{m \to 0} r_s^{**}(m) < \overline{r}$$

and

$$\lim_{m^e \to \frac{\gamma(1-\beta)e}{q-\gamma}} r(m^e) > \underline{r}.$$

And since $m^{**}(r_s) = 0$ for $r_s \ge \overline{r}$ and $m^{**}(r_s) = \frac{(1-\beta)\gamma e}{(q-\gamma)}$ for $r_s \le \underline{r}$, there exists at least one fixed point $\hat{m} \in (0, \frac{(1-\beta)\gamma e}{(q-\gamma)})$ such that $\hat{m} = m^{**}(r_s^{**}(\hat{m}))$.

As both functions r_s and m^{**} are strictly convex, there may exist more than one fixpoint. □

Proof of Proposition 3.6. We will derive the threshold values by comparing again the expected profits from the respective portfolios under borrowing with the expected profit from just investing equity (which always gives a positive expected profit).

If the bank decides to borrow, then it invests $y^{**} = \frac{e}{\beta}$ into the risky asset, it keeps liquidity holdings of $m^{**} \in \{0, \hat{m}, \frac{(1-\beta)\gamma}{\beta(q-\gamma)}\}$ and borrows $s^{**} = \frac{1-\beta}{\beta}e + m^{**}$. First, note that borrowing and full self–insurance against illiquidity risk is more profitable than just investing equity if and only if

$$\Pi\left(\frac{e}{\beta}, \frac{(1-\beta)\gamma}{\beta(q-\gamma)}, \frac{1-\beta}{\beta(1-\gamma/q)}e, r_s^{**}\left(\frac{(1-\beta)\gamma}{\beta(q-\gamma)}\right)\right) \ge \Pi(e, 0, 0, \cdot)$$

which yields the same condition that was already derived in Proposition 3.4,

$$qR \geq \equiv \frac{q(1-\gamma) - \nu\gamma(1-q)}{q-\gamma} \equiv \hat{R}_s.$$

Borrowing without insurance against illiquidity risk is more profitable than just investing equity if and only if

$$\Pi\left(\frac{e}{\beta}, 0, \frac{1-\beta}{\beta}e, r_s^{**}(0)\right) \geq \Pi(e, 0, 0, \cdot),$$

which implies the condition

$$qR \geq \frac{1}{1-\frac{\gamma}{q}} \equiv \hat{R}_n.$$

Given any equilibrium liquidity buffer $\hat{m} \in \left(0, \frac{(1-\beta)\gamma}{\beta(q-\gamma)}\right)$ which partially insures against illiquidity risk, there exists a critical value $\hat{R}_p(\hat{m}) \in \left(\hat{R}_s, \hat{R}_n\right)$ such that the bank considers borrowing with partial self–insurance more profitable than just investing equity if and only if

$$qR \geq \hat{R}_p(\hat{m}).$$

□

Proof of Proposition 3.7. From the proof of Proposition 3.5, we have

$$\underline{R} = \frac{1}{1-\gamma/q}\left((2-\beta)(1-\frac{\nu\gamma(1-q)}{q}-\gamma)\right) - q,$$

and

$$\overline{R} = \frac{1}{1-\gamma/q}\left(2-\frac{\beta q}{q-(1-\beta)\gamma}-\beta\gamma\right) - q.$$

We use the abbreviation $\tau \equiv \frac{\nu\gamma(1-q)}{q}$ and note that $\tau \in (0,1)$. By Corollary 3.2, there are multiple equilibria if and only if

$$\begin{aligned}
&\underline{R} < \overline{R}\\
\Leftrightarrow\ & -2(\gamma+\tau) < -\beta\tau - \frac{\beta(1-\beta)\gamma}{q-(1-\beta)\gamma}\\
\Leftrightarrow\ & -2(\gamma+\tau)(q-\gamma) - 2(\gamma+\tau)\gamma\beta < -\beta(\tau q + \gamma(1-\tau)) + \beta^2\gamma(1-\tau)\\
\Leftrightarrow\ & 0 < \beta^2\gamma(1-\tau) + \beta\left(2\gamma(\gamma+\tau) - \tau q - \gamma(1-\tau)\right) + 2(\gamma+\tau)(q-\gamma)\\
\Leftrightarrow\ & 0 < \beta^2 + (\phi-1)\beta + \psi,
\end{aligned}$$

where $\phi \equiv \frac{2\gamma(\gamma+\tau)-\tau q}{\gamma(1-\tau)}$ and $\psi \equiv \frac{2(\gamma+\tau)(q-\gamma)}{\gamma(1-\tau)}$. □

Corollary A3.4. *i)* $\underline{R}(0) < \overline{R}(0)$, *and* $\underline{R}(1) < \overline{R}(1)$.

ii) $\underline{R}(0) > \hat{R}_s$, *and* $\underline{R}(1) < \hat{R}_s$.

iii) $\overline{R}(0) > \hat{R}_n$.

Proof of Corollary A3.4. By using the definitions of the respective thresholds from Propositions 3.5 and 3.6, we calculate:

i) $\underline{R}(0) < \overline{R}(0) \Leftrightarrow -\gamma q - \nu\gamma(1-q) < 0$, and
$\underline{R}(1) < \overline{R}(1) \Leftrightarrow -\nu\gamma(1-q) < 0$.

ii) $\underline{R}(1) < \hat{R}_s \Leftrightarrow -q < 0$, and
$\underline{R}(0) > \hat{R}_s \Leftrightarrow q - \nu\gamma > 0$.

iii) $\overline{R}(0) > \hat{R}_n \Leftrightarrow 1 > q - \gamma$.

□

4 The 'Celtic Crisis': Guarantees, Transparency, and Systemic Liquidity Risk

(written in collaboration with Kartik Anand and Frank Heinemann)

4.1 Introduction

In the aftermath of the collapse of Lehman Brothers in September 2008, a great many, in particular European, countries issued sizable bank debt guarantee programs. In this paper we analyze the conditions conducive for the success of such schemes. We address this issue by answering several smaller, but more tractable questions. Firstly, how does a government's issuance of a banking sector liability guarantee scheme influence the lending behavior of sovereign and bank creditors? Secondly, what is the impact of the guarantee on the *ex ante* probabilities of banking and sovereign default, as well as on the likelihood of a systemic crisis? Thirdly, is there a guarantee that optimally trades off the risk of sovereign and bank default? And finally, how does the effectiveness of the (optimal) guarantee depend on balance sheet transparency and on the liquidity of banks and sovereigns alike?

The global financial crisis was marked by a severe loss of confidence by investors in financial markets all over the world. Triggered by losses on US sub–prime mortgages and other toxic financial assets interbank markets froze as banks ceased lending to each other.[1] Figure 4.1 Panel (a) illustrates this development. It shows the EURIBOR-OIS spread, a measure for interbank market tensions in the euro area, sharply and abruptly increasing three-fold following the collapse of Lehman Brothers in September 2008. Figure 4.1 Panel (b) shows the changes in the spreads for banking sector

[1] See Taylor and Williams (2008) or Holthausen and Pill (2010) for a detailed investigation of interbank money markets during the 2007–08 financial crisis.

and sovereign Credit Default Swaps (CDSs), between January 2007 and late September 2008 (shortly after the default of Lehman Brothers). Viewed as proxies for the probabilities of default of banks, we note a marked increase in the fragility of banking sector in several countries.

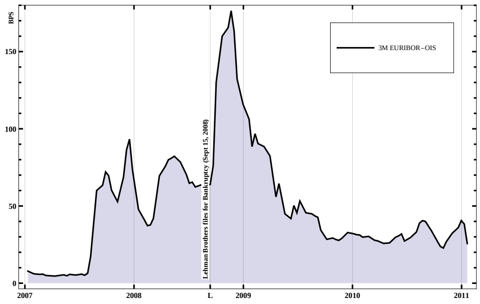
In light of such deteriorating conditions, governments sought to introduce measures to shore up confidence in their domestic financial sectors. Many, especially European countries introduced contingent guarantee schemes for retail and wholesale bank deposits. These schemes were viewed as cost effective measures to stave off bank runs, whereby governments lend their own creditworthiness to the financial sector.[2] Figure 4.1(c) compares the sizes of schemes introduced in several countries, relative to their GDP. The schemes in Italy and Spain amounted to about 3% and 9% of GDP respectively, while in Austria and the Netherlands they totaled at roughly 30% of GDP. Albeit sizeable, all these programs were dwarfed by the measures introduced in Ireland, wherein the state guaranteed *all* bank liabilities for a period of two years with no monetary cap. The broad mandate of the Irish scheme, which amounted to roughly 244% of GDP, followed from the consensus that, as Patrick Honohan (2010), governor of the Central Bank of Ireland, noted, "[n]o Irish bank should be allowed to fail".

In general, the guarantee schemes were successful in alleviating banking sector default risk. Yet, they led to a simultaneous increase in sovereign default risk. This can be seen from Figure 4.1 Panel (d) which compares the change in sovereign CDS–spreads with the change in banking sector CDSs. Based on this measure, it appears that the increase in the sovereigns' default probabilities was of much smaller magnitude than the reduction in the respective banking sector default probability. This phenomenon indicates that the guarantees not only led to a re–allocation of risks between banks and governments, but they may have also reduced economy–wide risks.

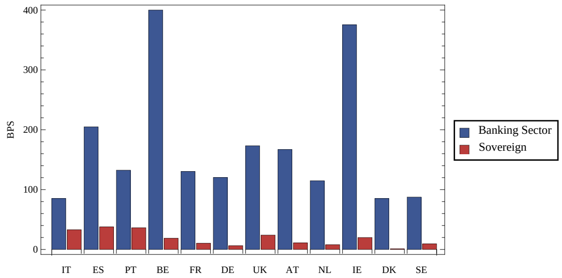
The case of Ireland requires particular attention, as it can be considered exemplary for the dramatic and systemic consequences that may follow from tying the government's funding situation to that of its banking sector by means of debt guarantees. Prior to the crisis, the Irish economy was considered 'sound', with low government

[2] Table A4.1 in the Appendix provides an overview of schemes introduced in several countries. See also Schich and Kim (2011) for an overview of different banking sector safety nets.

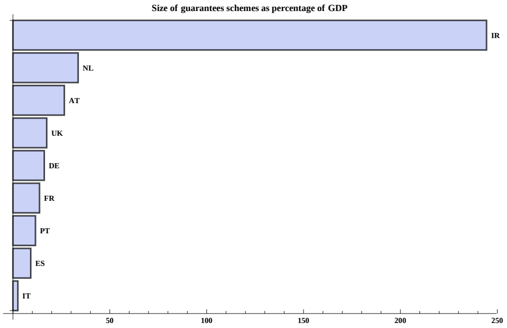
Figure 4.1: Stylized Facts



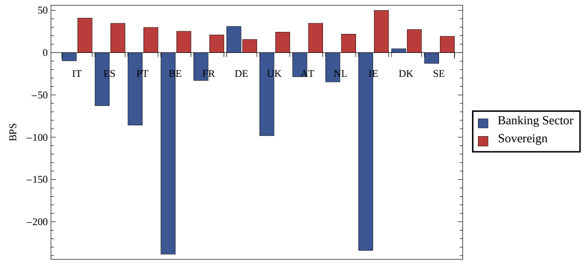
Panel (a): Time series of the 3 month Euribor-OIS spreads in basis points. The marker 'LB' indicates the date that Lehman Brothers filed for bankruptcy (September 15, 2008). Data taken from Bloomberg.



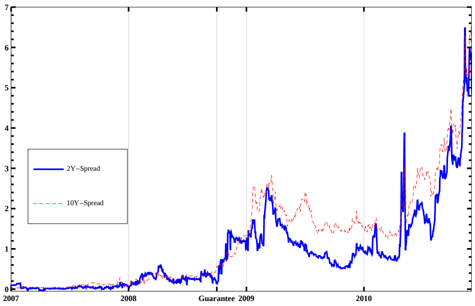
Panel (b): Change in CDS–spreads for banks and sovereigns between 1/1/2007 and 9/25/2008. Bank CDSs are unweighted averages of banks with headquarter in respective country. Data from Bloomberg.



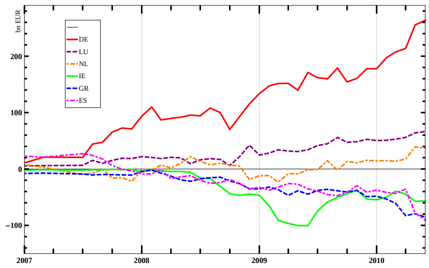
Panel (c): Guarantee sizes in % of GDP. Data taken from OECD.



Panel (d): Change in CDS–spreads for banks and sovereigns between 9/26/2008 and 10/21/2008. Bank CDSs are unweighted averages of banks with headquarter in respective country. Data from Bloomberg.



Panel (e): Irish spreads over German bund, in basis points. The marker 'G' indicates the date that the Irish government introduced the guarantee scheme, while 'EU-IMF' gives the date that the joint European Union and International Monetary Fund bailout for Ireland was announced. Data from Bloomberg.



Panel (f): Net TARGET2 Liabilities of selected euro area national central banks against the Eurosystem in millions of euro. Negative values reflect a Target2-liability, positive numbers a Target2-asset. Data taken from University of Osnabrück's Euro Crisis Monitor.

debt and deficit, prospects for growth, and low sovereign funding costs (see Figure 4.1 Panel (e)). Against this background, Ireland issued its first bank liability guarantee program in October 2008. The guarantee had the immediate effect of driving down CDS–spreads for the banking sector. However, as concerns among sovereign creditors rose whether the Irish government would be able to pay out the guarantee, Ireland's funding costs skyrocketed. Moreover, the guarantee failed to prevent large withdrawals away from Irish banks to the perceived safe havens like Germany or Luxemburg. Figure 4.1 Panel (f) illustrates this trend by showing net TARGET2 liabilities of the Irish Central Bank, which serve as a proxy for the cumulative net outflows of euro–denominated liquidity.[3] The systemic events culminated in the nationalization of Anglo-Irish Bank in January 2009, and the Irish government seeking a bail-out on 21 November, 2010, jointly from the European Union's European Financial Stability Facility and the International Monetary Fund.

The resulting 'Celtic crisis' differs dramatically from the actual goal of governments issuing bank debt guarantee schemes. The resulting systemic crisis was a direct consequence of the false belief that a guarantee will shore up investor confidence, without placing any strain on a government's own funding needs, and hence, on the credibility in keeping its guarantee promises. Or, as one financial market participant bluntly put it to the Wall Street Journal (2011) when asked to comment on the on-going banking sector problems in the euro area, "How useful would bank guarantees from member states be if these member states are themselves shut out of financial markets?".

In this chapter we model a systemic liquidity crisis. The model consists of a government, one bank and a large pool of bank and sovereign creditors. Bank creditors must decide whether to roll over their loans to the bank or to withdraw. Their decisions depend on the bank's recourse to liquidity and the contingent guarantee provided for by the government. Sovereign creditors, in turn, decide on whether to continue lending to the government or to withdraw. The decisions of sovereign credi-

[3]While the Irish guarantee scheme was introduced in October 2008, the outflows continued until May 2009, when they peaked at approximately €100 billion. While there was a reversal of trends between May and September 2009, the pace of withdrawals accelerated shortly thereafter and continued through 2010, and peaking only in January 2011. See Bindseil and König (2012) for details on the role and mechanics of the TARGET2 system during the financial crisis.

tors depend on the government's available resources and the possible payment of the bank guarantee. Using standard techniques from the literature on global games, we embed our model in an incomplete information setting, where creditors face strategic uncertainty concerning the actions of other creditors, as well as fundamental uncertainty over the bank's and the government's recourse to liquidity. Following well established lines of reasoning, we show that our model exhibits a unique equilibrium in threshold strategies, and that there are no other equilibria in non-threshold strategies.

Our model displays *strategic complementarities* within each group of creditors. That is, the incentives of individual bank (sovereign) creditors to roll over are increasing in the mass of bank (sovereign) creditors who also roll over. Furthermore, bank creditors' incentives to roll over are also increasing in the mass of sovereign creditors who lend to the government. Hence, sovereign creditors' actions are strategic complements for bank creditors. But the converse does not hold. The incentives of a sovereign creditor to lend are decreasing in the mass of bank creditors who roll over. The actions of bank creditors are therefore *strategic substitutes* for sovereign creditors. To better understand the latter property, suppose that, following the introduction of a guarantee, a large fraction of bank creditors roll over their loans. However, were the bank still to fail, a large guarantee payout would come due adding to the government's liabilities. Anticipating such an outcome, sovereign creditors would become doubtful about the government's liquidity and thus more reluctant to roll over their own claims. This property of our model must be interpreted with caution and against the background of the questions that we address. Although the government in the model wishes to avoid a bank default, we abstract away from direct payments being made by the bank to the government. If, for example, the government could collect taxes from the bank, its liquidity situation would be directly intertwined with the bank and the strategic substitutes effect would be less pronounced. However, since such taxes may distort the incentives of the bank to act with prudence and remain solvent, we abstract from their inclusion in order to derive the 'pure' strategic interactions between the different groups of creditors.

Finally, using numerical methods, we investigate how the optimal guarantee size and the welfare properties it induces, relate to the underlying model parameters.

The optimal guarantee is obtained by minimizing a cost of crisis function, which is a weighted sum of the output losses attributed to individual bank and government defaults, and the systemic crisis. Increases in the *ex ante* expected recourse to liquidity for both the bank and government lead to larger guarantees. We also find that policies which promote bank's balance sheet transparency are welfare enhancing. These gains are further improved by added balance sheet transparency of the government. We also explain why the reduction in banking sector CDS spreads which followed the introduction of guarantee schemes was often larger in absolute magnitude than the accompanying increase in sovereign CDS spreads. We argue that the strong reduction in banking sector CDSs may have been due to the guarantee's effect of removing strategic uncertainty among bank creditors, while the higher sovereign CDSs are attributed to the opacity on bank's balance sheets.

The chapter is structured as follows. We introduce the canonical bank debt roll over model in Section 3. In Section 4.4 we introduce the government which issues a guarantee, but is itself subject to roll over risk. The comparative statics properties of this extended model are provided in Section 5. In Section 6 we present numerical results for the effects of transparency in a calibrated exercise and section 7 concludes. Most of the mathematics and all proofs are deferred to the Appendix.

4.2 Relation to the Literature

The modern theoretical perspective on banks' maturity and liquidity mismatches and deposit guarantees is based on the seminal model of Diamond and Dybvig (1983). They show the existence of multiple, self-fulfilling equilibria for a bank with short-term financed illiquid assets. In one equilibrium, the bank is run by all depositors and fails as its liquid reserves are not sufficient to cover depositors' aggregate claims. In the second equilibrium, only a small amount of withdrawals occurs and the bank's liquidity is sufficient to avoid default. The two equilibria are brought about by a mis–coordination of beliefs. Deposit insurance financed by taxes helps to overcome this multiplicity by increasing depositors' expected payoffs from rolling over. The mere existence of such a deposit insurance is sufficient to coordinate creditors on the efficient equilibrium and to avoid a bank run. In equilibrium, the insurance is never paid out.

Morris and Shin (2000) and Goldstein and Pauzner (2005) solve the multiple equilibria problem by extending the setup of Diamond and Dybvig to an incomplete information setting where information on the liquidity of the bank is not common knowledge. By employing the global games approach of Morris and Shin (1998, 2003) they solve for the unique equilibrium in threshold strategies. If the information received by depositors is sufficiently precise and banks' fundamentals are below a critical threshold, most depositors withdraw, thus causing the bank's failure. If liquidity is sufficiently high, then depositors stay. Importantly, in equilibrium, the amount actually paid out due to the deposit guarantee is low as there are only a few depositors who roll over despite the bank's default. This logic has recently been translated to government guarantee schemes by Kasahara (2009) and Bebchuk and Goldstein (2010). Kasahara considers a standard global game model, where creditors to a firm enjoy the benefit of a government-financed debt guarantee. He shows that the guarantee removes inefficient coordination failures only if the government combines this policy with an information policy where it provides a sufficiently precise public signal about the firm's fundamental. Although the guarantee in Kasahara's model is exogenously financed, he also considers potential costs that may arise when the guarantee creates adverse incentives and leads to a moral hazard problem on the side of the firm.

Bebchuk and Goldstein (2010) consider a stylized global game model where the coordination failure occurs among banks who can decide whether to lend to the real economy or not. Among other policy measures, they consider how a guarantee of banks' loans could overcome the no-lending- or 'credit-freeze-equilibrium'. Similar to the effect of a deposit insurance in a bank-run model, they find that when the guarantee is sufficiently high, the risk of coordination failure may be reduced to zero. Goldstein and Bebchuk focus especially on the 'global game solution' of vanishing fundamental uncertainty concluding that "government's guarantees (...) do not lead to any capital being spent (...) this mechanism leads to an improvement in the threshold below which a credit freeze occurs without any actual cost" (p. 25). The authors nevertheless acknowledge that the validity of a guarantee mechanism crucially "depends on the credibility of the government in providing the guarantee" (p. 26). Our model contributes to this recent literature by explicitly considering the credibility of the guarantee by introducing a refinancing problem for the sovereign guarantor. As will be explained in greater detail below, Goldstein and Bebchuk’s conclusion still holds in our model whenever fundamental uncertainty vanishes. Yet, whenever bank creditors face some fundamental uncertainty, the guarantee leads to a higher default risk of the sovereign.

Cooper (2012) shows a similar result in a multiple equilibrium model of sovereign debt pricing. He studies how a guarantee by a sound country shifts strategic uncertainty towards the guarantor. In the absence of fundamental uncertainty, beliefs of creditors are not affected and the guarantee simply acts as a device that selects the good equilibrium. Yet, when fundamental uncertainty is present, the guarantee may influence the price of the sound country’s debt. Thereby the guarantee creates a contagion channel between the countries which was not present before.

Acharya, Drechsler, and Schnabl (2011) consider the related problem of financial sector bailouts and their impact on sovereign credit risk. Bank bailouts are financed by taxing the non-financial sector of the economy. While the bailout is successful in alleviating problems of the banks, the higher tax burden of the non-financial sector reduces the economy’s growth rate. Thus, the government’s task is to set the optimal tax rate in order to maximize the economy’s welfare. In this chapter, we abstract from taxation and finely focus on the coordination problem between bank creditors and sovereign creditors. This emphasis on joint coordination failures allows us to address more adequately the issues of the governments’ “ability-to-pay” and the credibility of the guarantee. The government in our model then sets the optimal guarantee in order to minimize the expected costs of crises and coordination failures.

Closely related to our model is the ‘twin crises’ global game of Goldstein (2005) which also includes two groups of agents, currency speculators and bank creditors. The former attack a pegged exchange rate, while the latter hold foreign currency denominated claims against a domestic bank. The (exogenous) political decision by a government to peg the exchange rate connects the actions of the two groups of agents. The greater the fraction of speculators who attack the currency, the more likely a devaluation of the currency becomes, and hence the more likely is the bank to default due to the currency mis–match on its balance sheet. Conversely, the greater the fraction of bank creditors who withdraw their funds, the larger is the outflow of foreign reserves, and it becomes more likely that the currency peg will break down. The actions of bank creditors and speculators are strategic complements. They reinforce each other giving rise to a vicious circle. In our model, the actions of sovereign and bank creditors are also connected through an exogenous political decision (guaranteeing bank debt). But in contrast to Goldstein's twin crisis theory, only the actions of sovereign creditors are strategic complements for bank creditors, while bank creditors' actions are strategic substitutes for sovereign creditors. Moreover, in Goldstein's model, the bank's and the sovereign's financial strength is determined by the same fundamental, whilst the financial strength of the respective institutions in our model is driven by different, independently distributed fundamentals.

Global games with different fundamentals have not yet been studied in the literature to a great extent. Two examples related to our model are Dasgupta (2004) and Manz (2010). Dasgupta models financial contagion in a global game between two banks in different regions that are exposed to independent regional shocks. Linkages between banks are created by cross–holdings of deposits in the interbank market and regional shocks may therefore trigger contagious bank failures in equilibrium. Manz considers a global game with two independently distributed fundamentals to study information-based contagion between distinct sets of creditors of two firms. Creditors have imperfect information about both, their debtor firm's fundamental and a common hurdle function which a fundamental must pass for the respective firm to become solvent. In contrast to Dasgupta, his model has a sequential structure where creditors to the second firm can observe whether the first firm failed or not. This observation functions as a common signal and provides second firm creditors some information about the hurdle which in turn influences their decision to liquidate their own claim or not. While we also resort to the assumption of independently distributed fundamentals, creditor decisions are taken simultaneously, which implies that informational contagion, based on the observation of a particular outcome in one refinancing game, cannot occur. Rather, the spill-overs between the bank's and the sovereign's refinancing problem are determined by the guarantee.

4.3 Canonical Bank Debt Roll Over Game

In this section, we describe the canonical roll over game that serves as the workhorse for the remainder of the chapter. We introduce an exogenously financed guarantee and discuss the relationship between balance sheet transparency and the costliness of the guarantee.

4.3.1 Model description

A bank, indexed b, is indebted to risk-neutral creditors $n_b \in [0, N_b]$, where $N_b \in \mathbb{R}_+$ measures the bank's exposure to funding illiquidity. Creditors hold identical claims against the bank, each with a face value of one monetary unit. The bank's recourse to liquidity is summarized by the random variable $\theta_b \sim U[-\eta_b, \eta_b + \theta_b^0]$, with the *ex ante* mean recourse to liquidity being $\theta_b^0/2$. θ_b is comprised of two parts. First, there are the liquid assets on the bank's balance sheet, which directly contribute to increasing θ_b. Second, the bank can raise cash by entering into secured finance arrangements – for example, repurchase agreements and covered bonds – where it pledges illiquid assets to investors in exchange for cash. These investors, who are not explicitly modeled, include other commercial banks, hedge funds, and also the central bank.

Creditors simultaneously decide whether to roll over their loans to the bank, or to withdraw. We express the set of actions for a typical bank creditor by $\{0, 1\}$, where 0 denotes rolling over, while 1 denotes withdrawing. Defining $\lambda_b \in [0, 1]$ as the fraction of bank creditors who withdraw, the bank defaults whenever aggregate withdrawals exceed the available liquid resources, i.e.

$$\lambda_b N_b \geq \theta_b. \tag{4.1}$$

We assume that all bank creditors have common payoffs, which are summarized in Table 4.2. Withdrawal by a creditor may entail additional transaction costs, which are subtracted from the unit claim held against the bank. Thus, the net payoff from withdrawing is $C_b \leq 1$, independent of whether the bank defaults or survives.[4] If, however, the creditor rolls over his loan and the bank survives, he is paid back $D_b >$

[4]The fact that creditors *always* receive C_b when they choose to withdraw deserves some comment. The interpretation of θ_b as available liquid resources implies that the bank is unable to pay one unit per claimant for $\theta_b < \hat{\theta}_b$. A more plausible setup would then be to impose a ‘sequential service con-

		Bank	
		Default	Survive
Bank Creditor	Withdraw	C_b	C_b
	Roll over	ℓ	D_b

Table 4.2: A typical bank creditor's payoffs.

1, which includes both the original amount lent, plus additional interest payments. Finally, if the bank defaults, creditors who rolled over their loans receive a fraction ℓ of their unit claim. We interpret ℓ as the payment stemming from a bank liability guarantee scheme. In what follows, we assume that ℓ is exogenously financed and that creditors receive the amount whenever it comes due. We further assume that $D_b > C_b \geq \ell \geq 0$, which entails that creditors face a coordination problem.[5]

straint' and assume that creditors receive only a fraction of the available resources in the case of bank default, which may be determined by θ_b, the fraction λ_b and possible transaction costs. The resulting payoff from withdrawing would inherit a negative dependency on λ_b. However, the realism added by modeling the problem in this way has to be traded off against technical difficulties that arise due to the resulting *partial strategic complementarities*. The proof of equilibrium employed above relies on the existence of *global strategic complementarities*, i.e. creditors' actions strictly decrease in λ_b. But with the more realistic assumption of a 'sequential service constraint', the expected payoff differential (rolling over vs withdrawing) becomes increasing in λ_b over a certain range. However, as Goldstein and Pauzner (2005) show, under the alternative assumption of the payoff differential obeying a single–crossing property, the nature of the equilibrium remains unaltered. There is still a unique symmetric threshold equilibrium. Under the additional restriction to uniform distributions, there are also no other non–threshold equilibria. Yet, their proof is more involved, leading to more complicated comparative statics calculations that continue to remain qualitatively identical. Thus, to keep the model tractable, we stick to the less realistic assumption that the payoff from withdrawing is fully safe which guarantees the global strategic complementarity property. This is in line with standard practice in the literature, e.g. Chui, Gai, and Haldane (2002) or Morris and Shin (2006). Rochet and Vives (2004) further motivate this approach by appealing to institutional managers who seek to make the right decision, while their payoffs do not depend directly on the face value of their claims.

[5]For simplicity, we deliberately ignore the possibility of default due to insolvency at some later date which may occur even though the roll over has been successfully managed.

4.3.2 Tripartite classification of the fundamental

The bank debt roll over game exhibits a *tripartite classification* of the fundamental θ_b, which is a characteristic of such coordination games.[6] For $\theta_b < 0$, the bank always defaults, irrespective of the fraction λ_b of creditors who withdraw. We refer to this as the *fundamental insolvency* case or the efficient default. It is a dominant action for creditors to withdraw in this case. For $\theta_b > N_b$, the bank always survives, even if all creditors were to withdraw their funds. Here it is dominant for all creditors to roll over.

If $\theta_b < 0$, there exists a unique Nash–equilibrium where all creditors withdraw and the bank defaults. For $\theta_b > N_b$, there is a unique Nash–equilibrium where all creditors roll over their loans and the bank survives. However, under the assumptions of *common knowledge* of θ_b, the game exhibits multiple equilibria – in pure strategies – for intermediate values $\theta_b \in [0, N_b]$. The equilibria in this interval are sustained by common self-fulfilling expectations about the behavior of other creditors. In one equilibrium, each creditor expects that all other creditors will withdraw, and hence withdrawing is the best response to this belief. Creditors' aggregate behavior leads to the bank's default, validating the initial beliefs. In the second equilibrium, each creditor expects all other creditors to roll over their loans. This implies that each creditor chooses to roll over as the best response to this belief. The resulting outcome is one where the bank survives, which once again vindicates the beliefs of creditors.

4.3.3 Information structure and strategies

To eliminate the multiplicity of equilibria we use the global games approach and relax the assumption of common knowledge about θ_b. Instead, we make the weaker assumption that creditors have heterogeneous and imperfect information concerning the bank's fundamental. Specifically, creditors receive private signals about the fundamental before choosing their action. The signals are modeled as $x_{n_b} = \theta_b + \varepsilon_{n_b}$, where ε_{n_b} is an idiosyncratic i.i.d. noise term uniformly distributed over the support $[-\varepsilon_b, \varepsilon_b]$. Following the literature on transparency, i.e., Heinemann and Illing (2002), Bannier and Heinemann (2005), and Lindner (2006), we interpret ε_b as the *degree of*

[6] See e.g. Diamond and Dybvig (1983), in the context of bank-runs, and Obstfeld (1996) in the context of currency crises.

balance sheet transparency in the banking sector. When ε_b is small there is a high degree of transparency as the signals that bank creditors receive enable them to better infer the true fundamental from their observed signals. Creditors use their private signals and the commonly known prior to form individual posteriors $\theta_b|_{x_{n_b}}$ by means of Bayesian updating. Furthermore, to apply global game methods, we need to ensure that the support of the fundamental distribution is sufficiently large to include an upper and a lower dominance region.[7]

A strategy for a typical creditor is a complete plan of action that determines for each realization of the signal whether the creditor rolls over or withdraws. Formally, a strategy is a mapping $s_{n_b} : x_{n_b} \mapsto \{0,1\}$. Strategies are *symmetric* if $s_{n_b}(\cdot) = s_b(\cdot)$ for all n_b. A strategy is called a *threshold strategy* if a creditor chooses to withdraw for all x_{n_b} below some critical $\hat{x}_{n_b}$ and rolls over otherwise. Finally, a *symmetric threshold strategy* is a threshold strategy where *all* creditors use the same critical $\hat{x}_b$.

4.3.4 Equilibrium

A symmetric equilibrium of the bank debt roll over game with heterogeneous information is given by the strategy $s_b(\cdot)$ and the aggregate choice $\lambda(\theta_b)$ such that creditors maximize their expected payoffs and

$$\lambda_b(\theta_b) = \frac{1}{2\varepsilon_b}\int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\,dx_{n_b}.$$

It is a well established result that coordination games such as our bank debt roll over game exhibit a unique equilibrium in symmetric threshold strategies.[8] The following proposition re-states this result in terms of our model.

[7] Given the support of the signal error, a creditor is certain that the bank defaults whenever he receives a signal $x_{n_b} < -\varepsilon_b$ (even if all other creditors roll over). And similarly, whenever he receives a signal $x_{n_b} > N_b + \varepsilon_b$, he is certain that the bank survives (even if all other creditors withdraw). We assume that the support of θ_b is sufficiently large to include states where all creditors find either rolling over or withdrawing dominant, i.e.

$$[-2\varepsilon_b, N_b + 2\varepsilon_b] \subset [-\eta_b, \theta_b^0 + \eta_b].$$

[8] See Morris and Shin (2003). For a general class of distributions of the fundamental other than the uniform distribution, uniqueness requires that the private signals of creditors are sufficiently precise, i.e. ε_b to be sufficiently small.

Proposition 4.1. *The bank debt roll over game has a unique equilibrium summarized by the tuple* $(\hat{x}_b, \hat{\theta}_b)$ *where*

$$\hat{x}_b = \hat{\theta}_b + 2\varepsilon_b \left(\frac{\hat{\theta}_b}{N_b} - \frac{1}{2} \right) \tag{4.2}$$

and

$$\hat{\theta}_b = \frac{N_b (C_b - \ell)}{D_b - \ell}. \tag{4.3}$$

Creditors with signals x_{n_b} *withdraw if* $x_{n_b} < \hat{x}_b$ *and roll over if* $x_{n_b} > \hat{x}_b$. *The bank defaults if and only if* $\theta_b < \hat{\theta}_b$.

Proof. See Morris and Shin (2003) for the proof of existence and uniqueness and the appendix for the calculations of equations (4.2) and (4.3). □

4.3.5 Changes to the guarantee size

Albeit stylized, we interpret ℓ as the payment from a bank liability guarantee scheme provided by the government. Creditors receive ℓ in case they roll over their loans and the bank defaults. If creditors choose to withdraw, they always receive C_b. In absence of a guarantee, i.e. $\ell = 0$, bank creditors will choose to roll over their loans as long as the probability attached to the bank's survival is sufficiently high. In terms of the payoffs, they will roll over as long as the spread between D_b and C_b is large enough to compensate for incurring the risk of ending up with a zero payoff in case of bank default. A positive guarantee $\ell > 0$ reduces the opportunity cost of rolling over (given by $C_b - \ell$) and therefore increases creditors' incentives to roll over. All other things equal, a larger guarantee lowers the critical thresholds $\hat{\theta}_b$ and $\hat{x}_b$, thereby leading to a higher *ex ante* survival probability, i.e.

$$\frac{\partial \hat{\theta}_b}{\partial \ell} = \frac{N_b (C_b - D_b)}{(D_b - \ell)^2} < 0.$$

4.3.6 Transparency and expected costs of a guarantee

The comparative static result above and its implications may have contributed to the widely held perception that bank liability guarantee schemes are a costless measure to shore up confidence in financial institutions. And while it is true that the guarantee serves as a device to change the incentives of creditors to coordinate on the efficient equilibrium, the question remains whether this is indeed a costless policy. To better appreciate the conditions under which this holds true, consider the case where creditors face only *strategic uncertainty* about the behavior of other creditors and no *fundamental uncertainty* about the true realization of θ_b. This corresponds to a high degree of balance sheet transparency with $\varepsilon_b \to 0$, which implies that $\hat{x}_b \to \hat{\theta}_b$. All creditors now receive almost identical signals. As they all use the same threshold strategy around $\hat{x}_b$, in equilibrium, either everyone rolls over and the bank survives or everyone forecloses and the bank defaults. The payoffs to the creditors are D_b if everyone rolls over their loans, or C_b if they all withdraw. While the guarantee payment ℓ raises the creditors' incentives to roll over, it is never paid out. A policy maker could therefore issue an arbitrarily large guarantee and effectively control the likelihood of default without ever having to follow up on its promises. In particular, by setting $\ell = C_b$, the bank's failure threshold converges to $\hat{\theta}_b = 0$ such that only a fundamentally insolvent bank defaults. By making such a choice, a policy maker can prevent inefficient bank runs due to coordination failures.

The result that guarantees are costless changes, however, with a lower degree of balance sheet transparency and creditors facing fundamental uncertainty, i.e. $\varepsilon_b > 0$. In this case, some creditors may decide to roll over their loans due to 'misleading' signals $x_{n_b} > \hat{x}_b$, even though $\theta_b < \hat{\theta}_b$ and the bank defaults. These creditors become benefactors of the guarantee scheme and receive ℓ. Denote by γ_b the fraction of agents who receive the guarantee payment. By the law of large numbers, γ_b equals the probability that a single signal x_{n_b} is above $\hat{x}_b$ conditional on the realized θ_b, i.e.,

$$\gamma(\theta_b, \hat{x}_b, \hat{\theta}_b) = \begin{cases} 0 & \text{if } \theta_b > \hat{\theta}_b \\ \frac{\theta_b - \hat{x}_b + \varepsilon_b}{2\varepsilon_b} & \text{if } \hat{x}_b - \varepsilon_b < \theta_b < \hat{\theta}_b \\ 0 & \text{if } \theta_b < \hat{x}_b - \varepsilon_b. \end{cases} \tag{4.4}$$

Figure 4.1 plots λ_b and γ_b against the fundamental θ_b for the cases of full balance sheet transparency, $\epsilon_b = 0$ (dashed lines), and with lower transparency, $\epsilon_b > 0$ (solid lines). In the case of full transparency, λ_b is a step function with a jump discontinuity at $\hat{\theta}_b$, while γ_b is always equal to 0. With lower transparency, however, λ_b decreases linearly from 1 to 0 over the range $[\hat{x}_b - \varepsilon_b, \hat{x}_b + \varepsilon_b]$, with γ_b increasing linearly in θ_b from 0 to $(\hat{\theta}_b - \hat{x}_b + \varepsilon_b)/2\varepsilon_b$ over the range $[\hat{x}_b - \varepsilon_b, \hat{\theta}_b]$. The increase in γ_b illustrates

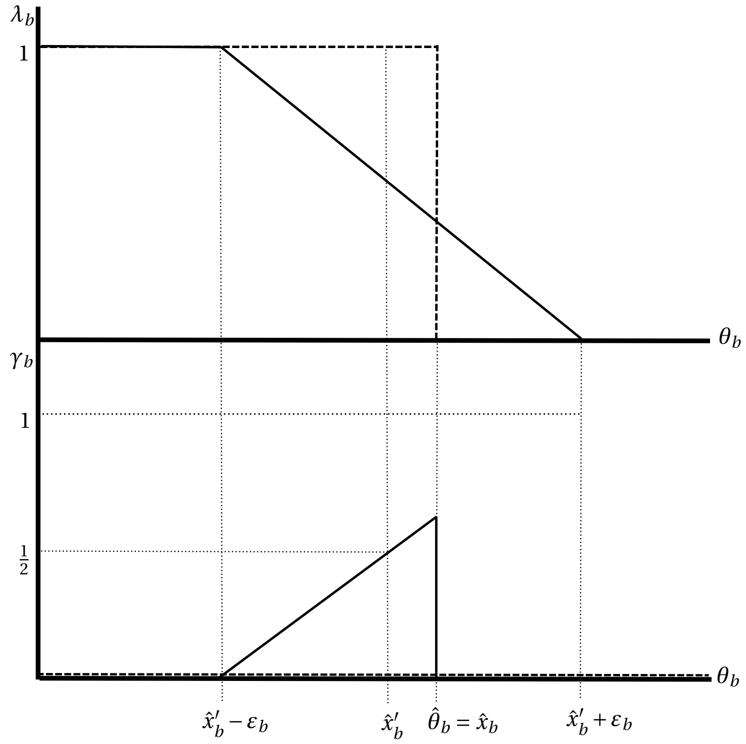


Figure 4.1: Upper diagram: Fraction of bank creditors who withdraw, λ_b. Lower diagram: Fraction of bank creditors who receive guarantee payment, γ_b. The case $\varepsilon_b = 0$ is represented by the dotted lines, whereas the case $\varepsilon_b > 0$ is represented by solid lines. An increase in ε_b does not affect $\hat{\theta}_b$, but it changes $\hat{x}_b$ to $\hat{x}'_b$. The diagram is drawn under the assumption that $\frac{C_b-\ell}{D_b-\ell} < \frac{1}{2}$ so that $\hat{x}'_b < \hat{\theta}_b$ if $\varepsilon_b > 0$.

the potential costs stemming from the guarantee scheme. The *ex ante* expected fraction of agents who benefit from the guarantee, and hence expected costs, rise when the bank becomes less transparent. When balance sheet transparency is rather low, creditors’ information is widely dispersed and many creditors may erroneously believe that the bank will not default even if, in fact, it does. These creditors, in turn, become eligible for the guarantee payment.

Several vital questions arise from these considerations. To which extent do the costs stemming from the guarantee pose a threat to the guarantor’s own solvency or liquidity position? Are guarantees still effective in reducing the likelihood of bank default whenever one takes the funding risk of the guarantor into account? What are the effects of variations in bank and guarantor liquidity parameters on the behavior of creditors? In what follows, we answer these questions by explicitly modeling the guarantor's, i.e. the government's, funding risks.

4.4 Bank Debt Roll Over Game with Endogenous Sovereign Funding Risk

4.4.1 Model description

Building on the canonical bank debt roll over model outlined in section 4.3 we now explicitly introduce the refinancing problem of the government that issued the guarantee. In case of bank default, the government pays out ℓ to those bank creditors that rolled over their loans. However, the government is itself facing a roll over game involving a set of sovereign creditors $n_g \in [0, N_g]$ who are all different from the bank's creditors. We normalize the mass of sovereign creditors to unity, $N_g \equiv 1$. Each sovereign creditor holds a claim with a face value of one monetary unit against the government. Sovereign creditors decide simultaneously whether to continue lending to the government or to withdraw. The government defaults whenever its liquid resources are insufficient to service debt withdrawals and guarantee payments. We represent the government's liquidity by the random variable θ_g, which is uniformly distributed over $[-\eta_g, \theta_g^0 + \eta_g]$, where $\theta_g^0/2$ is the *ex ante* mean recourse to liquidity. Moreover, with respect to the relation between θ_b and θ_g, we impose the following assumption.

Assumption: *The government's liquidity, θ_g, and the bank's liquidity, θ_b, are independently distributed.*

Sovereign creditors receive noisy signals $x_{n_g} = \theta_g + \varepsilon_{n_g}$ concerning the government's liquidity θ_g, where ε_{n_g} is a uniform i.i.d. random variable with support $[-\varepsilon_g, \varepsilon_g]$. As in the banking game, reduced information dispersion, i.e. a lower ε_g is associated with a higher degree of transparency of the government's financial situation. By assumption, the signals of bank and sovereign creditors are completely uninformative about the fundamental of the respective other entity.

Table 4.3 gives the payoffs in the sovereign roll over game. A sovereign creditor who withdraws early receives $C_g < 1$ which is the unit claim less potential transaction

		Government	
		Default	Survive
Sovereign Creditor	Withdraw	C_g	C_g
	Roll over	0	D_g

Table 4.3: A typical sovereign creditor's payoffs.

costs. If the government survives, creditors who rolled over their loans receive D_g. If the government defaults, the sovereign creditors who rolled over get a zero payoff as there is no guarantee in place for them.

The bank's creditors, however, continue to enjoy the benefit of a guarantee in case the bank defaults and the government survives. The payoffs for a typical bank creditor are shown in Table 4.4 where we have normalized $C_b = 1$ in order to reflect the relatively small transaction costs in bank funding markets.

		Bank Default		Bank Survive
		Govt Survive	Govt Default	
Bank Creditor	Withdraw	$C_b = 1$	$C_b = 1$	$C_b = 1$
	Roll over	ℓ	0	D_b

Table 4.4: Updated bank creditor's payoffs.

As our assumption of independence between sovereign and banking sector liquidity appears restrictive, some comments are in order.

- Firstly, the assumption should be judged against the clear but narrow objective of our chapter, namely that we want to demonstrate how, and to what extent, the introduction of a guarantee induces a dependency between the refinancing situation of sovereign and banking sector. For example, it is by now widely known that some euro area members got stuck in a 'diabolic loop' where problems in the banking sector and problems of the sovereign tend to amplify each other. One casual explanation for the high exposure of sovereigns vis–à–vis their banking sectors usually put forth is that governments, through the issuance of guarantees, linked their own funding situation with that of the bank.[9] Yet, this implies that the observed correlation has been *caused*, among other things, by governments issuing guarantees. It was not necessarily present *before* the introduction of guarantees. From this perspective, our objective in this chapter is to provide analytical underpinnings to this side of the diabolic loop. The simplest setting for such an analysis is one where, absent the guarantee, no dependency between the two coordination games exists.

- Secondly, as our focus is on liquidity crises, it can be argued that the correlation between the banking sector's liquidity and that of its government is rather low. Indeed, the liquidity of the government is essentially determined by its revenues from taxes, public dues and tariffs. In contrast, as Shin (2012) notes, internationally active banks may tap domestic as well as international markets and can issue a greater variety of financial instruments. Moreover, if banks have branches in other countries, there may be intra-banking group liquidity transactions, so that the bank's liquidity may depend on the economic fundamentals in those countries as well. Consequentially, the liquidity situation of banks need not be strongly correlated with the liquidity situation of their resident government. Figure A4.2 illustrates this for the case of Ireland. The top panel of Figure A4.2 plots foreign claims of Irish banks on banks in other countries against the Irish government's revenue, both as fractions of Irish GDP. As can be readily gleaned, the linear correlation between the time-series is low. The bottom panel of Figure A4.2 shows claims of banks in foreign countries on Irish banks against the Irish government's revenue, expressed relative to Irish GDP. Once again, the linear correlation between the series is close to zero. The claims of and on Irish banks serve as a proxy for θ_b, while government revenue is captured θ_g. As such, Figure A4.2 provides some evidence in favor of our independence assumption.

- Finally, on purely technical grounds, the assumption of independence allows us to devise a simple proof for the existence of a unique equilibrium in threshold strategies and the non-existence of equilibria in other strategies. The in-

[9] See e.g. DIW (2012).

tuition behind this result is straightforward. Assumption 1 implies that a bank (sovereign) creditor's signal is only informative about the liquidity situation of the bank (sovereign), but completely uninformative about the liquidity of the sovereign (bank). We can therefore treat the behavior of sovereign creditors in the bank roll over game, respectively the bank creditors in the sovereign game, as exogenously given. Hence, given any arbitrary strategy used by creditors in the other group, each roll over game has a unique equilibrium in threshold strategies. The following Proposition summarizes this result.

Proposition 4.2. *There exists a unique equilibrium where sovereign and bank creditors use threshold strategies. There are no other equilibria in non-threshold strategies.*

Proof. See appendix. □

As a consequence of Proposition 4.2 we restrict our attention to threshold strategies for sovereign and bank creditors. Absent a guarantee ($\ell = 0$) the two roll over problems are independent of each other and the critical thresholds for the government and the bank can be calculated from the respective formulae in Proposition 4.1. However, once the government issues a guarantee ($\ell > 0$) its refinancing problem becomes tied to the bank's roll over problem. For states of the world where the bank defaults, the government faces additional costs due to the guarantee payout. This alters the critical threshold for sovereign creditors, which in turn changes the government's default point *in all states of the world*, even in those where the bank survives. Moreover, the possibility that the government may default changes the critical threshold of bank creditors and thus the bank's default point.

We now turn to an explicit derivation of the threshold equilibrium. Firstly, we solve for the bank's and the government's default conditions. Secondly, we exploit the indifference of agents at the threshold signal to characterize the equilibrium.

4.4.2 Bank and sovereign default conditions

The possibility of government default does not alter the bank's failure condition, which remains $\lambda_b N_b > \theta_b$. Suppose that bank creditors use a threshold strategy around $\hat{x}_b$. From equation (4.2) we obtain that the bank's default point $\hat{\theta}_b$ can be written as a function of the critical threshold signal $\hat{x}_b$ as

$$\hat{\theta}_b(\hat{x}_b) = \frac{\hat{x}_b + \varepsilon_b}{1 + 2\varepsilon_b N_b^{-1}}. \tag{4.5}$$

Thus, the bank fails if and only if $\theta_b < \hat{\theta}_b(\hat{x}_b)$.

In calculating the government's failure point we must distinguish between two cases. Firstly, if $\theta_b > \hat{\theta}_b$, the bank survives and the government does not pay out the guarantee. Assuming that government creditors use a symmetric threshold strategy around $\hat{x}_g$, the government defaults whenever $\lambda_g > \theta_g$, where λ_g is the fraction of sovereign creditors whose signals are below $\hat{x}_g$. The government's failure point is calculated as the solution to $\hat{\theta}_g = \lambda_g(\hat{\theta}_g)$, yielding

$$\hat{\theta}_g = \frac{\hat{x}_g + \varepsilon_g}{1 + 2\varepsilon_g}.$$

Secondly, suppose $\theta_b < \hat{\theta}_b$ and the bank defaults. The government is obliged to pay ℓ to each bank creditor who rolled over their loan. Since bank creditors use the threshold strategy around $\hat{x}_b$, we can use equation (4.4) to calculate total guarantee payments conditional on the realized θ_b, as

$$N_b \ell \gamma\left(\theta_b, \hat{x}_b, \hat{\theta}_b \middle| \theta_b < \hat{\theta}_b\right) = \frac{\ell N_b}{2\varepsilon_b} \int_{\hat{x}_b}^{\theta_b + \varepsilon_b} \mathrm{d}u.$$

The government's failure point in case of a bank default then follows by solving

$$\hat{\theta}_g - \frac{\ell N_b}{2\varepsilon_b} \int_{\hat{x}_b}^{\theta_b + \varepsilon_b} \mathrm{d}u = \lambda_g(\hat{\theta}_g)$$

yielding

$$\hat{\theta}_g = \frac{\hat{x}_g + \varepsilon_g}{1 + 2\varepsilon_g} + \frac{\varepsilon_g}{\varepsilon_b} \frac{\ell N_b (\theta_b + \varepsilon_b - \hat{x}_b)}{1 + 2\varepsilon_g}.$$

Taken together, the government's failure point is

$$\hat{\theta}_g(\hat{x}_g, \hat{x}_b, \theta_b) = \begin{cases} \frac{\hat{x}_g + \varepsilon_g}{1 + 2\varepsilon_g} & \text{if } \theta_b \geq \hat{\theta}_b(\hat{x}_b) \\ \frac{\hat{x}_g + \varepsilon_g}{1 + 2\varepsilon_g} + \frac{\ell N_b \varepsilon_g}{\varepsilon_b (1 + 2\varepsilon_g)} (\theta_b + \varepsilon_b - \hat{x}_b) & \text{if } \theta_b < \hat{\theta}_b(\hat{x}_b). \end{cases} \tag{4.6}$$

The government defaults if and only if $\theta_g < \hat{\theta}_g(\hat{x}_g, \hat{x}_b, \theta_b)$.

4.4.3 Creditors' expected payoffs

Given the default points of bank and government, we now turn to the differences in expected payoffs for typical bank and sovereign creditors who observe signals x_{n_b} and x_{n_g}, respectively, and believe that all other bank and sovereign creditors are using the threshold strategy around $\hat{x}_b$ and $\hat{x}_g$.

For the typical bank creditor with signal x_{n_b}, the expected payoff difference between rolling over and withdrawing is given by

$$\pi^b\left(\hat{x}_b, \hat{x}_g, x_{n_b}\right) \equiv \frac{D_b}{2\varepsilon_b}\int_{\hat{\theta}_b(\hat{x}_b)}^{x_{n_b}+\varepsilon_b} \mathrm{d}u + \frac{\ell}{2\varepsilon_b}\int_{x_{n_b}-\varepsilon_b}^{\hat{\theta}_b(\hat{x}_b)}\left(\frac{1}{\sigma_g}\int_{\hat{\theta}_g(\hat{x}_g,\hat{x}_b,u)}^{\widetilde{\sigma}_g}\mathrm{d}v\right)\mathrm{d}u - 1, \tag{4.7}$$

where

$$\sigma_g = (\theta_g^0 + 2\eta_g), \quad \text{and} \quad \widetilde{\sigma}_g = \theta_g^0 + \eta_g,$$

are the width of the support for the θ_g and the upper bound of the support, respectively. The second summand is the payment from the guarantee ℓ multiplied by the probability attached by the bank to the survival of the government.

The difference in expected payoffs from rolling over and withdrawing for a typical sovereign creditor with signal x_{n_g} is

$$\pi^g\left(\hat{x}_g, \hat{x}_b, x_{n_g}\right) \equiv \frac{D_g}{\sigma_b}\int_{-\eta_b}^{\widetilde{\sigma}_b}\left(\frac{1}{2\varepsilon_g}\int_{\hat{\theta}_g(\hat{x}_g,\hat{x}_b,u)}^{x_{n_g}+\varepsilon_g}\mathrm{d}v\right)\mathrm{d}u - C_g, \tag{4.8}$$

where

$$\sigma_b = (\theta_b^0 + 2\eta_b), \quad \text{and} \quad \widetilde{\sigma}_b = \theta_b^0 + \eta_b,$$

are the width of the support for θ_b and the upper bound, respectively. Using the piecewise definition of $\hat{\theta}_g$ from equation (4.6), we can rewrite the double integral in equation (4.8) as

$$\frac{D_g}{\sigma_b}\left(\frac{\sigma_b}{2\epsilon_g}\left(x_{n_g} + \epsilon_g - \frac{\hat{x}_g + \epsilon_g}{1 + 2\epsilon_g}\right) - \frac{\ell N_b}{(1 + 2\varepsilon_g)}\int_{-\eta_b}^{\hat{\theta}_b}\int_{\hat{x}_b}^{u+\varepsilon_b}\frac{\mathrm{d}u}{2\varepsilon_b}\right).$$

Note further that no guarantee payments come due in the case that all bank creditors receive signals $x_{n_b} < \hat{x}_b$ and withdraw. By virtue of the uniform distribution assumption the signals lie on the interval $[\theta_b - \varepsilon_b, \theta_b + \varepsilon_b]$. If the upper bound $\theta_b + \varepsilon_b$ is less than the threshold $\hat{x}_b$, all creditors will withdraw. Thus, for realizations of the fundamental $\theta_b < \hat{x}_b - \epsilon_b$ the bank fails, but because all bank creditors withdrew, no guarantee payout has to be made by the government. Utilizing this fact, we can finally write the payoff difference between rolling over and withdrawing for a sovereign creditor as

$$\pi^g\left(\hat{x}_g, \hat{x}_b, x_{n_g}\right) = \frac{D_g}{2\epsilon_g}\left(x_{n_g} + \epsilon_g - \frac{\hat{x}_g + \epsilon_g}{1 + 2\epsilon_g}\right) - \frac{D_g\,\ell\,N_b}{(1+2\varepsilon_g)\sigma_b}\int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b} \frac{u + \varepsilon_b - \hat{x}_b}{2\varepsilon_b}\mathrm{d}u - C_g. \tag{4.9}$$

4.4.4 Equilibrium

From Proposition 4.2, we know that there exists a unique equilibrium in threshold strategies. Creditors who receive the critical signals $(\hat{x}_b, \hat{x}_b)$ must be indifferent between rolling over and withdrawing. Hence,

$$\pi^b\left(\hat{x}_b, \hat{x}_g, \hat{x}_b\right) = 0, \tag{4.10}$$

and $\pi^b(\hat{x}_b, \hat{x}_g, x_b) \gtreqless 0$ if and only if $x_{n_b} \gtreqless \hat{x}_b$, and

$$\pi^g\left(\hat{x}_g, \hat{x}_b, \hat{x}_g\right) = 0, \tag{4.11}$$

and $\pi^g(\hat{x}_g, \hat{x}_b, x_g) \gtreqless 0$ if and only if $x_{n_g} \gtreqless \hat{x}_g$.

An equilibrium is a combination of critical signals simultaneously solving equations (4.10) and (4.11). We explore the properties of the equilibrium using graphical techniques.

Proposition 4.3. *The solutions to creditors' indifference conditions, equations* (4.10) *and* (4.11) *can be characterized by functions f_b and f_g where $\hat{x}_b = f_b(\hat{x}_g)$ and $\hat{x}_g = f_g(\hat{x}_b)$. Moreover, f_b is strictly increasing, whereas f_g is strictly decreasing.*

Proof. See appendix. □

The functions f_b and f_g can be interpreted as aggregate best response functions between bank and sovereign creditors. The equilibrium of the model is then given by the intersection of the two curves.

Figure 4.2 illustrates the equilibrium. The best response curve for bank creditors, f_b, is strictly increasing over the entire range of $\hat{x}_g$, implying that the actions of

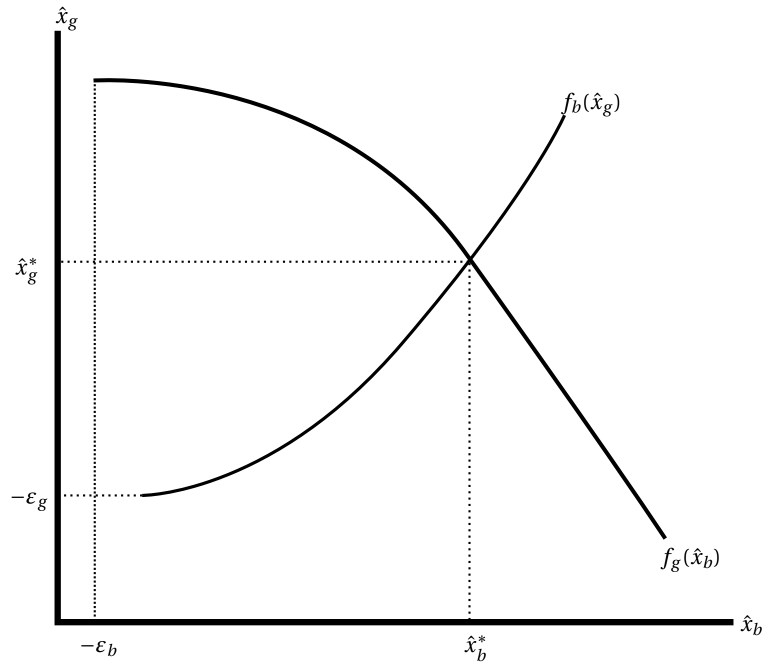


Figure 4.2: Best reply curves f_b and f_g. The joint equilibrium in the roll over games occurs at the intersection point $(\hat{x}_b^*, \hat{x}_g^*)$.

sovereign creditors are *strategic complements* for bank creditors. As sovereign creditors increase their critical signal, the risk of a government default increases and the likelihood that the guarantee will be paid out decreases. In response, bank creditors increase their critical signal as well. In contrast, f_g is strictly decreasing over the entire range of $\hat{x}_b$, implying that the actions of bank creditors are *strategic substitutes* for sovereign creditors. This deserves some comment. We show in the proof of Proposition 4.3 that

$$f_g'(\hat{x}_b) \propto \frac{\partial}{\partial \hat{x}_b}\left(\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b(\hat{x}_b)} (u+\varepsilon_b-\hat{x}_b)\,\mathrm{d}u\right).$$

Suppose that bank creditors increase their critical signal $\hat{x}_b$. This exerts two opposing effects on sovereign creditors' payoffs and thus on their critical signal $\hat{x}_g$. Firstly, a higher $\hat{x}_b$ increases $\hat{\theta}_b$ and enlarges the range of θ_b realizations where the bank may default and the guarantee comes due. This in turn decreases sovereign creditors' expected payoffs from rolling over and induces them to increase their critical signal as well. From the expression above, this effect is up to a constant given by

$$(\hat{\theta}_b + \varepsilon_b - \hat{x}_b)\frac{\partial \hat{\theta}_b}{\partial \hat{x}_b}.$$

There is, however, a second, opposing effect. As $\hat{x}_b$ increases, fewer bank creditors *mistakenly* roll over their debt whenever the bank fails. Consequently, the guarantee payout for the government is lowered. This is true for all states $\theta_b < \hat{\theta}_b$. In turn, the likelihood that the government survives rises and a typical sovereign creditor's expected payoff from rolling over increases. Formally, this effect is, up to the same constant, given by

$$-(\hat{\theta}_b + \varepsilon_b - \hat{x}_b).$$

The second effect outweighs the first one as long as $\varepsilon_b > 0$ since

$$\frac{\partial \hat{\theta}_b}{\partial \hat{x}_b} = \frac{N_b}{N_b + 2\varepsilon_b} < 1\,,$$

leading to the downward sloping aggregate best response curve for the sovereign creditors.

4.4.5 Comparative statics

We now analyze the comparative statics properties of the critical signals with respect to the guarantee size ℓ, the degree of bank's funding illiquidity N_b, and the *ex ante* expected liquidities θ_b^0 and θ_g^0 for bank and government, respectively.

Figure 4.3(a) depicts the effects of a marginal increase in ℓ. The increase shifts the f_b–curve to the left. For any given $\hat{x}_g$, a higher guarantee increases bank creditors' expected payoff from rolling over and lowers their critical signal. The f_g–curve is shifted to the right. For any given $\hat{x}_b$, a higher guarantee lowers the probability that the government survives and, in response, sovereign creditors raise their critical signal. The increase in the guarantee thereby exerts a direct effect on the payoffs for both bank and sovereign creditors. In addition, it exerts an indirect effect through the change in the critical signal of the respective other type of creditors. For sovereign creditors, both effects work in the same direction and produce a clear-cut total effect. For bank creditors, the two effects work in opposite directions. An increase in the critical signal of sovereign creditors lowers bank creditors' expected payoffs from rolling over and thereby countervails the positive effect of the higher guarantee. If, however, the rightward shift in the f_g–curve is sufficiently small, then the latter effect outweighs the former and bank creditors' critical signal is lowered. The following Proposition provides a necessary and sufficient condition for this to occur.

Proposition 4.4. *A marginal increase in the guarantee lowers bank creditors' critical signals, i.e.* $\partial \hat{x}_b / \partial \ell < 0$*, if and only if*

$$\frac{\ell N_b}{\sigma_b} \int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b} \frac{u + \varepsilon_b - \hat{x}_b}{2\varepsilon_b} \mathrm{d}u < \widetilde{\sigma}_g - \hat{\theta}_g(\hat{\theta}_b) \tag{4.12}$$

Proof. See proof of Lemma A4.6 in the appendix. □

The left–hand side of condition (4.12) is the *ex ante* expected guarantee payout, conditional on the government surviving. The right–hand side is the difference between the government's maximal cash–flow, i.e. the upper bound $\widetilde{\sigma}_g$ of the support for θ_g, and the minimal, cash flow it needs to survive. We may interpret the right–hand side as the 'slack' in available liquidity for the government.

A marginal increase in the guarantee induces bank creditors to decrease their critical signal if and only if the *ex ante* expected guarantee payout is less than the government's slack in liquidity. Condition (4.12) can thus be interpreted as a 'credibility condition'. We say that a guarantee $\ell = \tilde{\ell}$ is *credible* if condition (4.12) is satisfied when evaluated at $\ell = \tilde{\ell}$. If condition (4.12) fails to hold, bank creditors may *ex ante* judge government's resources to be insufficient to cover the guarantee promise and respond by raising their critical signal. It is straightforward to show that the condition always holds for $\ell = 0$, implying that the introduction of a small guarantee is always credible and lowers bank creditors' critical signal. However, as the following corollary states, if a guarantee is credible, then further increases in the guarantee can lead to a reversal of the condition, i.e. by increasing the expected burden on the government's budget, the guarantee erodes its own credibility.

Corollary 4.1. *Suppose condition* (4.12) *is satisfied for a given guarantee* $\tilde{\ell}$*. A further marginal increase in the guarantee increases the the* ex ante *expected guarantee payout and simultaneously diminishes the government's slack of liquidity.*

Figure 4.3(b) depicts the effect of an increase in the bank's exposure to funding illiquidity, N_b. A higher degree of funding illiquidity is associated with a higher probability of bank failure and consequently with larger expected guarantee payments.

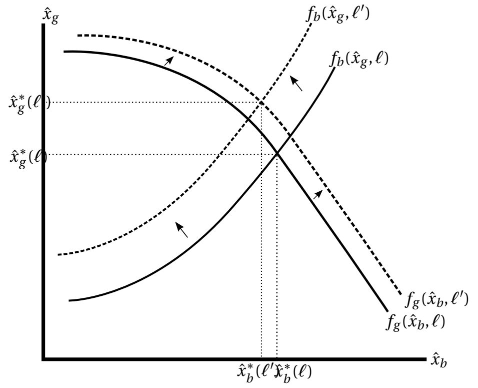
Thus, increases in N_b shift both the f_b– and f_g–curves to the right. This leads to a higher critical signal for bank creditors. From the graphical analysis alone, the sign of the effect on sovereign creditors' critical signal is not clear-cut. On one hand, a larger N_b increases the *ex ante* guarantee payments, which diminishes the government's liquidity and increases the critical signal for sovereign creditors (given ℓ and $\hat{x}_b$). However, as a consequence of strategic substitutability, a higher critical signal for bank creditors makes sovereign creditors more willing to roll over, thereby mitigating the effect on the sovereign creditors' critical signal. As shown in Lemma A4.6 in the appendix, the latter 'substitutability effect' is smaller in magnitude than the former 'complementarities effect', implying that a larger N_b always leads to an increase in sovereign creditors' critical signal.

Figures 4.3(c) and 4.3(d) finally depict the effects of increases in the *ex ante* expected liquidity for the bank θ_b^0 and government θ_g^0 respectively. An increase in θ_b^0 leaves the f_b–curve unaffected and shifts f_g to the left, thereby lowering the critical signals for both, bank and sovereign creditors. The decisions of bank creditors are based on updated information on θ_b that is obtained from the signals x_{n_b}, which do not depend on θ_b^0. Sovereign creditors, on the other hand, do not receive updated information about θ_b, and must instead reply on θ_b^0. A higher *ex ante* liquidity for the bank raises the probability that the bank survives and lowers the government's expected payments due to the guarantee promise. This in turn increases sovereign creditors' expected payoffs from rolling over and lowers their critical signal. By virtue of the strategic complementarities, the lowering of $\hat{x}_g$ leads to a lowering of the critical signal $\hat{x}_b$ for the bank's creditors.

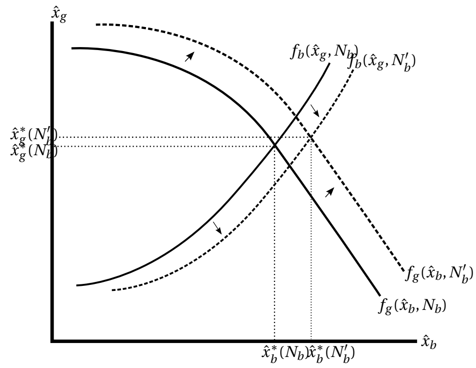
An increase in θ_g^0, on the other hand, has a significantly different effect. Following similar lines of reasoning as above, θ_g^0 affects only bank creditors' expected payoffs and leaves sovereign creditors' expected payoffs unaffected. An increase in θ_g^0 then increases the likelihood that the government manages to roll over its debt and therefore it increases the probability that the guarantee can be paid out. This leads bank creditors to lower their critical signal. However, since the actions of bank creditors are strategic substitutes for sovereign creditors, the critical signal for sovereign creditors is increased.

These results suggest that whenever bank and sovereign are connected through

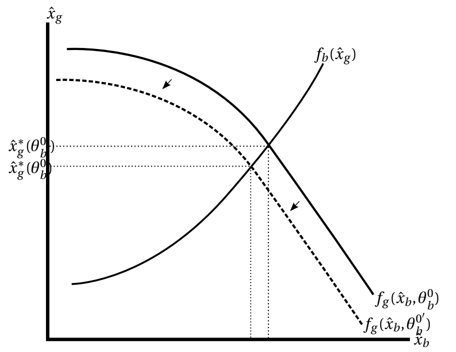
Figure 4.3: Comparative statics of $(\hat{x}_b^*, \hat{x}_g^*)$.



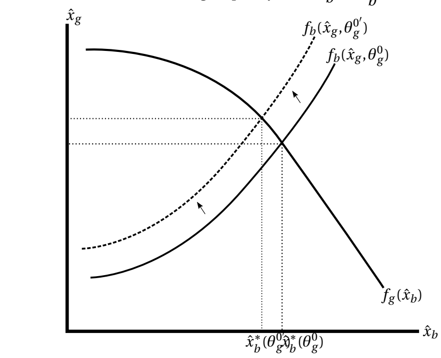
Panel (a): Change in $(\hat{x}_b^*, \hat{x}_g^*)$ due to increase in guarantee from ℓ to ℓ', given that (4.12) holds.



Panel (b): Change in $(\hat{x}_b^*, \hat{x}_g^*)$ due to increase in funding illiquidity from N_b to N_b'.



Panel (c): Change in $(\hat{x}_b^*, \hat{x}_g^*)$ due to increase in bank's expected liquidity from $\theta_b^0/2$ to $\theta_b^{0'}/2$.



Panel (d): Change in $(\hat{x}_b^*, \hat{x}_g^*)$ due to increase in government's expected liquidity from $\theta_g^0/2$ to $\theta_g^{0'}/2$.

the guarantee promise, a positive spill-over effect exists from the bank's liquid resources to the likelihood that the government manages its debt roll over and survives. Similarly, an improvement in the government's *ex ante* liquidity also spills over to the likelihood that the bank survives. Yet, this comes at the cost of a higher critical signal of sovereign creditors which in turn may jeopardize the beneficial effect of the improved θ_g^0 on the government's likelihood of managing the debt roll over.

4.5 The Optimal Guarantee and its Properties

In this section, we determine the optimal guarantee based on a stylized measure for the expected costs of crises. Moreover, we discuss how the guarantee affects the probabilities of sovereign default, bank default, and dual default (a systemic crisis).

4.5.1 A measure for expected costs of crises

In determining the appropriate guarantee to provide the bank's creditors, the government faces a trade–off between lowering the expected costs stemming from a bank default and placing additional strains on its own budget, thereby raising the likelihood that it enters into default itself. We formalize this trade-off by defining a measure for the expected costs of crises, which the government minimizes by setting ℓ optimally.

We denote by ϕ_b the costs incurred when the bank defaults and the government survives. Similarly, ϕ_g denotes the costs from a sovereign default, where the bank survives. Finally, the costs of a systemic crisis, i.e. a crisis where both government and bank default is denoted ϕ_s. We normalize all costs by setting $\phi_s \equiv 1$. We interpret the costs as the loss in the economy's output that materializes following a default event. In particular, ϕ_b results from a disruption in financial intermediation and the reduction in available bank credit in the aftermath of default. Banks typically make sizable investments into screening and monitoring technologies, and build long-term relationships with borrowers. Following a bank default, the soft information accrued is lost and has to be acquired anew, which involves costs for the economy as a whole. Moreover, due to the specificity of this information, some of the bank's borrowers cannot easily find a new bank and may become credit constrained. Such constraints may become binding for households and small businesses which, faced with high costs when attempting to borrow on financial markets directly, are highly dependent on financial intermediation via the banking sector.[10]

Equivalently, ϕ_g is the foregone output due to a sovereign default. The default may impose reputation costs on the government, implying higher borrowing costs in the future or even a full exclusion from financial markets. A government default may also exert a negative effect on trade through either sanctions and retaliations, or through reduced access to trade credit. Moreover, empirically, sovereign default is also associated with an immediate effect on economic growth in the default period.[11]

Denoting by $K(\ell)$ the expected default costs stemming from the different scenarios, the government's objective is to

$$\min_{\{\ell \in [0,1]\}} K(\ell) \equiv \phi_g \left(P_g(\ell) - q(\ell)\right) + \phi_b \left(P_b(\ell) - q(\ell)\right) + q(\ell), \tag{4.13}$$

where $P_g(\ell)$ denotes the probability of government default, $P_b(\ell)$ stands for the probability of bank default and $q(\ell)$ is the probability of a systemic crisis.

We compare the expected costs under the optimally chosen guarantee denoted by $K^{opt} \equiv K(\ell^{opt})$ to two benchmarks, (1) the first–best outcome K^{FB} that occurs in the absence of coordination risks for both sovereign and bank creditors, and (2) the costs $K^0 \equiv K(0)$ incurred in the absence of a guarantee.

Without coordination failures, the government and the bank default if and only if θ_b and θ_g are less than zero. Following the uniform distribution assumption, the first-best benchmark can be calculated as

$$K^{FB} = \phi_g \frac{\eta_g}{\sigma_g} + \phi_b \frac{\eta_b}{\sigma_b} + (1 - \phi_g - \phi_b) \frac{\eta_b}{\sigma_b} \frac{\eta_g}{\sigma_g}. \tag{4.14}$$

While K^{FB} provides a floor to the expected costs, the ceiling is given by the costs incurred in absence of a guarantee, i.e.,

$$K^0 = K^{FB} + \phi_g \frac{C_g/D_g}{\sigma_g} + \phi_b \frac{1/D_b}{\sigma_b} + (1 - \phi_g - \phi_b) \frac{(C_g/D_g + \eta_g)(1/D_b + \eta_b) - \eta_g \eta_b}{\sigma_g \sigma_b}. \tag{4.15}$$

[10] See, for example Leland and Pyle (1977) and Allen and Gale (2001).

[11] See, for example, Eaton and Gersovitz (1981) and Borensztein and Panizza (2009).

4.5.2 Probabilities of crises

In what follows, we write the equilibrium critical signals as $\hat{x}_b^*(\ell)$ and $\hat{x}_g^*(\ell)$ to emphasize their dependency on the guarantee ℓ.[12] The probabilities of bank, government and systemic crises, as expressed in the cost function $K(\ell)$, are

$$P_b(\ell) \equiv \mathbf{Pr}\left(\theta_b < \hat{\theta}_b^*(\ell)\right) \qquad \text{and} \qquad P_g(\ell) \equiv \mathbf{Pr}\left(\theta_g < \hat{\theta}_g^*(\ell)\right),$$

and

$$q(\ell) \equiv \mathbf{Pr}\left(\{\theta_b < \hat{\theta}_b^*(\ell)\} \cap \{\theta_g < \hat{\theta}_g^*(\ell)\}\right)$$

respectively. Moreover, the probability that there is at least one crisis is

$$Q(\ell) \equiv \mathbf{Pr}\left(\{\theta_b < \hat{\theta}_b^*(\ell)\} \cup \{\theta_g < \hat{\theta}_g^*(\ell)\}\right).$$

With respect to the probability of a bank default, the guarantee influences $\hat{\theta}_b^*$ via the critical signal $\hat{x}_b^*$. This can be seen by writing explicitly

$$P_b(\ell) \;=\; \frac{1}{\sigma_b}\int_{-\eta_b}^{\hat{\theta}_b^*(\ell)} \mathrm{d}u \;=\; \frac{\frac{N_b(\hat{x}_b^*(\ell)+\varepsilon_b)}{N_b+2\varepsilon_b} + \eta_b}{\sigma_b}. \tag{4.16}$$

The guarantee's influence on the probability of a government crisis works through two channels. Firstly, there is an effect on the critical signal $\hat{x}_g^*(\ell)$ which induces a level-shift in the default point $\hat{\theta}_g^*(\ell,\theta_b)$. This effect is similar to that induced by the guarantee on the bank's default point $\hat{\theta}_b^*(\ell)$. Secondly, the government's default point depends directly on the bank's liquidity θ_b. This induces a functional interdependence between the likelihood of a government default and the bank's liquidity. Calculating the government's probability of default therefore requires to integrate over both θ_b and θ_g. Formally,

$$\begin{aligned} P_g(\ell) \;&=\; \frac{1}{\sigma_b}\int_{-\eta_b}^{\hat{\theta}_b^*(\ell)} \left(\frac{1}{\sigma_g}\int_{-\eta_g}^{\hat{\theta}_g^*(\ell,u)} \mathrm{d}v\right)\mathrm{d}u \;+\; \frac{1}{\sigma_b}\int_{\hat{\theta}_b^*(\ell)}^{\tilde{\sigma}_b} \mathrm{d}u \,\frac{1}{\sigma_g}\int_{-\eta_g}^{\hat{\theta}_g^*(\ell)} \mathrm{d}v \\ &=\; \frac{\frac{\hat{x}_g^*(\ell)+\varepsilon_g}{1+2\varepsilon_g} + \eta_g}{\sigma_g} \;+\; \frac{1}{\sigma_b\sigma_g}\frac{\ell N_b 2\varepsilon_g}{(1+2\varepsilon_g)}\int_{\hat{x}_b^*-\varepsilon_b}^{\hat{\theta}_b^*(\ell)} \frac{u+\varepsilon_b-\hat{x}_b^*(\ell)}{2\varepsilon_b}\mathrm{d}u, \end{aligned} \tag{4.17}$$

[12] The default points of government and bank are written as $\hat{\theta}_b^*(\ell) \equiv \hat{\theta}_b(\hat{x}_b^*(\ell))$ and $\hat{\theta}_g^*(\ell,\theta_b) \equiv \hat{\theta}_g(\hat{x}_g^*(\ell), \hat{x}_b^*(\ell), \theta_b)$.

where the final term illustrates the functional dependency between the government’s default probability and the bank’s fundamental. This clearly shows how the government’s fate does not exclusively lie in the hand of its own creditors but, through the guarantee, becomes closely tied to that of the bank, even though the liquidity resources that otherwise govern individual default probabilities are fully independent.

In much the same way, the probability of a systemic crisis can be calculated as

$$
\begin{aligned}
q(\ell) &= \frac{1}{\sigma_b}\int_{-\eta_b}^{\hat{\theta}_b^*(\ell)}\left(\frac{1}{\sigma_g}\int_{-\eta_g}^{\hat{\theta}_g^*(\ell,u)}\mathrm{d}v\right)\mathrm{d}u \\
&= \frac{\frac{\hat{x}_g^*(\ell)+\varepsilon_g}{1+2\varepsilon_g}+\eta_g}{\sigma_g}\times\frac{\frac{N_b(\hat{x}_b^*(\ell)+\varepsilon_b)}{N_b+2\varepsilon_b}+\eta_b}{\sigma_b} \quad + \quad \frac{1}{\sigma_b\sigma_g}\frac{\ell N_b 2\varepsilon_g}{(1+2\varepsilon_g)}\int_{\hat{x}_b^*-\varepsilon_b}^{\hat{\theta}_b^*(\ell)}\frac{u+\varepsilon_b-\hat{x}_b^*(\ell)}{2\varepsilon_b}\mathrm{d}u.
\end{aligned}
\tag{4.18}
$$

Figure 4.4 illustrates the impact of the guarantee on the default points $\hat{\theta}_g^*(\ell,\theta_b)$ and $\hat{\theta}_b^*(\ell)$. The guarantee decreases $\hat{x}_b^*(\ell)$ and increases $\hat{x}_g^*(\ell)$. The dotted lines separate the regions of default and survival in absence of the guarantee. The introduction of a guarantee ℓ shifts the bank’s default point to the left (dashed line) and enlarges the region where the bank survives. Moreover, as the guarantee increases the sovereign creditors’ critical signal, the dotted horizontal line moves to the solid line, increasing the region where the government defaults. In the region where the bank defaults (to the left of the dashed line), the government’s default point is a function of θ_b and therefore the solid line slopes upwards.

4.5.3 The influence of transparency on the optimal guarantee

The influence of the guarantee in reducing the likelihood of bank default depends on its ‘credibility’, which in turn is determined by the risk of sovereign default. The pertinent question is then whether, and to what degree, a particular guarantee promise undermines the government’s credibility to pay by placing undue strains on its refinancing needs. As discussed in Section 4.3.6, the costs associated with a guarantee promise are crucially dependent on the degree of balance sheet transparency. To better understand the effects of changes in the degrees of balance sheet transparency, ε_b and ε_g, on the optimal policy, we explore two extreme cases.

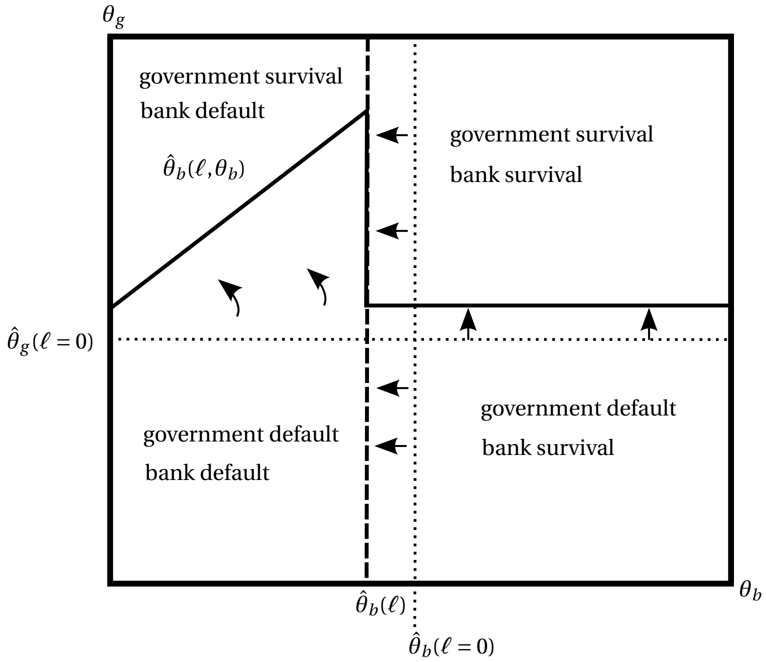


Figure 4.4: Regions of bank and/or sovereign default in θ_b–θ_g–space.

Transparent bank

With a high degree of balance sheet transparency for the bank, i.e. ε_b becoming negligibly small, bank creditors face only strategic uncertainty about the behavior of other bank creditors. The coordination failure of bank creditors can be avoided, at zero cost to the government, by issuing a sufficiently large guarantee promise.[13]

Lemma 4.1. *In the limit when the bank is fully transparent ($\varepsilon_b \to 0$) and for any degree of transparency of the government ($\epsilon_g \geq 0$), the default points for bank and government are given by*

$$\hat{\theta}_b^*(\ell) = \frac{N_b\left(1-\ell(1-P_g)\right)}{D_b-\ell(1-P_g)} \quad \text{and} \quad \hat{\theta}_g^* = \frac{C_g}{D_g},$$

where $P_g = \left(C_g/D_g + \eta_g\right)/\sigma_g$.

Proof. See appendix. □

While the sovereign default risk influences the critical threshold $\theta_b^*(\ell)$, the guarantee does not put any additional strains on the government and its threshold con-

[13] This is the result obtained by Bebchuk and Goldstein (2010).

verges to the one in the canonical model. This implies a clear-cut negative effect of a higher guarantee on the costs of crises $K(\ell)$. The government's program has a corner solution.

Lemma 4.2. *If the bank is fully transparent, the first-order necessary condition for the government's program is given by*

$$K'(\ell) = -\frac{N_b}{\sigma_b}\frac{(1-P_g)(D_b-C_b)}{(D_b-\ell(1-P_g))^2}\left(\left(1-P_g\right)\phi_b + P_g\left(1-\phi_g\right)\right) < 0. \tag{4.19}$$

Proof. See appendix. □

The optimal guarantee for a fully transparent bank is provided in the following proposition.

Proposition 4.5. *If the bank is fully transparent, the optimal guarantee becomes* $\ell^{opt} = 1$*, and it provides a full coverage of bank creditors' claims.*

Proof. See appendix. □

Although the full guarantee diminishes the range of fundamentals where inefficient bank runs occur, it does not completely remove the possibility of inefficient bank failures. As the government itself defaults with probability P_g, even a full guarantee is not enough to achieve $\hat{\theta}_b(1) = 0$. To remove all inefficient bank failures, the government would have to set

$$\ell = \frac{1}{1-P_g} > 1, \tag{4.20}$$

which is tantamount to rewarding bank creditors for a bank failure.

Opaque bank and transparent government

The result presented in Proposition 4.5 depends only on the transparency of the bank and is independent of the government's transparency. Indeed, transparency of the government plays an entirely different role than transparency of the bank. ε_g has no decisive influence on whether the guarantee creates an actual cost or not. Equation (4.17) suggests that higher government transparency can reduce the guarantee's effect on the government's critical threshold in cases where the bank's balance sheet is rather opaque. But even when the government is fully transparent, the optimal policy set out in Proposition 4.5 may change if the bank is opaque. For example, for $\varepsilon_b > 0$ and $\varepsilon_g \to 0$, the default points of bank and government are given by

$$\hat{\theta}_b^*(\ell) = \frac{N_b(\hat{x}_b^*(\ell) + \varepsilon_b)}{N_b + 2\varepsilon_b} \quad \text{and} \quad \hat{\theta}_g^*(\ell) = \hat{x}_g^*(\ell),$$

and the derivative of the cost of crisis function becomes

$$\begin{aligned} K'(\ell) = & \frac{1}{\sigma_b}\left(\phi_b(1 - P_g(\ell)) + (1-\phi_g)P_g(\ell)\right)\frac{N_b}{N_b + 2\varepsilon_b}\frac{\partial \hat{x}_b^*(\ell)}{\partial \ell} \\ & + \frac{1}{\sigma_g}\left(\phi_g(1 - P_b(\ell)) + (1-\phi_b)P_b(\ell)\right)\frac{\partial \hat{x}_g^*(\ell)}{\partial \ell}, \end{aligned} \tag{4.21}$$

with $P_g(\ell) := \frac{\hat{x}_g^*(\ell)+\eta_g}{\sigma_g}$ and $P_b(\ell) := \frac{N_b(\hat{x}_b^*(\ell)+\varepsilon_b+\eta_b)+2\varepsilon_b\eta_b}{\sigma_b(N_b+2\varepsilon_b)}$.

The sign of $K'(\ell)$, and hence the optimal guarantee policy, are no longer parameter–independent. In particular, they crucially depend on the costs of crises ϕ_b and ϕ_g and on the remaining parameters governing the model. While conceptually simple, the government's program does not yield tractable analytical solutions. We therefore resort to a numerical analysis in order to determine the optimal guarantee and examine its dependency on the degrees of transparency and on the parameters governing the liquidity situations of government and bank.

4.6 Numerical Analysis

In this section, we explore the consequences of changes in the degrees of banking sector and government transparency through a set of numerical exercises, where we fix the cost parameters ϕ_b and ϕ_g, associated with bank and sovereign defaults respectively, at some empirically plausible values and where we calibrate, in broad strokes, the model to the Irish economy.

4.6.1 Calibrating the Celtic crisis

According to Table A4.1, the first guarantee scheme introduced by the Irish government covered banking sector liabilities that amounted to 244% of Irish GDP. According to IMF (2011), the refinancing needs of the Irish banks amounted to around 25% of their total liabilities. This roughly equates to refinancing needs in the order of 61%

of GDP. In contrast, the Irish government faced financing needs of only 19.5% of GDP in 2011. This implies that the amount of maturing claims of Irish banks was approximately three times that of the Irish government, resulting in a value of $N_b = 3$, where we maintain $N_g = 1$. Moreover, in line with the experience prior to the crisis, we assume that the risk premia of Irish banks were higher than the risk premium of the Irish government and thus set $D_b = 1.75$ and $D_g = 1.5$. We also set $C_b = C_g = 1$.

To ensure that the dominance regions of the two roll over games are well-defined, we take $\eta_b = 4.01$, $\eta_g = 1.01$, $\theta_b^0 = 3$ and $\theta_g^0 = 4$. Consequently, the banking sector is exposed to a large roll over risk with expected liquidity $\theta_b^0/2$ covering only 50% of total maturing claims. For the government, in contrast, expected liquidity is double the amount of maturing claims.[14]

We normalize the cost of a systemic crisis to $\phi_s = 1$. Cost parameters ϕ_b and ϕ_g are thus interpreted as the output losses due to individual bank and sovereign crises, respectively, relative to the loss due to a systemic crisis. Table 4.5 provides a brief overview of the empirical estimates of such losses. The cumulative output losses associated with a systemic crisis amount to 54% of the pre-crisis GDP. The output loss of a sovereign default only event is at around 10% of GDP. Estimated losses due to a solo banking crisis range from 6.3% to 28% of GDP. For the first exercise in this section we set $\phi_g = 0.2$ (which approximates $\frac{10\%}{54\%} = 0.185 \approx 0.2$) and $\phi_b = 0.1$ (approximating $\frac{6.3\%}{54\%} = 0.116 \approx 0.1$). In the second exercise, we maintain the value of ϕ_g, but we change ϕ_b to 0.5, thus approximating 28%/54%.

In what follows, we measure the welfare gain from introducing the optimal guarantee as

$$\text{welfare} = K^0 - K^{opt}.$$

Moreover, in order to assess the impact of the optimal guarantee on the likelihood of crises, we consider the differences in the probabilities of different crises between having the optimal guarantee and having no guarantee, i.e. we write

$$\Delta P_b \equiv P_b(\ell^{opt}) - P_b(0) \quad \text{and} \quad \Delta P_g \equiv P_g(\ell^{opt}) - P_g(0),$$

[14]The choice of η_b allows for variations of ε_b up to 2, whereas the choice of η_g allows for variations of ε_g up to 0.5. As the preceding sections illustrated, the choice of ε_g is of less importance for the outcome of the model, which is why we restrict ourselves to only a limited range of variations.

Source	Type of crisis	Duration	Average annual output loss
Hoggarth, Reis, and Saporta (2002)	Banking	3.2	1.9%
Honohan and Klingebiel (2000)	Banking	3.5	3.6%
Hutchison and Noy (2005)	Banking	3.3	3.0%
De Paoli, Hoggarth, and Saporta (2009)	Sovereign	4	2.5%
De Paoli, Hoggarth, and Saporta (2009)	Twin (Sovereign and Banking)	11	4.9%
Boyd, Kwa, and Smith (2005)	Banking	5.1	5.4%

Table 4.5: Costs of different types of crises. Output loss in percent of annual GDP. Reported values are the average losses reported in the respective studies.

as well as

$$\Delta Q \equiv Q(\ell^{opt}) - Q(0) \quad \text{and} \quad \Delta q \equiv q(\ell^{opt}) - q(0).$$

4.6.2 Results

Figure 4.5 shows the comparative statics exercises with respect to ε_b and ε_g where we have set $\phi_g = 0.2$ and calibrate the costs of a banking crisis to $\phi_b = 0.1$. As can be seen from Panel (a), a lower degree of transparency in the banking sector (higher ε_b) may decrease the optimal guarantee. Moreover, as the difference between the black, the gray and the dashed gray line in Panel (a) indicates, this effect is more pronounced when the degree of government transparency is also lower (i.e. ε_g is higher). As shown in Panel (b), the expected welfare gain is highest when transparency of banks and government is maximal, amounting to roughly 1.2% of GDP ($\approx 0.022 \times 54\%$). Reductions in the government's transparency are associated with an expected welfare loss of at most 0.27% of GDP. Panels (c)–(f) in Figure 4.5 show how the probability differences ΔQ, Δq, ΔP_b and ΔP_g vary with changes in ε_b and ε_g. As one would expect, the probability of a sovereign crisis rises by the introduction of the optimal guarantee. However, it rises by less than the reduction in the probability of a banking crisis, which in turn explains why the probabilities q and Q are decreasing. Higher bank balance sheet transparency is clearly enhancing the effect of the guarantee on probabilities P_b, q and Q, while it mitigates the adverse effect on P_g. When the bank becomes fully transparent ($\varepsilon_b \to 0$) the introduction of a guarantee comes at no cost for the government and therefore exerts no effect on the probability P_g. Moreover, a less transparent government significantly dampens the effect of the guarantee on all probabilities.

Figure 4.6 shows the numerical results when ϕ_g is kept at 0.2 and when $\phi_b = 0.5$, thereby approximating the highest output loss of a solo banking crisis in Table 4.5. Several important differences emerge compared to the previous exercise. Firstly, as can be seen from Panel (a), given the high costs of a bank default, the government finds it now optimal to provide a full guarantee ($\ell^{opt} = 1$) independent of its own degree of transparency and the degree of bank transparency. Secondly, from Panel (f), ΔP_g increases linearly with lower transparency of the banks, yet it is unaffected by changes in the government's transparency.[15] Thirdly, Panel (c) shows that a combination of low degree of bank and government transparency (high ε_b and ε_g) may now increase the probability of experiencing a systemic crises above the level which obtains in the absence of a guarantee. This effect is basically driven by the increase in ΔP_g, since, from Panel (e), the change in the probability of a banking crisis is rather flat. Quantitatively, this effect seems to be rather small, yet it constitutes a marked qualitative difference to the previous exercise where the costs of a banking crisis were smaller than the costs of a sovereign crisis. Finally, the maximum welfare gain (when government and banking sector are quite transparent) amounts to roughly 2.38% of GDP, which is larger than previously.

A robust finding throughout these numerical exercises is that the increase in the government's default probability is, in absolute magnitude, significantly smaller than the reduction in the bank's default probability. This replicates the empirical behavior of CDS–spreads that we alluded to in the introduction (see Figure 4.1, Panel (d)) and allows to put forward an interpretation of this stylized fact. Recall that in our model, under a regime of full bank transparency ($\varepsilon_b \to 0$), no guarantee payout will ever come due. This implies, as can be seen from the corresponding panels in Figures 4.5 and 4.6, that for a relatively high degree of bank transparency, the sovereign's default probability remains almost unchanged when the guarantee is introduced, whereas the impact on the bank's default probability is large. The guarantee removes strategic uncertainty, thereby serving as a device to coordinate bank creditors on the efficient

[15]This result is robust to other numerical specifications whenever $\phi_b > \phi_g$.

equilibrium. When the degree of bank transparency becomes smaller, the mass of bank creditors who may eventually claim the guarantee increases and, in case the bank defaults, the guarantee creates an actual cost burden for the government. As a result, the government's default probability begins to increase. The large decrease in CDS spreads across countries (and especially in Ireland), that was observed right after the issuance of bank debt guarantees, may therefore mirror the removal of strategic uncertainty among bank creditors. However, sovereign CDS–spreads increased at the same time, suggesting that the corresponding banking sectors may not have operated under a regime of full transparency. Market participants in sovereign funding markets may have conjectured that the guarantees would create an actual cost for the sovereign and therefore withdrew funding.

Moreover, while it is tempting to criticize the Irish government for having provided an enormous guarantee, at least our numerical exercises suggest that even such a guarantee may have been the optimal one. In particular, as Ireland's financial industry constituted an important sector of its economy, the output costs of an economy–wide banking crisis may have been quite so large that for any degree of transparency, the government would have considered a 100% coverage optimal (see exercise in Figure 4.6). Yet, if transparency was rather low, such a policy may have contributed to heighten *ex ante* the likelihood of the systemic crisis which Ireland eventually experienced. Figure 4.6 suggests that, given the strong reduction in the probability of a relatively costly banking crisis, the government may optimally drive up the likelihood of its own default, which is less costly, to avert the cost burden of a banking crisis, even if this also means to raise the probability of a systemic crisis above the level in absence of a guarantee.

4.7 Conclusion

In this chapter we have analyzed the effects of a bank debt guarantee provided by the government and the role of the degree of balance sheet transparency in making the guarantee costly. To examine this phenomenon, we used a stylized global games framework to address the following questions: (i) How does the introduction of a bank liability guarantee by a government affect the behavior of banking and sovereign creditors? (ii) How does the guarantee affect the likelihood of crises? (iii)

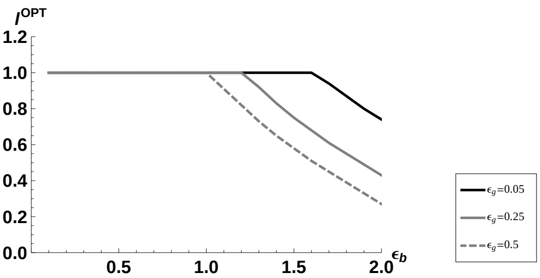
What is the optimal guarantee that trades off the expected costs associated with the different types of crises? and (iv) How do changes in the parameters governing fundamental uncertainty/transparency and liquidity impact on the optimal guarantee?

As the guarantee promise increases the sovereign's expected liabilities, sovereign creditors may lend to the government less often, thereby increasing the government's own likelihood of default. This in turn can jeopardize the effectiveness of the guarantee as bank creditors become less eager to rely on the guarantee when they expect that the government becomes unable to fund its promises.

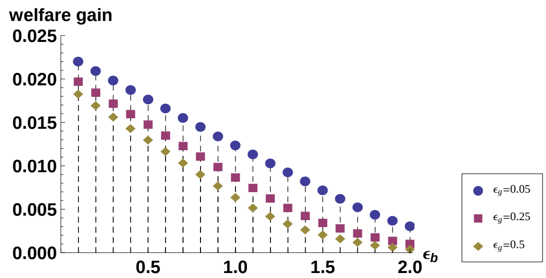
Proposition 4 provides a necessary and sufficient condition for the guarantee to be effective in raising the incentives of bank creditors to roll over their loans. Moreover, our model provides a theoretical foundation for the empirically observed behavior of credit default spreads during the recent crisis across the different countries which issued bank debt guarantees. Our results show a clear–cut welfare improvements with greater transparency lowering fundamental uncertainty. This would suggest that in designing guarantee schemes, authorities can improve on their credibility by mandating greater disclosure on the part of the banks. These findings are in line with the new approaches being sought by several countries, as discussed in the Basel Committee for Banking Supervision (2011) report. Moreover, by improving on the government's own transparency, these gains can be further enhanced.

While reduced form, the model captures key strategic interactions across sovereign and bank creditors in the design of optimal guarantee schemes that are often assumed exogenous. Such cautionary tales equally apply to the design of new regulations, where authorities focus on effects in partial, rather than general equilibrium models.

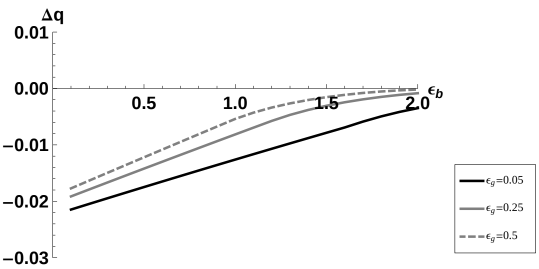
Figure 4.5: Comparative statics of ε_b and ε_g with $\phi_b = 0.1$ and $\phi_g = 0.2$



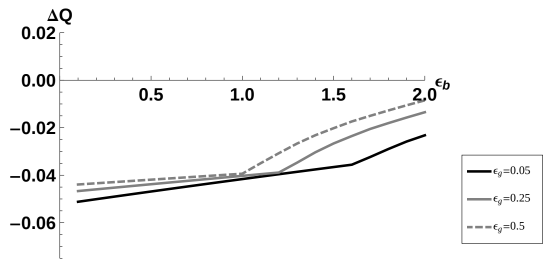
Panel (a): Optimal guarantee: ℓ^{opt}



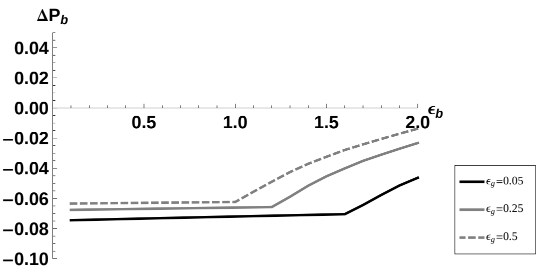
Panel (b): Welfare gain: $K^0 - K^{opt}$



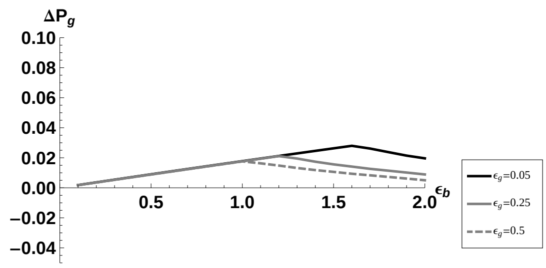
Panel (c): Change in probability of systemic crisis: Δq



Panel (d): Change in probability of any crisis: ΔQ

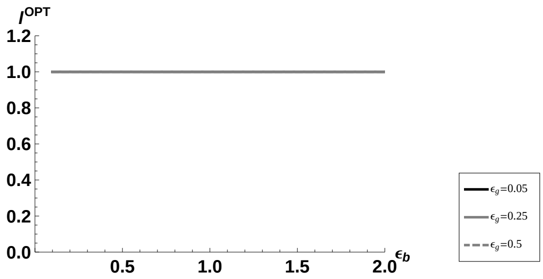


Panel (e): Change in probability of banking crisis: ΔP_b

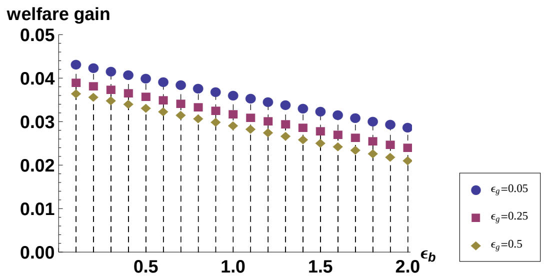


Panel (f): Change in probability of sovereign crisis: ΔP_g

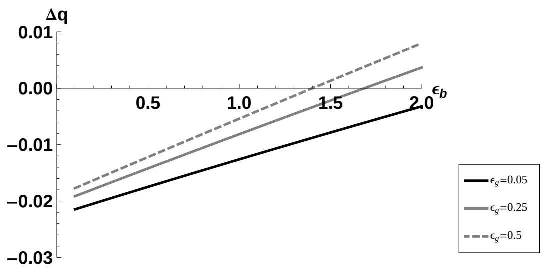
Figure 4.6: Comparative statics of ε_b and ε_g with $\phi_b = 0.5$ and $\phi_g = 0.2$



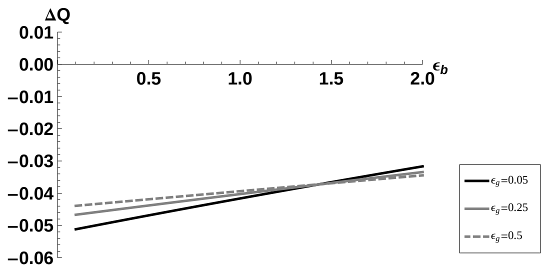
Panel (a): Optimal guarantee: ℓ^{opt}



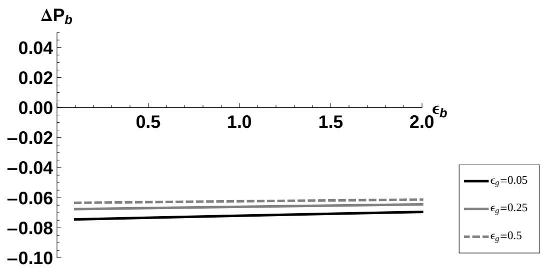
Panel (b): Welfare gain: $K^0 - K^{opt}$



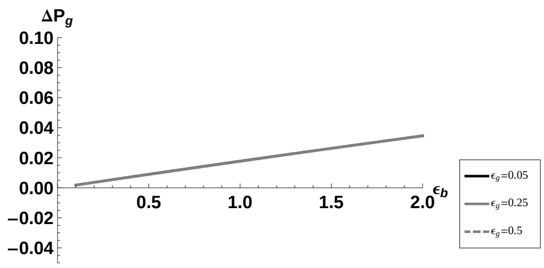
Panel (c): Change in probability of systemic crisis: Δq



Panel (d): Change in probability of any crisis: ΔQ



Panel (e): Change in probability of banking crisis: ΔP_b

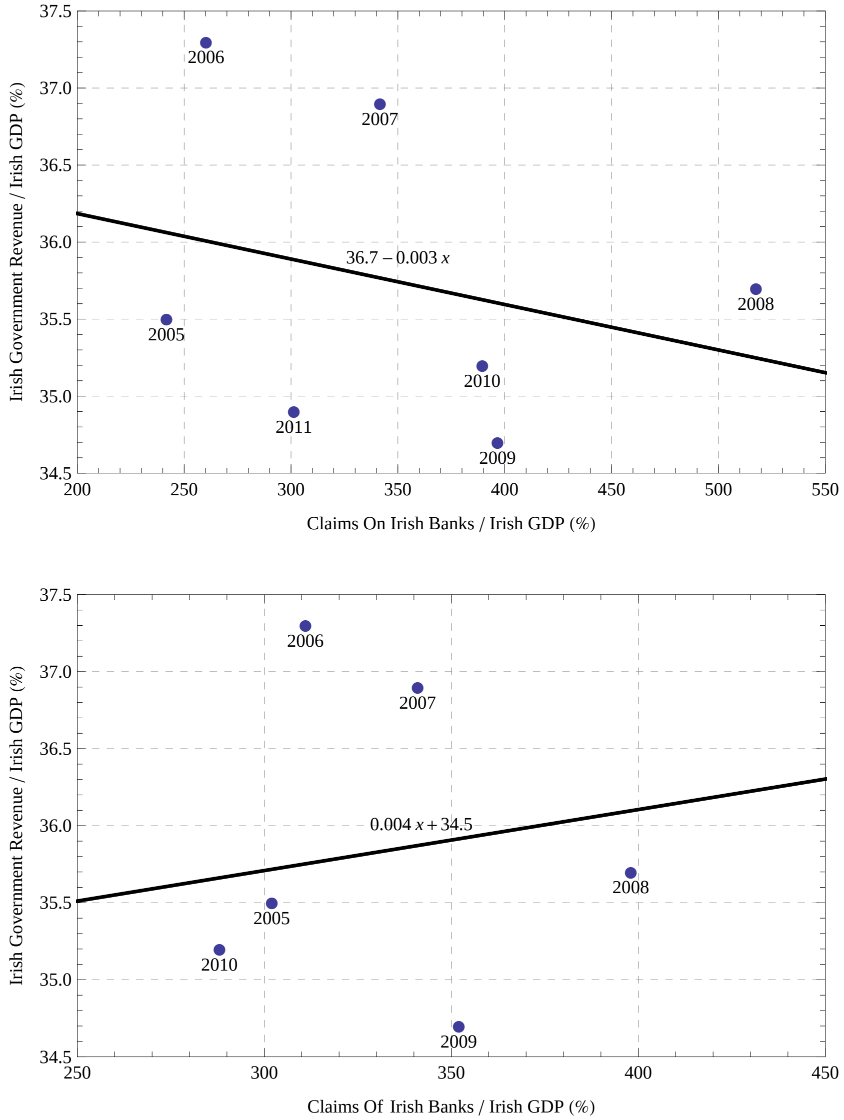


Panel (f): Change in probability of sovereign crisis: ΔP_g

Country	Name of program	Issued	Tenor	Size	GDP	Size	GSD	Size
				(bn of domestic currency)	(bn of domestic currency)	(% of GDP)	(bn of domestic currency)	(% of GSD)
Austria	Interbank Market Support Act (Finanzmarktstabilisierungs-gesetz)	Oct 2008	3-5 years	75	283	27%	181	42%
France	Société de Refinancement des Activités des Etablissements de Crédit	Oct 2008	5 years	265	1,931	14%	1,319	20%
Ireland	Financial Support Act 2008	Oct 2008	2 years	440	180	244%	80	553%
Ireland	Eligible Liabilities Guarantee Scheme 2009	Dec 2009	5 years	150	161	93%	105	143%
Italy	Italian Guarantee Scheme	Nov 2008	5 years	40	1,575	3%	1,667	2%
Netherlands	2008 Credit Guarantee Scheme	Oct 2008	5 years	200	594	34%	348	58%
Portugal	Portuguese State Guarantee Scheme 2008	Oct 2008	3 years	20	172	12%	123	16%
Spain	Spanish Guarantee Scheme	Dec 2008	5 years	100	1,088	9%	437	23%
United Kingdom	2008 Credit Guarantee Scheme	Oct 2008	3 years	250	1,434	17%	752	33%

Table A4.1: Summary of guarantee schemes introduced in several developed economies following the collapse of Lehman Brothers. All monetary figures are provided in the country of origin's local currency. The column labeled 'Size' refers to the size of the guarantee; 'GDP' refers to the Gross Domestic Product; 'GSD' stands for Gross Sovereign Debt.

Figure A4.2: Claims on and of Irish banks vs. the Irish government’s revenue as fractions of Irish GDP.



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Appendix

Proof of Proposition 4.1. Morris and Shin (2003) show that the model has a unique symmetric threshold equilibrium where creditors use the strategy around $\hat{x}_b$ and the bank defaults whenever $\theta_b < \hat{\theta}_b$. The creditor who observes $x_{n_b} = \hat{x}_b$ must therefore be indifferent between rolling over and withdrawing. Thus, the expected payoff difference between rolling over and withdrawing is given by

$$D_b \mathbf{Pr}\left(\theta_b > \hat{\theta}_b \middle| \hat{x}_b\right) + \ell \mathbf{Pr}\left(\theta_b \leq \hat{\theta}_b \middle| \hat{x}_b\right) - C_b = 0, \tag{A4.1}$$

which, by using the assumed uniform distributions, can be written as

$$\frac{D_b - C_b}{D_b - \ell} = \frac{1}{2\varepsilon_b} \int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b} \mathrm{d}u. \tag{A4.2}$$

Due to the law of large numbers, $\lambda_b(\theta_b) = \mathbf{Pr}\left(x_{n_b} \leq \hat{x}_b \middle| \theta_b\right) = \frac{\int_{\theta_b - \varepsilon_b}^{\hat{x}_b} \mathrm{d}u}{2\varepsilon_b}$. Combining the latter with failure condition (4.1) yields

$$\frac{1}{2\varepsilon_b} \int_{\hat{\theta}_b - \varepsilon_b}^{\hat{x}_b} \mathrm{d}u = \frac{\hat{\theta}_b}{N_b}. \tag{A4.3}$$

From equation (A4.2),

$$1 - \frac{D_b - C_b}{D_b - \ell} = \frac{C_b - \ell}{D_b - \ell} = 1 - \frac{1}{2\varepsilon_b} \int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b} \mathrm{d}u = \frac{1}{2\varepsilon_b} \int_{\hat{\theta}_b - \varepsilon_b}^{\hat{x}_b} \mathrm{d}u,$$

and combining the latter with equation (A4.3) gives equation (4.3) in the text,

$$\frac{N_b \left(C_b - \ell\right)}{D_b - \ell} = \hat{\theta}_b.$$

Moreover, solving equation (A4.3) for $\hat{x}_b$, gives equation (4.2) in the text,

$$\frac{1}{2\varepsilon_b} \int_{\hat{\theta}_b - \varepsilon_b}^{\hat{x}_b} \mathrm{d}u = \frac{\hat{x}_b - \hat{\theta}_b + \varepsilon_b}{2\varepsilon_b} = \frac{\hat{\theta}_b}{N_b} \quad \Rightarrow \hat{x}_b = \hat{\theta}_b \left(1 + \frac{2\varepsilon_b}{N_b}\right) - \varepsilon_b.$$

□

Proof of Proposition 4.2. By our assumption on the independence between random variables θ_b and θ_g, we can consider each game separately and treat the fundamental and the strategy in the respective other game as exogenously given. Thus, as shown in the following Lemmas A4.3 and A4.4, bank creditors respond to any strategy played by sovereign creditors by using a unique threshold strategy. Moreover, as shown in Lemma A4.5, government creditors respond to any strategy played by bank creditors by using a unique threshold strategy. As a direct consequence, the unique equilibrium in the model is a threshold equilibrium. □

To prove Lemmas A4.3 - A4.5, the following Claims A4.1 and A4.2 provide some properties of the payoff differentials of bank and sovereign creditors respectively.

Denote the fraction of bank creditors who withdraw by λ_b and suppose that government creditors play any symmetric strategy $s_g(x_{n_g})$. Given the government's liquidity θ_g, we can write the fraction of government creditors who withdraw as $\int_{\theta_g-\varepsilon_g}^{\theta_g+\varepsilon_g} s(x_{n_g})\mathrm{d}x_{n_g}$. The payoff differential between rolling over and withdrawing for a typical bank creditor can then be written as

$$\pi^b(\theta_b,\lambda_b,\theta_g,s_g(\cdot)) = \begin{cases} D_b - C_b & \text{if } \lambda_b < \theta_b,\ \forall\theta_g \\ \ell - C_b & \text{if } \lambda_b > \theta_b,\ \int_{\theta_g-\varepsilon_g}^{\theta_g+\varepsilon_g} s_g(x_{n_g})\mathrm{d}x_{n_g} < \theta_g - (1-\lambda_b)\ell \\ -C_b & \text{if } \lambda_b > \theta_b,\ \int_{\theta_g-\varepsilon_g}^{\theta_g+\varepsilon_g} s_g(x_{n_g})\mathrm{d}x_{n_g} > \theta_g - (1-\lambda_b)\ell. \end{cases} \tag{A4.4}$$

Claim A4.1. *The bank creditors' payoff differential* (A4.4) *has the following properties.*

1. *Action single-crossing in λ_b: For any θ_b and θ_g, there exists λ_b^* such that $\pi^b > 0$ for any $\lambda_b < \lambda^*$ and $\pi^b < 0$ for any $\lambda_b > \lambda_b^*$.*
2. *State monotonicity in θ_b: π^b is non-decreasing in θ_b.*
3. *Laplacian State Monotonicity: There exists a unique θ_b^* such that*

$$\int_0^1 \pi(\theta_b^*,\lambda_b,\theta_g,s_g(\cdot))\mathrm{d}\lambda_b = 0.$$

4. *Uniform Limit Dominance: There exist $\underline{\theta}_b$ and $\overline{\theta}_b$ such that $\pi^b < -\delta$ for $\theta_b < \underline{\theta}_b$ and $\pi^b > \delta$ for $\theta_b > \overline{\theta}_b$ for some $\delta > 0$.*

Moreover, the noise distribution satisfies

5. *Monotone Likelihood Property.*
6. *Finite expectations of signals.*

Proof of Claim A4.1.

1. Note that $D_b - C_b > 0 > \ell - C_b > -C_b$. Action single-crossing then follows by setting $\lambda_b^* = \theta_b$.
2. Can be inferred immediately from equation (A4.4).
3. We can write the integral $\int_0^1 \pi(\theta_b,\lambda_b,\theta_g,s_g(\cdot))\mathrm{d}\lambda_b$ as follows

$$(D_b - C_b)\int_0^{\theta_b}\mathrm{d}\lambda_b - C_b\int_{\theta_b}^{\min\left\{1,1-\ell^{-1}(\theta_g - \int_{\theta_g-\varepsilon_g}^{\theta_g+\varepsilon_g} s_g(x_{n_g})\mathrm{d}x_{n_g})\right\}}\mathrm{d}\lambda_b$$
$$+ (\ell - C_b)\int_{\min\left\{1,1-\ell^{-1}(\theta_g - \int_{\theta_g-\varepsilon_g}^{\theta_g+\varepsilon_g} s_g(x_{n_g})\mathrm{d}x_{n_g})\right\}}^1 \mathrm{d}\lambda_b = 0.$$

   As the left hand side of the equality sign is negative for $\theta_b = 0$, positive for $\theta_b = 1$ and otherwise strictly increasing in θ_b, there exists a unique θ_b^* such that $\int_0^1 \pi(\theta_b^*,\lambda_b,\theta_g,s_g(\cdot))\mathrm{d}\lambda_b = 0$.
4. The claim follows by setting $\underline{\theta}_b = 0$, $\overline{\theta}_b = 1$ and $\delta = \min\{C_b - \ell, D_b - C_b\}$.
5. Uniform noise satisfies MLRP, see (Shao, 2003, p. 399).

6. This follows immediately from the assumption of a uniform distribution with bounded support.

□

Suppose that bank creditors play any strategy $s_b(x_{n_b})$. Given any θ_b, we can then write the fraction of bank creditors who withdraw as $\int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\mathrm{d}x_{n_b}$. The payoff differential between rolling over and withdrawing for a typical government creditor is then given by

$$\pi^g(\theta_g,\lambda_g,\theta_b,s_b(\cdot)) = \begin{cases} D_g - C_g & \text{if } \lambda_g < \theta_g,\ \int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\mathrm{d}x_{n_b} < \theta_b \\ D_g - C_g & \text{if } \lambda_g < \theta_g - (1-\int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\mathrm{d}x_{n_b})\ell,\ \int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\mathrm{d}x_{n_b} > \theta_b \\ -C_g & \text{if } \lambda_g > \theta_g - (1-\int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\mathrm{d}x_{n_b})\ell,\ \int_{\theta_b-\varepsilon_b}^{\theta_b+\varepsilon_b} s_b(x_{n_b})\mathrm{d}x_{n_b} > \theta_b \\ -C_g & \text{if } \lambda_g > \theta_g,\ \forall\theta_b. \end{cases} \tag{A4.5}$$

Claim A4.2. *Government creditors' payoff differential* (A4.5) *has the following properties.*

1. *Action monotonicity in λ_g: π^g is non-increasing in λ_g.*
2. *State monotonicity in θ_g: π^g is non-decreasing in θ_g.*
3. *Laplacian State Monotonicity: There exists a unique θ_g^* such that*

$$\int_0^1 \pi(\theta_g^*,\lambda_g,\theta_b,s_b(\cdot))\mathrm{d}\lambda_g = 0.$$

4. *Uniform Limit Dominance: There exist $\underline{\theta}_g$ and $\overline{\theta}_g$ such that $\pi_g < -\delta$ for $\theta_g < \underline{\theta}_g$ and $\pi_g > \delta$ for $\theta_g > \overline{\theta}_g$ for some $\delta > 0$.*

Moreover, the noise distribution satisfies

5. *Monotone Likelihood Property.*
6. *Finite expectations of signals.*

Proof of Claim A4.2.

1. Suppose $\theta_b > \lambda_b$, then, since $D_g - C_g > -C_g$, π^g is clearly non-increasing in λ_g for any θ_g. Similarly for the case where $\theta_b < \lambda_b$.
2. Suppose $\theta_b > \lambda_b$, then π^g is increasing in θ_g for any λ_g. Similarly for $\theta_b < \lambda_b$.
3. If $\theta_b > \lambda_b$, then $\theta_g^* = C_g/D_g$. If $\theta_b < \lambda_b$, then $\theta_g^* = C_g/D_g + (1-\lambda_b)\ell$.
4. This follows by setting $\overline{\theta}_g = 1+\ell$ and $\underline{\theta}_g = 0$ and $\delta = D_g - C_g$.
5. Uniform noise satisfies MLRP, see (Shao, 2003, p. 399).
6. This follows immediately from the assumption of a uniform distribution with bounded support.

□

Lemma A4.3. *For any strategy $s_g(\cdot)$ played by government creditors, the roll over game between bank creditors has a unique threshold equilibrium.*

Proof of Lemma A4.3. Since the payoff differential satisfies properties (1) to (6) in Claim A4.1, the Lemma follows from Morris and Shin (2003, Lemma 2.3). □

Lemma A4.4. *There are no other equilibria in non-threshold strategies.*

Proof of Lemma A4.4. Since noise terms are uniformly distributed and the payoff differential satisfies action single-crossing, the Lemma follows immediately from the proof to Goldstein and Pauzner (2005, Theorem 1). □

Lemma A4.5. *For any strategy $s_b(\cdot)$ played by bank creditors, the roll over game between government creditors has a unique equilibrium in threshold strategies. Moreover, there are no equilibria in non-threshold strategies.*

Proof of Lemma A4.5. Since the payoff differential satisfies properties (1) to (6) in Claim A4.2, the Lemma follows immediately from Morris and Shin (2003, Proposition 2.2). □

Proof of Proposition 4.3. From the proof of Proposition 4.2 follows that each game has a unique equilibrium in threshold strategies. That is, for given $\hat{x}_g$, there exists a unique $\hat{x}_b$ that satisfies equation (4.10) and for given $\hat{x}_b$, there exists a unique $\hat{x}_g$ that satisfies (4.11). To see this directly, fix $\hat{x}_g$. Due to the existence of dominance regions there exist $\underline{\hat{x}}_b$ and $\overline{\hat{x}}_b$ such that $\pi^b(\hat{x}_b, \hat{x}_g, \hat{x}_b) < 0$ for any $\hat{x}_b < \underline{\hat{x}}_b$, and $\pi^b(\hat{x}_b, \hat{x}_g, \hat{x}_b) > 0$ for any $\hat{x}_b > \overline{\hat{x}}_b$. Similarly, for $\pi^g(\hat{x}_g, \hat{x}_b, \hat{x}_g)$. Since $\pi^b(\cdot)$ and $\pi^g(\cdot)$ are continuous they both cross the x-axis at least once. To show that there exists exactly one threshold signal, it suffices to show that $\pi^b(\hat{x}_b, \hat{x}_g, \hat{x}_b)$ is strictly increasing in $\hat{x}_b$ and $\pi^g(\hat{x}_g, \hat{x}_b, \hat{x}_g)$ is strictly increasing in $\hat{x}_g$.

The derivative of $\pi^g(\cdot)$ with respect to $\hat{x}_g$ is given by

$$\frac{\partial \pi^g(\hat{x}_g, \hat{x}_b, \hat{x}_g)}{\partial \hat{x}_g} = \frac{D_g}{1+2\varepsilon_g} > 0, \tag{A4.6}$$

where we have used

$$\frac{\partial \hat{\theta}_g}{\partial \hat{x}_g} = \frac{1}{1+2\varepsilon_g} \quad \forall \theta_b.$$

Next, consider the derivative of π^b with respect to $\hat{x}_b$. Observe first that $\hat{\theta}'_b(\hat{x}_b) = N_b(N_b+2\varepsilon_b)^{-1}$ and $(1-\hat{\theta}'_b(\hat{x}_b)) = 2\varepsilon_b(N_b+2\varepsilon_b)^{-1}$. Moreover, if $\theta_b < \hat{\theta}_b$, then $\partial\hat{\theta}_g/\partial\hat{x}_b = -\ell N_b \varepsilon_g(\varepsilon_b(1+2\varepsilon_g))^{-1}$. Let $\hat{\theta}_g^T := (\hat{x}_g + \varepsilon_g)(1+2\varepsilon_g)^{-1}$, so that we can write $\hat{\theta}_g(\hat{x}_g, \hat{x}_b, \theta_b) = \hat{\theta}_g^T + \frac{\ell N_b \varepsilon_g}{1+2\varepsilon_g}\frac{\theta_b - \hat{x}_b + \varepsilon_b}{N_b + 2\varepsilon_b}$, while $\hat{\theta}_g(\hat{x}_g, \hat{x}_b, \hat{x}_b - \varepsilon_b) = \hat{\theta}_g^T$. Using these facts and definitions, the derivative of $\pi^b(\cdot)$ with respect to $\hat{x}_b$ is given by

$$\begin{aligned}
\frac{\partial \pi^b\left(\hat{x}_b, \hat{x}_g, \hat{x}_b\right)}{\partial \hat{x}_b} &= \frac{D_b}{2\varepsilon_b}\left(1-\hat{\theta}'_b(\hat{x}_b)\right) + \frac{\ell}{2\varepsilon_b}\left(\frac{\hat{\theta}'_b(\hat{x}_b)}{\sigma_g}\int_{\hat{\theta}_g(\hat{x}_g,\hat{x}_b,\hat{\theta}_b)}^{\tilde{\sigma}_g} \mathrm{d}v - \frac{1}{\sigma_g}\int_{\hat{\theta}_g(\hat{x}_g,\hat{x}_b,\hat{x}_b-\varepsilon_b)}^{\tilde{\sigma}_g} \mathrm{d}v - \int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b} \frac{\frac{\partial \hat{\theta}_g(\cdot)}{\partial \hat{x}_b}}{\sigma_g} \mathrm{d}u\right) \\
&= \frac{D_b}{N_b+2\varepsilon_b} + \frac{\ell}{2\varepsilon_b\sigma_g}\left(\frac{N_b}{N_b+2\varepsilon_b}\left(\theta_g^0 + \eta_g - \hat{\theta}_g(\hat{\theta}_b)\right) - \left(\theta_g^0 + \eta_g - \hat{\theta}_g^T\right) + \left(\frac{\ell N_b 2\varepsilon_g}{1+2\varepsilon_g}\frac{(N_b - \hat{x}_b + \varepsilon_b)}{N_b+2\varepsilon_b}\right)\right) \\
&= ((N_b+2\varepsilon_b)\sigma_g)^{-1}\left[\sigma_g D_b - \ell(\tilde{\sigma}_g - \hat{\theta}_g^T) + \frac{\ell}{2\varepsilon_b}\left(\frac{\ell N_b 2\varepsilon_g}{1+2\varepsilon_g}\left(1-\frac{N_b}{N_b+2\varepsilon_b}\right)(N_b - \hat{x}_b + \varepsilon_b)\right)\right].
\end{aligned} \tag{A4.7}$$

Now observe that $\sigma_g D_b - \ell(\widetilde{\sigma}_g - \hat{\theta}_g^T) = \sigma_g \left(D_b - \ell \frac{(\widetilde{\sigma}_g - \hat{\theta}_g^T)}{\sigma_g} \right) > 0$ since $D_b > \ell$ and $\frac{(\widetilde{\sigma}_g - \hat{\theta}_g^T)}{\sigma_g} \le 1$ because it is a probability. Furthermore $N_b + \varepsilon_b - \hat{x}_b \ge 0$ because the existence of an upper dominance region implies that $\hat{x}_b$ is bounded above by $N_b + \varepsilon_b$. Thus, $\frac{\partial \pi^b(\hat{x}_b, \hat{x}_g, \hat{x}_b)}{\partial \hat{x}_b} > 0$.

The existence of functions f_b and f_g follows by applying the implicit function theorem to equations (4.10) and (4.11). The slopes of the two functions are given by

$$f_b'(\hat{x}_g) = -\frac{\partial \pi^b / \partial \hat{x}_g}{\partial \pi^b / \partial \hat{x}_b} \quad \text{and} \quad f_g'(\hat{x}_b) = -\frac{\partial \pi^g / \partial \hat{x}_b}{\partial \pi^g / \partial \hat{x}_g}.$$

We have $f_b' > 0$, since

$$\frac{\partial \pi^b}{\partial \hat{x}_g} = -\frac{\ell}{2\varepsilon_b} \int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b} \frac{1}{\sigma_g} \mathrm{d}u < 0, \tag{A4.8}$$

and $f_g' < 0$, because

$$\begin{aligned} \frac{\partial \pi^g}{\partial \hat{x}_b} &= -\frac{D_g \ell N_b}{2\varepsilon_b \sigma_b (1 + 2\varepsilon_g)} \frac{\partial}{\partial \hat{x}_b} \left(\int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b(\hat{x}_b)} (u + \varepsilon_b - \hat{x}_b) \, \mathrm{d}u \right) \\ &\propto -\frac{\partial}{\partial \hat{x}_b} \left(\int_{\hat{x}_b - \varepsilon_b}^{\hat{\theta}_b(\hat{x}_b)} (u + \varepsilon_b - \hat{x}_b) \, \mathrm{d}u \right) \\ &= (\hat{\theta}_b + \varepsilon_b - \hat{x}_b) \left(1 - \frac{\partial \hat{\theta}_b}{\partial \hat{x}_b} \right) > 0, \end{aligned} \tag{A4.9}$$

since $\frac{\partial \hat{\theta}_b}{\partial \hat{x}_b} = \frac{N_b}{N_b + 2\varepsilon_b} < 1$. □

Lemma A4.6. *The signs of the derivatives of the critical signals $\hat{x}_b$ and $\hat{x}_g$ with respect to parameters $\{\ell, N_b, \theta_b^0, \theta_g^0\}$ are given by*

$$\begin{aligned} &\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\ell} > 0 \quad \textit{and} \quad \frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\ell} \lesseqgtr 0 \\ &\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}N_b} > 0, \quad \textit{and} \quad \frac{\mathrm{d}\hat{x}_g}{\mathrm{d}N_b} > 0 \\ &\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\theta_b^0} < 0 \quad \textit{and} \quad \frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\theta_b^0} < 0 \\ &\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\theta_g^0} < 0 \quad \textit{and} \quad \frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\theta_g^0} > 0. \end{aligned}$$

Proof of Lemma A4.6. Let $\xi = (\ell, N_b, \theta_b^0, \theta_g^0)$ with typical element ξ_k. The total effects $\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\xi_k}$ and $\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\xi_k}$ can be found by applying the implicit function theorem to the set of equations

$$\begin{aligned} \pi^g(\hat{x}_g, \hat{x}_b, \xi) &= 0 \\ \pi^b(\hat{x}_b, \hat{x}_g, \xi) &= 0. \end{aligned}$$

The Jacobian of this system is given by

$$\mathbf{J} = \begin{pmatrix} \frac{\partial \pi^b}{\partial \hat{x}_b} & \frac{\partial \pi^b}{\partial \hat{x}_g} \\ \frac{\partial \pi^g}{\partial \hat{x}_b} & \frac{\partial \pi^g}{\partial \hat{x}_g} \end{pmatrix} = \begin{pmatrix} (+) & (-) \\ (+) & (+) \end{pmatrix},$$

and thus its determinant is positive, $|\mathbf{J}| > 0$.

The total effects can be computed as

$$\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\xi_k} = \frac{\begin{vmatrix} -\frac{\partial \pi^b}{\partial \xi_k} & \frac{\partial \pi^b}{\partial \hat{x}_g} \\ -\frac{\partial \pi^g}{\partial \xi_k} & \frac{\partial \pi^g}{\partial \hat{x}_g} \end{vmatrix}}{|\mathbf{J}|} = \frac{-\frac{\partial \pi^b}{\partial \xi_k}\frac{\partial \pi^g}{\partial \hat{x}_g} + \frac{\partial \pi^b}{\partial \hat{x}_g}\frac{\partial \pi^g}{\partial \xi_k}}{|\mathbf{J}|}. \tag{A4.10}$$

and

$$\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\xi_k} = \frac{\begin{vmatrix} \frac{\partial \pi^b}{\partial \hat{x}_b} & -\frac{\partial \pi^b}{\partial \xi_k} \\ \frac{\partial \pi^b}{\partial \hat{x}_g} & -\frac{\partial \pi^g}{\partial \xi_k} \end{vmatrix}}{|\mathbf{J}|} = \frac{-\frac{\partial \pi^g}{\partial \xi_k}\frac{\partial \pi^b}{\partial \hat{x}_b} + \frac{\partial \pi^g}{\partial \hat{x}_g}\frac{\partial \pi^b}{\partial \xi_k}}{|\mathbf{J}|}. \tag{A4.11}$$

The partial derivatives with respect to ℓ are given by

$$\begin{aligned}
\frac{\partial \pi^b}{\partial \ell} &= \frac{1}{2\varepsilon_b}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b} \frac{1}{\sigma_g}\int_{\hat{\theta}_g(u)}^{\widetilde{\sigma}_g} \mathrm{d}v\,\mathrm{d}u - \frac{\ell}{2\varepsilon_b}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b} \frac{\varepsilon_g N_b}{\varepsilon_b(1+2\varepsilon_g)}\frac{(u+\varepsilon_b-\hat{x}_b)}{\sigma_g}\mathrm{d}u \\
&= \frac{1}{2\varepsilon_b\sigma_g}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b}\left[\int_{\hat{\theta}_g(u)}^{\widetilde{\sigma}_g}\mathrm{d}v - \frac{\varepsilon_g \ell N_b}{\varepsilon_b(1+2\varepsilon_g)}(u+\varepsilon_b-\hat{x}_b)\right]\mathrm{d}u \\
&= \frac{1}{2\varepsilon_b\sigma_g}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b}\left[\widetilde{\sigma}_g - \hat{\theta}_g^T - \frac{2\varepsilon_g \ell N_b}{\varepsilon_b(1+2\varepsilon_g)}(u+\varepsilon_b-\hat{x}_b)\right]\mathrm{d}u \\
&= \frac{\hat{\theta}_b - \hat{x}_b + \varepsilon_b}{2\varepsilon_b}\left\{\left(\frac{\widetilde{\sigma}_g - \hat{\theta}_g^T}{\sigma_g}\right) + \frac{2\ell\varepsilon_g N_b(\hat{x}_b-\varepsilon_b)}{\sigma_g\varepsilon_b(1+2\varepsilon_g)} - \frac{2\ell\varepsilon_g N_b(\hat{\theta}_b+\hat{x}_b-\varepsilon_b)}{2\sigma_g\varepsilon_b(1+2\varepsilon_g)}\right\} \\
&= \frac{\hat{\theta}_b - \hat{x}_b + \varepsilon_b}{2\varepsilon_b}\left\{\frac{\widetilde{\sigma}_g - \hat{\theta}_g^T}{\sigma_g} + \frac{\ell\varepsilon_g N_b(\hat{x}_b-\varepsilon_b-\hat{\theta}_b)}{\sigma_g\varepsilon_b(1+2\varepsilon_g)}\right\} \\
&= \frac{\hat{\theta}_b - \hat{x}_b + \varepsilon_b}{2\varepsilon_b}\left\{\frac{\widetilde{\sigma}_g - \hat{\theta}_g(\hat{\theta}_b)}{\sigma_g}\right\} \geq 0,
\end{aligned} \tag{A4.12}$$

where we have used the abbreviation $\hat{\theta}_g(u) := \hat{\theta}_g(\hat{x}_g, \hat{x}_b, u)$.

Furthermore,

$$\begin{aligned}
\frac{\partial \pi^g}{\partial \ell} &= \frac{-D_g}{2\varepsilon_g\sigma_b}\int_{-\eta_b}^{\hat{\theta}_b}\frac{\varepsilon_g N_b(u+\varepsilon_b-\hat{x}_b)}{\varepsilon_b(1+2\varepsilon_g)}\mathrm{d}u \\
&= \frac{-D_g N_b}{\sigma_b(1+2\varepsilon_g)}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b}\frac{u+\varepsilon_g-\hat{x}_b}{2\varepsilon_b}\mathrm{d}u < 0.
\end{aligned} \tag{A4.13}$$

Given the signs of equations (A4.12) and (A4.13), it follows from equations (A4.10) and (A4.11) that

$$\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\ell} > 0 \quad \text{and} \quad \frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\ell} \lesseqgtr 0.$$

Condition (4.12) in the text can be derived by explicitly calculating

$$-\frac{\partial\bar{\pi}^b}{\partial\ell}\frac{\partial\bar{\pi}^g}{\partial\hat{x}_g}+\frac{\partial\bar{\pi}^b}{\partial\hat{x}_g}\frac{\partial\bar{\pi}^g}{\partial\ell}.$$

Using equations (A4.6), (A4.8), (A4.12) and (A4.13), we obtain

$$-\frac{D_g}{1+2\varepsilon_g}\left(\frac{\hat{\theta}_b-\hat{x}_b+\varepsilon_b}{2\varepsilon_b}\right)\left(\frac{\widetilde{\sigma}_g-\hat{\theta}_g(\hat{\theta}_b)}{\sigma_g}\right)+\left(\frac{\hat{\theta}_b-\hat{x}_b+\varepsilon_b}{2\varepsilon_b}\right)\frac{D_g\ell N_b}{\sigma_g\sigma_b(1+2\varepsilon_g)}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b}\frac{u+\varepsilon_b-\hat{x}_b}{2\varepsilon_b}\mathrm{d}u,$$

which is negative if and only if

$$\frac{\ell N_b}{\sigma_b}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b}\frac{u+\varepsilon_b-\hat{x}_b}{2\varepsilon_b}\mathrm{d}u<\widetilde{\sigma}_g-\hat{\theta}_g^*(\hat{\theta}_b^*),$$

which is condition (4.12).

The derivatives with respect to N_b are given by

$$\frac{\partial\pi^b}{\partial N_b}=\frac{1}{(N_b+2\varepsilon_b)^2}\left[\left(-D_b+\ell\frac{\widetilde{\sigma}_g-\hat{\theta}_g(\hat{\theta}_b)}{\sigma_g}\right)-\frac{\ell^2}{\sigma_g(1+2\varepsilon_g)}\frac{(N_b+\varepsilon_b-\hat{x}_b)}{(N_b+2\varepsilon_b)}\left((N_b+2\varepsilon_b)^2+N_b(N_b+4\varepsilon_b)\right)\right]<0 \tag{A4.14}$$

and

$$\frac{\partial\pi^g}{\partial N_b}=-\frac{D_g\ell}{2\varepsilon_b(1+2\varepsilon_g)\sigma_b}\left[\int_{-\eta_b}^{\hat{\theta}_b}(u+\varepsilon_b-\hat{x}_b)\mathrm{d}u+\frac{2\varepsilon_b(\hat{x}_b+\varepsilon_b)}{(N_b+2\varepsilon_b)^2}\left(\hat{\theta}_b-\hat{x}_b+\varepsilon_b\right)\right]<0. \tag{A4.15}$$

Given the signs of equations (A4.14) and (A4.15), it follows from equations (A4.10) and (A4.11) that

$$\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}N_b}>0,\quad\text{and}\quad\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}N_b}\gtrless 0.$$

To show that $\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}N_b}>0$, we calculate

$$-\frac{\partial\pi^g}{\partial N_b}\frac{\partial\pi^b}{\partial\hat{x}_b}+\frac{\partial\pi^g}{\partial\hat{x}_b}\frac{\partial\pi^b}{\partial N_b}.$$

Using equations (A4.7), (A4.9), (A4.14) and (A4.15), we obtain

$$\Omega\left(\frac{\hat{\theta}_b+\varepsilon_b-\hat{x}_b}{4\varepsilon_b}+N_b(\hat{x}_b+\varepsilon_b)\right)-\frac{\Omega N_b}{N_b+2\varepsilon_b}\frac{\hat{x}_b+\varepsilon_b}{N_b+2\varepsilon_b}-\frac{\ell^2N_b\varepsilon_g(\hat{\theta}_b+\varepsilon_b-\hat{x}_b)^2}{4\varepsilon_b^2\sigma_g(N_b+2\varepsilon_b)(1+2\varepsilon_g)},$$

where $\Omega:=\frac{D_b-\ell\frac{\tilde{\sigma}-\hat{\theta}_g(\hat{\theta}_b)}{\sigma_g}}{N_b+2\varepsilon_b}$. Since $N_b\geq 1$, we have

$$\Omega N_b(\hat{x}_b+\varepsilon_b)>\frac{\Omega N_b}{N_b+2\varepsilon_b}\frac{\hat{x}_b+\varepsilon_b}{N_b+2\varepsilon_b}.$$

Moreover,

$$\begin{aligned}
&\Omega\left(\frac{\hat{\theta}_b+\varepsilon_b-\hat{x}_b}{4\varepsilon_b}\right)-\frac{\ell^2 N_b\varepsilon_g(\hat{\theta}_b+\varepsilon_b-\hat{x}_b)^2}{4\varepsilon_b^2\sigma_g(N_b+2\varepsilon_b)(1+2\varepsilon_g)}>0\\
\Leftrightarrow\ &\Omega>\frac{\ell^2 N_b\varepsilon_g(\hat{\theta}_b+\varepsilon_b-\hat{x}_b)}{\varepsilon_b\sigma_g(N_b+2\varepsilon_b)(1+2\varepsilon_g)}\\
\Leftrightarrow\ &D_b-\ell\frac{\widetilde{\sigma}-\hat{\theta}_g^T}{\sigma_g}+\frac{\ell^2 N_b\varepsilon_g(\hat{\theta}_b+\varepsilon_b-\hat{x}_b)}{\varepsilon_b(1+2\varepsilon_g)\sigma_g}>\frac{\ell^2 N_b\varepsilon_g(\hat{\theta}_b+\varepsilon_b-\hat{x}_b)}{\varepsilon_b\sigma_g(1+2\varepsilon_g)}\\
\Leftrightarrow\ &D_b-\ell\frac{\widetilde{\sigma}-\hat{\theta}_g^T}{\sigma_g}>0.
\end{aligned}$$

We thus have $-\frac{\partial\pi^g}{\partial N_b}\frac{\partial\pi^b}{\partial\hat{x}_b}+\frac{\partial\pi^g}{\partial\hat{x}_b}\frac{\partial\pi^b}{\partial N_b}>0$, which implies $\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}N_b}>0$.

Finally, the derivatives with respect to θ_b^0 and θ_g^0 are given by

$$\frac{\partial\pi^b}{\partial\theta_g^0}=\frac{\ell}{2\varepsilon_b}\int_{x_{n_b}-\varepsilon_b}^{\hat{\theta}_b(\hat{x}_b)}\left(\frac{1}{\sigma_g^2}\int_{\hat{\theta}_g(\hat{x}_g,\hat{x}_b,u)}^{\widetilde{\sigma}_g}\mathrm{d}v\right)\mathrm{d}u>0,$$

$$\frac{\partial\pi^b}{\partial\theta_b^0}=0,$$

$$\frac{\partial\pi^g}{\partial\theta_g^0}=0,$$

$$\frac{\partial\pi^g}{\partial\theta_b^0}=\frac{D_g\ell N_b}{(1+2\varepsilon_g)\sigma_b^2}\int_{-\eta_b}^{\hat{\theta}_b}\frac{u+\varepsilon_b-\hat{x}_b}{2\varepsilon_b}>0.$$

Combining these with equations (A4.10) and (A4.11), we obtain

$$\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\theta_b^0}<0,\ \frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\theta_g^0}<0,\ \frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\theta_b^0}<0,\ \frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\theta_g^0}>0.$$

□

Proof of Corollary 4.1. Suppose $\ell=\tilde{\ell}$ and condition (4.12) holds when evaluated at $\tilde{\ell}$. This implies that $\mathrm{d}\hat{x}_b(\tilde{\ell})/\mathrm{d}\ell<0$.

The derivative of the left–hand side of condition (4.12) is given by

$$\frac{N_b}{\sigma_b}\int_{\hat{x}_b-\varepsilon_b}^{\hat{\theta}_b}\frac{u+\varepsilon_b-\hat{x}_b}{2\varepsilon_b}\mathrm{d}u-\frac{\ell N_b}{\sigma_b}\cdot\frac{\hat{\theta}_b+\varepsilon_b-\hat{x}_b}{2\varepsilon_b}\frac{2\varepsilon_b}{N_b+2\varepsilon_b}\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\ell},$$

which is positive by the supposition that (4.12) holds.

Consider the derivative of the right–hand side with respect to ℓ. It is given by

$$-\frac{\frac{\mathrm{d}\hat{x}_g}{\mathrm{d}\ell}}{1+2\varepsilon_g}-\frac{\varepsilon_g N_b(\hat{\theta}_b+\varepsilon_b-\hat{x}_b)}{\varepsilon_b(1+2\varepsilon_g)}+\frac{\varepsilon_g\ell N_b}{\varepsilon_b(1+2\varepsilon_g)}\frac{2\varepsilon_b}{N_b+2\varepsilon_b}\frac{\mathrm{d}\hat{x}_b}{\mathrm{d}\ell},$$

which is negative by the supposition that (4.12) holds. □

Proof of Lemma 4.1. Observe that for given θ_b, total guarantee payments are given by

$$\begin{cases} \frac{N_b \ell}{2\varepsilon_b} \int_{\hat{x}_b}^{\theta_n+\varepsilon_b} \mathrm{d}u & \text{if } \theta_b < \hat{\theta}_b^* \\ 0 & \text{else} \end{cases}.$$

Hence, whenever $\varepsilon_b \to 0$, $\hat{x}_b^* \to \hat{\theta}_b^*$ and the integral collapses to zero. But then, the guarantee does not appear anymore in the government's default condition and the threshold for government default converges to $\hat{\theta}_g^* = C_g/D_g$, as in the canonical model. The probability of a government default can then be calculated as $P_g \equiv \mathbf{Pr}\left(\theta_g < \hat{\theta}_g^*\right) = \frac{C_g/D_g+\eta_g}{\sigma_g}$.

The critical bank creditor's indifference condition can be explicitly written as

$$\bar{\pi}^b(\hat{x}_b, \hat{x}_g) = \frac{D_b(\hat{x}_b + 2\varepsilon_b)}{N_b + 2\varepsilon_b} + \frac{\ell(\widetilde{\sigma}_g - \widehat{\theta}_g^T)(\widehat{\theta}_b - \widehat{x}_b + \varepsilon_b)}{\sigma_g 2\varepsilon_b} - \frac{\ell \varepsilon_g N_b(\widehat{\theta}_b - \widehat{x}_b + \varepsilon_b)^2}{4\varepsilon_b \sigma_g (1 + 2\varepsilon_g)} - 1 = 0.$$

Observe that $\widehat{\theta}_b - \widehat{x}_b + \varepsilon_b = 2\varepsilon_b(N_b - \widehat{x}_b + \varepsilon_b)/(N_b + 2\varepsilon_b)$. Substituting this into the indifference condition and taking the limit $\varepsilon_b \to 0$ leads to

$$\bar{\pi}^b(\widehat{x}_b) = D_b \widehat{x}_b + (1 - P_g)\ell(N_b - \widehat{x}_b) - N_b = 0,$$

which can be solved for the critical signal,

$$\widehat{x}_b = \widehat{\theta}_b = \frac{N_b(1 - \ell(1 - P_g))}{D_b - \ell(1 - P_g)}. \tag{A4.16}$$

□

Proof of Lemma 4.2. We obtain from equation (A4.16)

$$\frac{\partial \widehat{\theta}_b^*}{\partial \ell} = \frac{N_b(1 - P_g)(1 - D_b)}{(1 - \ell(1 - P_g))^2} < 0.$$

The probability of a systemic crisis can be computed as

$$q(\ell) = P_g \times P_b(\ell),$$

with $P_b(\ell) = \frac{\widehat{\theta}_b^* + \eta_b}{\sigma_b}$. Since P_g does not depend on ℓ, the derivative of the cost of crises measure with respect to ℓ can then be computed as

$$K'(\ell) = (1 - P_g)\phi_b \frac{\partial P_b}{\partial \ell} + P_g(1 - \phi_g)\frac{\partial P_b}{\partial \ell}.$$

Substituting

$$\frac{\partial P_b}{\partial \ell} = \frac{1}{\sigma_b}\left(\frac{N_b(1 - P_g)(1 - D_b)}{(1 - \ell(1 - P_g))^2}\right)$$

gives the expression in the text. □

5 TARGET2 Imbalances in the Euro Area: Causes, Consequences and Re–Balancing

5.1 Introduction

Since the beginning of the financial crisis in 2007 and, in particular, with the surge of sovereign debt and banking problems in the euro area since 2008 and 2009, the TARGET 2[1] (T2) positions on the balance sheets of national central banks (NCBs) in the euro area show unprecedented increases. T2 is the payment system operated by the Eurosystem. Here, the Eurosystem acts as the settlement institution and settles payments via T2 in central bank liquidity. *T2 balances* are asset or liability positions on the balance sheets of NCBs related to the settlement of payments via T2.[2] The reason for changes in T2 balances is the cross–border flow of central bank liquidity between T2–participants in different euro area member countries. Whenever a member country experiences a net outflow of central bank liquidity to another member, its NCB records a T2 liability on its balance sheet. Conversely, whenever it experiences a net inflow, a T2 asset is recorded. On the consolidated balance sheet of the Eurosystem, T2 asset and liability positions are netted out and therefore vanish.

Prior to the crisis, *T2 imbalances*, i.e. the fact that at the same time, some NCBs record T2 liabilities whereas some others record T2 assets, occurred in particular as a consequence of differences in payment habits across countries, foreign currency transactions by banks or technical factors such as centralization of banks' liquidity management. Even though persistent imbalances were accumulated over time, these

[1] TARGET stands for *T*rans–European *A*utomated *R*eal–time *G*ross *S*ettlement *E*xpress *T*ransfer System.

[2] The technical term for T2 balances is usually *Net liabilities / assets related to transactions with the ESCB (European System of Central Banks).* T2 balances are recorded as a sub–item of Intra–Eurosystem positions.

were rather moderate compared to the aggregate liquidity in the euro area banking sector.

The crisis hit euro area countries in an asymmetric fashion, leading to massive reversals of euro–area–internal capital flows away from countries in the periphery and towards safe haven countries. The consequences of such an inversion of direction in capital flows are equilibrating price and quantity adjustments that, at some point, must lead to a re–balancing of external accounts and a deleveraging of private sector entities. Yet, the question is how and at what cost the new equilibrium is reached. In order to prevent a sudden and disorderly adjustment, the Eurosystem vigorously stepped in and accommodated the capital outflows by increasing its liquidity provision to the banking sector. As the outflows were moved via the T2 system, the T2 liabilities of peripheral NCBs and the T2 assets of core NCBs strongly went up, thus giving rise to large imbalances in the payment system.

The build–up of these imbalances has sparked a fierce debate among academic economists, policy makers and media commentators about the causes and consequences as well as the necessity and the possible means to keep T2 positions under control. It is no exaggeration to say that there is hardly any recent economic topic which is inherently technical in nature but which experienced such a fast rise in interest and such boisterous debate.

This chapter can probably not solve the quarrels once and for all. The rift between the participants in the debate is deep and it is our feeling that arguments (on both sides) are frequently mixed with individual political opinions and preferences, and are all too often presented in a rather loose language which impedes on the mutual understanding. Yet, we will try to put forward a balanced viewpoint that may provide a first step towards a consensus view on the issue. The layout of the chapter is the following. In section 5.2 we provide an overview of the Eurosystem's liquidity management prior and post the Lehman default and discuss the rationale for the Eurosystem's additional liquidity support during the crisis, as well as the downside of these interventions, the resulting higher risk exposure. This establishes the ground to understand the workings of the T2 system in normal times and during the crisis in section 5.3. We further emphasize that the T2 positions do not constitute an independent source of risk, beyond the risks incurred due to higher liquidity support, as long as no T2 debtor country exits the monetary union. But what if this happens? The Eurosystem's 'exit risks' due to T2 imbalances are thus discussed in section 5.4, while the subsequent section 5.5 contains a critical assessment of some of the most popular proposals of how to deal with these risks. If the monetary union makes it through the crisis without loosing a member on the way, the return to the pre–crisis mode of liquidity management will automatically reduce T2 imbalances substantially, in most circumstances it will even eliminate them completely. Hence, the fear that after an end of the crisis, hysteresis balances will prevail is largely unfounded.

5.2 Eurosystem Liquidity Management

In this section, we provide an overview of the liquidity management of the Eurosystem prior to the Lehman default in 2008, when it followed the *aggregate liquidity management model*, and since the collapse of Lehman brothers when it switched to a *fixed–rate full allotment* procedure. In our view, a proper understanding of the liquidity management techniques is important in order to understand the role of the T2 system and the reason for the unprecedented increase in T2 positions, which could, essentially, only occur because the Eurosystem switched its liquidity management procedure.

5.2.1 Prior to Lehman default

Demand for central bank liquidity

Through its liquidity management, the Eurosystem provides (absorbs) central bank liquidity to (from) the euro area interbank market in order to ensure that the market clears at the interest rate which is in line with its desired policy stance. As the monopoly supplier of central bank liquidity, the Eurosystem exerts control over the quantity supplied and the associated price, i.e. the interest rate it charges in its monetary policy operations. Moreover, it also exerts considerable influence over the demand for liquidity as it can require banks[3] to hold a certain minimum amount on their reserve accounts with the Eurosystem.

[3] The term 'banks' henceforth refers to the monetary financial institutions that are counterparties of the Eurosystem.

The demand for central bank liquidity consists of the demand for *excess reserves* (also called *working balances*) and the demand for *required reserves*. Excess reserves are typically held as a buffer stock against payment flow uncertainty, i.e. they are determined by seasonal factors, opportunity costs of intra–day overdrafts, institutional characteristics of the payment system and payment habits.[4] Since excess reserves are not remunerated, they constitute a cost for the bank. Under normal conditions, banks therefore economize on excess reserves and keep them at the lowest level compatible with a smooth operationing of their daily business. Hence, even though the costs of keeping excess reserves are increasing with the interest rate, the demand function for excess reserves is highly interest inelastic.[5]

The Eurosystem imposes reserve requirements for the purposes of *stabilizing money market interest rates* and *creating or enlarging a structural liquidity deficit*.[6] To achieve the former, reserve requirements are made subject to an *averaging provision* which allows banks to smoothly fulfill the requirements over a certain period (*maintenance period*) on average, rather than exactly on each day. Reserve requirements are determined in relation to the *reserve base*. In the euro area, the reserve base for a given maintenance period comprises overnight deposits and deposits and debt instruments with a maturity of up to two years which were disclosed on a bank's balance sheet in a past period.[7] Therefore, the level of reserve requirements in a given maintenance period is not directly affected by current interest rates and demand for required reserves *over* a given maintenance period is rather interest inelastic.[8] In contrast, as a consequence of the averaging provision, the demand for reserves *within* the maintenance period is usually much more interest elastic provided that

[4]See Disyatat (2008, p. 4), Bindseil (2004, pp. 62), or Borio (1997, p. 14).

[5]See Bindseil (2004, p. 63) for empirical evidence that excess reserves in the euro area are indeed interest inelastic. Bindseil also puts forward the argument of 'costs of staying late in the office' to explain why euro area banks do not move excess reserves onto the deposit facility at the end of the day where they could earn some interest, but instead keep them on their reserve accounts.

[6]ECB (2011a, p. 82). See Bindseil (2004) for a discussion of the different reasons that central banks have historically put forward to justify reserve requirements.

[7]ECB (2011a, p. 85)

[8]See Disyatat (2008) or Friedman and Kuttner (2010). Changes in interest rates can affect *future* required reserves, when the interest rate change induces a change in the composition of banks' liabilities.

market participants expect the market interest rate to be relatively constant. If this holds, banks are indifferent with respect to the particular day on which they fulfill their reserve requirements. For example, suppose that interest rate expectations are anchored at the level of the central bank's policy rate. At the first day of the maintenance period, the demand function becomes horizontal at the level of expected rates. If the market rate exceeds the expected rate, banks try to make a profit by lending out reserves and comply with their requirement later in the period. Conversely, if the market rate is below the expected rate, all banks try to borrow funds to comply with their requirement at lower costs. The averaging provision entails that at the beginning of the maintenance period the demand function becomes highly elastic with respect to the spread between current market rate and expected future rate. In the course of the maintenance period, as the number of days diminishes on which requirements can be met, the demand function becomes less and less elastic until, on the last day, it becomes completely inelastic. The demand function on the last day of the maintenance period may become vertical at the level of working balances and the remaining portion of the requirement.

Supply of central bank liquidity

The Eurosystem supplies liquidity to the banking sector through its *monetary policy operations* and through *autonomous liquidity factors*.

The latter are not directly related to its monetary policy decisions but affect the Eurosystem's balance sheet and therefore exert an impact on the *liquidity position* of the banking sector *vis–à–vis* the central bank. Examples of autonomous factors are banknotes in circulation, central bank capital or assets held for purposes of portfolio management. Generically, all items on the asset side of a central bank's balance sheet provide liquidity to the banking sector, while all items on the liability side absorb liquidity from the banking sector. The liquidity position of the banking sector, ℓ, can then be defined as the sum of all autonomous liquidity factors netted on the liability side of the central bank's balance sheet plus required reserves and desired excess reserves. Whenever $\ell > 0$, the banking sector is said to be in *liquidity deficit*, while it is in *liquidity surplus* if $\ell < 0$. This is illustrated in Table 5.1 which contains stylized examples of balance sheets of a banking sector and its central bank at some day during the maintenance period.[9] The item ‘loans’ on the asset side of the banking sector’s balance sheet is meant to encompass all kinds of assets (loans to households, mortgage loans, government bonds, corporate bonds etc.) that banks may invest in, while the item ‘deposits’ comprises all different types of debt instruments regularly issued by banks (commercial paper, wholesale and retail deposits, bank bonds etc.).

The item ‘outright’ (denoted by Z) on the asset side of the central bank’s balance sheet contains security holdings for monetary policy purposes (often government bonds), whereas the item ‘other assets’ (A) includes assets that the central bank may hold for the purpose of portfolio and risk management and which are not directly related to monetary policy. On the liability side, the central bank records ‘banknotes’ (B), essentially reflecting the cash demand of the private sector, and ‘capital’ (C) which is usually paid in by the government. The autonomous liquidity factors are A, C and B. By assuming for simplicity that excess reserves are equal to zero, we can write liquidity position as $\ell \equiv B + \bar{R} + C - A$.

The Eurosystem’s monetary policy operations can be divided into operations that are activated at the discretion of the Eurosystem and those that are activated at the discretion of the banking sector. As the Eurosystem normally operates under a liquidity deficit, the former are usually conducted as liquidity–providing open market operations, either as reverse transactions (where the Eurosystem enters into a repurchase agreement with a counterparty) or as outright transactions (where the Eurosystem purchases assets).[10] Operations activated at the discretion of the banking sector are the two standing facilities. Firstly, the deposit facility allows counterparties to deposit liquidity overnight with the Eurosystem at an interest rate which is set several basis points below the policy rate. Secondly, the marginal lending facility allows counterparties to borrow overnight any amount of liquidity that they need (against eligible collateral) at an interest rate which is set several basis points above the policy rate.[11] The main task of the Eurosystem’s liquidity management is then to choose the right mix of monetary policy operations such that the market interest rate is steered

[9]See Bindseil and König (2012) for a more detailed derivation of a system of financial accounts of a closed economy.

[10]The Eurosystem can also conduct absorbing operations, e.g. by issuing fixed–term deposits, to eliminate any excess liquidity.

[11]See ECB (2011a, ch. 3 and 4) for more detailed description of these operations and facilities.

towards the level of the policy rate.

Table 5.1: Basic Financial Accounts of Banking Sector and Central Bank

Banking Sector				**Central Bank**			
Assets		Liabilities		Assets		Liabilities	
loans	$B+C+D+E-Z-A$	deposits	D	credit banks	$B+\bar{R}+C-Z-A$	banknotes	B
bank reserves	$\bar{R}$	CB credit	$B+\bar{R}+C-Z-A$	outright	Z	bank reserves	R
		equity	E	other assets	A	capital	C

Control of interest rates

In the discussion of the demand for liquidity in the previous paragraph, we assumed that interest rate expectations were anchored at the level of the target rate and were constant over the maintenance period. Under this assumption, deviations of the market rate from the expected rate are immediately corrected and the interest rate is steered towards the target level. To understand how this can be achieved in practice, let us consider the last day of the maintenance period. On this day, the demand function is completely inelastic. If there was an aggregate shortage of liquidity in the market, banks would bid up the interest rate. The upper bound to the market rate is the interest rate applied to the marginal lending facility, r_L. Therefore under an aggregate shortage, the market rate r would equal r_L. Conversely, if there was an aggregate liquidity surplus, banks would bid down the rate to the lower bound which is given by the deposit facility rate r_D. Under the *symmetric corridor approach* of the Eurosystem, the target rate is set as the midpoint between the standing facility rates, i.e. $r^* = (r_L + r_D)/2$. The Eurosystem ensures market participants that it stands ready to provide *neutral liquidity conditions* on the last day of the maintenance period, which means that at the penultimate day, banks can expect the market to be short or long of reserves with equal probability on the last day. This implies that $\mathbf{E}_{n-1}(r_n) = r^*$ (where $\mathbf{E}_j$ denotes the mathematical expectations operator with information set as of date j). Given these expectations, banks at the penultimate day are again indifferent between satisfying the remaining portion of their required reserves immediately or on the following last day. The demand function is flat at the level of the expected rate. By backward induction, it follows that

$$\mathbf{E}_{n-k}(r_{n+1-k}) = r^*, \quad \forall\, k = 1, ..., n.$$

This equation is a statement of the *martingale property* of overnight rates, which implies that overnight rates over the maintenance period are linked to the liquidity position on the last day of the maintenance period.[12]

A further qualification to this stylized description has to be made as we implicitly assumed that averaging in both directions was possible. However, the Eurosystem does not allow overnight overdrafts, so that a bank which ends the day with a negative reserve balance has to take recourse to the marginal lending facility. Similarly for banks which have satisfied their requirement prior to the last day of the maintenance period. These banks will most likely move liquidity to the deposit facility. Taken together, this implies that expected rates in general also depend on the probabilities of overdraft, early fulfillment or average fulfillment as well as on the interest rates r_D and r_L. Yet, given that prior to the crisis the standard deviations of liquidity shocks in the euro area were small compared to the average reserve requirement, the probabilities of taking recourse to the standing facilities during the maintenance period were rather small, so that the stylized description above does not fall too far apart from real world practice.[13]

How did the Eurosystem ensure neutral liquidity conditions on the last day and a sufficiently large supply of liquidity over the maintenance period prior to the crisis? The former is essentially equivalent to accommodating the liquidity deficit on this day. In a world without uncertainty it would mean to provide liquidity M such that $\ell - M = 0$, where ℓ can be calculated from the Eurosystem's consolidated balance sheet. In a world with uncertainty, where some determinants of the liquidity deficit are random variables, guaranteeing neutral liquidity conditions requires to precisely estimate the liquidity deficit. Furthermore, it requires to understand the distributions of the shocks and autonomous factors in order to guarantee that recourse to

[12] Würtz (2003), Gaspar, Pérez Quirós, and Rodríguez Mendizábal (2008) or Cassola (2008) provide empirical evidence that the overnight interest rate in the euro area follows the martingale hypothesis.

[13] See Välimäki (2008, p. 11). The first formal model of interest rate determination over a maintenance period can be found in the seminal paper by Poole (1968), recent contributions include Tapking (2002), Quiros and Mendizabal (2006), or the monograph by Neyer (2007). Less formal discussions can be found in Borio (1997), Bindseil (2004), Disyatat (2008) or Friedman and Kuttner (2010).

one or the other facility on the last day occurs with equal probability.[14] As a maintenance period usually lasts for four weeks, the Eurosystem ensured that banks could during this period meet their reserve requirements on average and that no aggregate systematic shortage or overhang occurred (otherwise the market rate would become rather volatile). Hence, liquidity was supplied during the maintenance period by a mix of weekly main refinancing operations (MROs) and a single longer–term operation (LTRO). The major part of liquidity (around three quarters) was supplied through MROs, while the remainder came through LTROs with a maturity of three months. The amount of liquidity supplied via an MRO is called *benchmark allotment amount*. It is calculated in such way as to ensure that banks *in aggregate* can smoothly fulfill their reserve requirements over the maintenance period given (a) the liquidity effects stemming from autonomous liquidity factors, (b) the liquidity effects stemming from other monetary policy operations (e.g. LTROs), and (c) the assumption that in expected terms, banks do not take recourse to the standing facilities.[15]

Hence, prior to the crisis, the Eurosystem took only the euro area banking sector's aggregate liquidity position into account and left the allocation of liquidity between the different banks entirely to the market. As the interbank market worked relatively smoothly, overnight transactions occurred at rates close to the policy rate. Moreover, most banks followed a linear reserve pattern with overnight balances close to the average reserve requirement.[16] Figure 5.1 illustrates a typical maintenance period. It shows the evolution of EONIA, the average daily reserve surplus and the daily reserve surplus for the maintenance period July 11 to August 7, 2007, which was the last maintenance period before the beginning of the financial crisis.[17] Horizontal lines mark the dates where refinancing operations took place during the period. It can be seen that all variables are fairly constant over the whole period, which points

[14]The Eurosystem has often used fine–tuning operations at the end of the maintenance period to adjust the liquidity position more precisely.

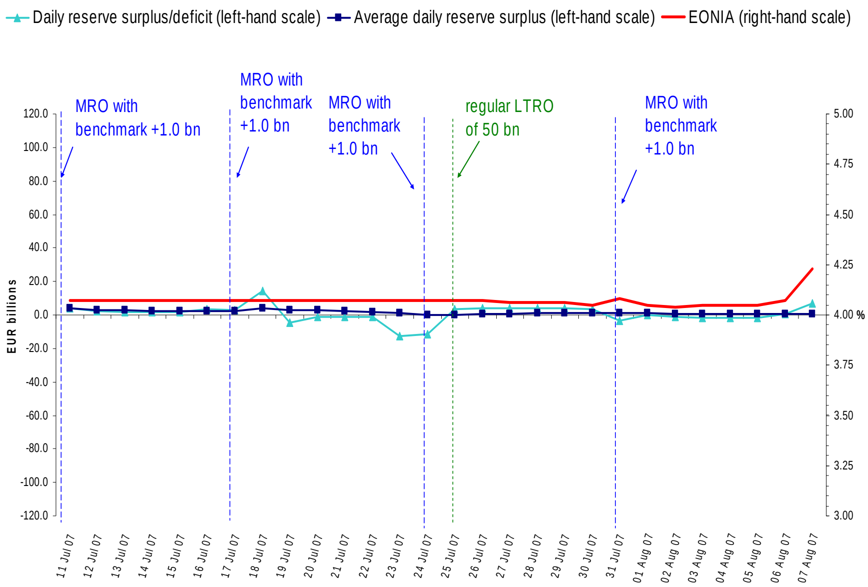
[15]See ECB (2013) for a detailed explanation how the benchmark amount is calculated.

[16]Cassola (2008) provides evidence that banks targeted reserve holdings around the minimum requirement level. The exception are small banks which kept excess reserves.

[17]The European OverNight Index Average is a volume–weighted index of overnight interest rates computed by the ECB from a panel of euro area banks. The daily reserve surplus is computed as the difference between banks' reserve holdings on a given day and the average reserve requirement. The average daily reserve surplus is a cumulative rolling average over daily reserve surpluses.

to a smooth functioning of the euro area interbank market before the crisis.

Figure 5.1: EONIA, average daily reserve surplus and daily reserve surplus for the last pre–crisis maintenance period July 9, 2007 to August 7, 2007.



When the financial crisis erupted in summer 2007, the close connection between overnight rates and the end–of–maintenance–period liquidity position weakened. Overnight interest rates lost the martingale property. Heightened uncertainty about future liquidity shocks and liquidity conditions drove interest rate expectations away from the policy rate and caused higher volatility of the market rate.[18] This led to a change in banks' reserve fulfillment paths. Rather than meeting their requirements on average per day, banks chose to overfulfill the requirement early in the maintenance period to be armed against future liquidity shocks and uncertain market con-

[18]In terms of the analytical discussion above, the probabilities of taking recourse to the standing facilities under normal benchmark allotment during the maintenance period were not negligible anymore.

ditions. Under benchmark allotment, this precautionary liquidity hoarding would have exerted upward pressure on interest rates early in the maintenance period. The Eurosystem accommodated this behavior through so–called *frontloading*. At the beginning of the maintenance period the liquidity supply in the weekly operations was increased to a level above the benchmark amount in order to relieve interest rates from upward pressure. The liquidity supply was reduced later in the maintenance period to keep allotted liquidity over the period in accordance with the aggregate liquidity needs.

Figure 5.2 illustrates this. It shows the EONIA, average daily reserve surplus and daily reserve surplus for the first crisis maintenance period August 8 to September 11, 2007. Precautionary hoarding is well–visible from the hump–shaped average daily reserve surplus curve. EONIA was highly volatile and deviated from the policy rate throughout the maintenance period. Moreover, as the vertical lines indicate, the Eurosystem heavily intervened by means of fine–tuning operations and higher–than–benchmark allotment in its MROs.

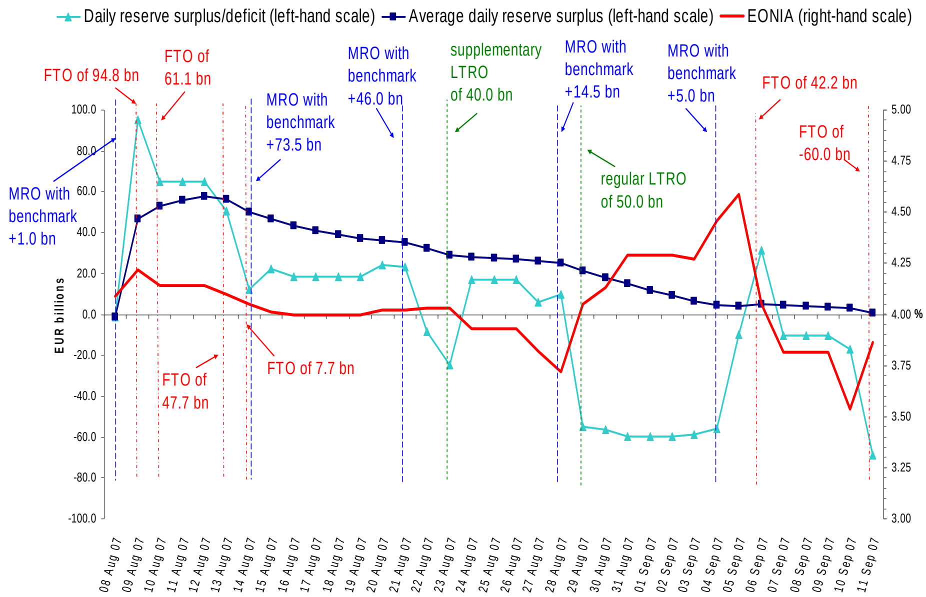
This is but one illustration of what ECB board member Gonzalez-Paramo (2009) referred to as "active liquidity management by adjusting the temporal and quantitative distribution of its [ECB's] liquidity provision within the maintenance period." A further notable change to the Eurosystem's liquidity management during this phase of the crisis was a shift in the maturity profile of its refinancing operations from short–term to longer–term operations in order to reduce uncertainty about future liquidity conditions. The total allotted amount, however, was still determined by the benchmark amount, i.e. by the *aggregate* liquidity needs of the euro area banking sector.

5.2.2 Post Lehman default

The central bank as interbank market–maker

The default of Lehman Brothers in September 2008 and problems of American International Group caused funding markets all over the world to seize up. When interbank lending in major economies ground to a halt, the mechanism that previously allowed central banks to focus on aggregate liquidity conditions rather than on banks' individual liquidity needs became largely dysfunctional. In order to maintain

Figure 5.2: EONIA, average daily reserve surplus and daily reserve surplus for first crisis maintenance period August 8, 2007 to September 11, 2007.



the stability of their banking and financial systems, major central banks took over the role of *interbank market–makers* and provided additional facilities to replace the demand and supply side of the interbank market, which in turn resulted in unprecedented expansions of their respective balance sheets. The Eurosystem essentially began to intermediate the market in October 2008, when it switched to a *fixed–rate full–allotment* procedure in all its operations (MROs, LTROs and foreign currency operations). Provided they possessed enough collateral, banks could, from then on, borrow any amount of liquidity they desired at a fixed interest rate.[19]

[19]The introduction of the fixed–rate full allotment was probably the most important measure by the Eurosystem. Other measures included an expansion of the set of eligible assets that could be put forward as collateral in monetary policy operations. This allowed banks to refinance assets whose market liquidity had strongly deteriorated during the crisis. Moreover, additional long–term opera-

It is instructive to compare the differences in the balance sheet mechanics between the aggregate liquidity management and the fixed–rate full–allotment procedures. For simplicity, we assume that the banking sector considered in Table 5.1 consists of two banks with identical balance sheets prior to the occurrence of a liquidity shock. Without loss of generality, we set $E = C = A = \bar{R} = 0$, so that the aggregate liquidity deficit is just given by banknotes in circulation, $\ell = B$. The balance sheets under the aggregate liquidity management model are shown in Table 5.2. The central bank focuses only on the aggregate liquidity needs of its banks and provides liquidity of $B - Z$ through credit operations and Z through outright purchases. Given that all autonomous liquidity factors were set to zero, the central bank has a perfectly lean balance sheet.[20] We assume that bank 2 faces a net liquidity outflow of amount Θ. In a closed economy with an unchanged amount of banknotes in circulation, this is tantamount to a net liquidity inflow of amount Θ to bank 1. Bank 2 has still access to the interbank market despite the deposit outflow and since the interbank market functions well there is no need for the central bank to step up its liquidity provision. The liquidity shock creates excess liquidity for bank 1 and a liquidity deficit for bank 2. Bank 1 will offer its excess liquidity on the interbank market where bank 2 borrows it to close its liquidity gap. The liquidity deficit is immediately re–allocated on the market.

Now consider the balance sheet mechanics that obtain in case of a dysfunctional interbank market when the central bank offers full allotment and intermediates the market. This is shown in Table 5.3 where we assume that bank 2 has lost access to the market. Instead of offering the excess liquidity Θ on the market, bank 1 uses it to repay its own central bank borrowing. Whenever the liquidity shock exceeds bank 1's initial central bank credit, it deposits the excess liquidity on its reserve account with

tions lengthened the overall maturity of liquidity provision and thereby contributed to reduce maturity mismatches on banks' balance sheets, while foreign currency operations, financed through swap lines with peer central banks, reduced the currency mismatches. Later in 2009 the ECB initiated the covered bond program where it purchased covered bonds outright in order to boost activity in this particular market segment.

[20] A perfectly lean central bank concentrates exclusively on monetary policy implementation and on no other auxiliary activities. The liability side of a lean central bank balance sheet contains only the monetary base. The Federal Reserve before the crisis is an example of a rather lean central bank, see Bindseil (2004, p. 50).

Table 5.2: Effect of deposit shift Θ with functioning interbank market.

	Bank 1		**Bank 2**		**Central Bank**	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
loans	$(B+D-Z)/2$	–	$(B+D-Z)/2$	–	–	–
bank reserves	0	–	0	–	–	0
deposits	–	$D/2+\Theta$	–	$D/2-\Theta$	–	–
interbank	Θ	–	–	Θ	–	–
CB credit	–	$(B-Z)/2$	–	$(B-Z)/2$	$B-Z$	–
banknotes	–	–	–	–	–	B
outright	–	–	–	–	Z	–
total	$\Theta+(B+D-Z)/2$	//	$(B+D-Z)/2$	//	B	//

the central bank.[21] Conversely for bank 2. As no alternative sources of funding are left it turns to the central bank in order to obtain additional credit to close its funding gap.

By offering absorbing and storing facilities (reserve accounts, deposit facility, fixed–term deposits) the central bank substitutes for the demand side of the market, while its additional liquidity support replaces the supply side. As long as the liquidity shock Θ falls short of bank 1's initial central bank credit, the central bank's liquidity provision does not exceed aggregate liquidity needs and its balance sheet does not expand. This is the case of *relative central bank intermediation*, where the aggregate liquidity deficit ℓ is allocated by means of central bank facilities rather than via the market. If Θ exceeds the liquidity needs of bank 1 and whenever bank 1 finds itself in excess of liquidity after repayment of its central bank credit, its reserve holdings rise and the central bank's balance sheet expands. In this case we speak of *absolute central bank intermediation*. The central bank's balance sheet becomes demand–determined. It expands and contracts automatically as a response to idiosyncratic liquidity shocks of banks.

[21] Alternatively, bank 1 may move excess liquidity into the deposit facility in order to earn interest, or the central bank may issue fixed term deposits to absorb the excess liquidity. For example, at present date (June 25, 2013), the ECB's weekly financial statement shows fixed term deposits (liability item L2.3) of euro 195 bn EUR, current account holdings (item L2.1) of 280 bn EUR (almost three times the average reserve requirements, which currently stand at 105 bn EUR) and recourse to the deposit facility of 90 bn (item L2.2). Issuance of fixed term deposits is mainly intended to absorb the liquidity from the SMP bond purchase program.

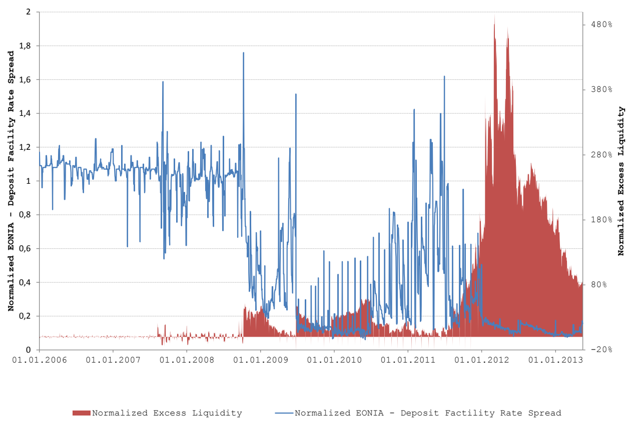


Figure 5.3: EONIA–Deposit Facility Rate Spread, normalized by half of the corridor width, and aggregate excess liquidity, normalized by aggregate liquidity needs of euro area banking sector *(Data Source: ECB Statistical Data Warehouse)*

Figure 5.3 illustrates the consequence of market intermediation by the Eurosystem on the overnight interest rate. It depicts the spread between EONIA and the deposit facility rate and excess liquidity for the period starting in January 2006 until April 2013. The spread is normalized by half the corridor width such that, under the Eurosystem's symmetric corridor approach, it should hover around unity whenever the Eurosystem manages to steer the market rate towards the policy rate. Excess liquidity is defined as the difference between reserve holdings of banks plus net recourse to the deposit facility and minimum reserves of banks.[22] Under the aggregate liquidity management model, excess liquidity should hover around zero. It can be seen that the spread and the excess liquidity measure start to behave more volatile with the beginning of the financial crisis in summer 2007, but as the Eurosystem still stuck to providing only the liquidity needed in aggregate, no large excess liquidity was built up. The switch to fixed–rate full–allotment in October 2008 created considerable ex-

[22] By the Eurosystem's balance sheet identity, this is equal to the difference between open market operations and the sum of net autonomous liquidity factors (netted on the liability side) and reserve requirements.

cess liquidity and pushed the spread below unity. The spread behaved rather volatile throughout 2011 when excess liquidity was low. When excess liquidity started to rise to unprecedented levels during 2012, the EONIA was again compressed against the deposit facility rate and the spread's volatility abated considerably.

Table 5.3: Effect of deposit shift Θ with intermediating central bank.

	Bank 1		**Bank 2**		**Central Bank**	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
loans	$\frac{B+D-Z}{2}$	–	$\frac{B+D-Z}{2}$	–	–	–
bank res.	$\max\left\{\Theta-\frac{B-Z}{2},0\right\}$	–	0	–	–	$\max\left\{\Theta-\frac{B-Z}{2},0\right\}$
deposits	–	$\frac{D}{2}+\Theta$	–	$\frac{D}{2}-\Theta$	–	–
interbank	0	–	–	0	–	–
CB credit	–	$\max\left\{\frac{B-Z}{2}-\Theta,0\right\}$	–	$\frac{B-Z}{2}+\Theta$	$\max\left\{\frac{B-Z}{2}+\Theta,B-Z\right\}$	–
banknotes	–	–	–	–	–	B
outright	–	–	–	–	Z	–
total	$\max\left\{\frac{B+D-Z}{2},\Theta+\frac{D}{2}\right\}$	//	$\frac{B+D-Z}{2}$	//	$\max\left\{\frac{B+Z}{2}+\Theta,B\right\}$	//

Rationale for interbank intermediation and liquidity support

In the previous balance sheet example in Table 5.3, we assumed that bank 2 increased its central bank credit but aimed at keeping the size of its balance sheet unchanged. In general, banks can meet deposit outflows either by acquiring additional funding (managing their liability side), or by selling off earning assets and shrink their balance sheets (managing their asset side). Asset management may therefore be an alternative solution to the liquidity outflow and would avoid taking additional recourse to central bank facilities. Yet, asset management can become very costly for banks if the respective asset markets are not sufficiently liquid. Whenever large–scale funding outflows occur, banks are typically in urgent need for liquidity. Given that a large number of bank assets are informationally sensitive and often traded on rather thin markets, a bank needs to spend time and incurs search costs to find the buyer with the highest valuation to sell the asset at a price close to its fundamental value. The more unique the bank's assets are, the lower the immediate, or *fire-sales* prices and the larger the losses from liquidating assets quickly. These problems are particularly severe in an environment of dysfunctional markets with a large number of other banks trying to liquidate assets of similar type at the same time. In particular, a large concentration of such quick sales are likely to induce a *fire–sale externality*,

> "in order to deal with such liquidity problems (...) the bank in difficulties will often be forced to sell assets (fire sales). But such sales will drive down the current market price of the same assets held on other banks' books, when these are valued on a mark-to-market basis. (...) In short, there is an internal amplifying process (liquidity spirals) whereby a falling asset market leads banks, investment houses, etc., to make more sales (deleveraging), which further drives down asset prices and financial intermediaries' assessed profit and loss and balance sheet net worth." (Geneva Report (2009, p. 4))

The authors of the Geneva Report (2009) highlight the fire–sale externality as one of the chief reasons for prudentially regulating banks and financial institutions *prior* to a crisis. *Mutatis mutandis*, it is also a major concern for central banks and the most important reason for stepping up the liquidity support *during* a crisis. Being endowed with the monopoly and the freedom to issue central bank money, the ultimate means of settlement, the central bank can never become illiquid in its own currency and it can basically avert any funding liquidity problems of its counterparties and thereby prevent asset fire–sales and downward liquidity spirals.

Risk–taking and central bank 'leverage'

The downside of the central bank's extended liquidity support and interbank intermediation is an increase in the its risk exposure and leverage. In normal times, the Eurosystem's risk exposure from its monetary policy operations is generally limited by the following two facts:

- Credit is provided solely to banks. These are strongly regulated and supervised entities whose capital positions have to meet certain adequacy standards.
- Credit is provided only under secured financing arrangements and counterparties are obliged to pledge adequate high–quality collateral.

These practices reduce the credit risk exposure of the Eurosystem vis–à–vis its counterparties. However, in case a counterparty defaults, it becomes subject to

- *liquidity risk*, i.e. the possibility of a change in the value of collateral due to endogenous price changes when the collateral is sold to make good any losses;
- *market risk*, i.e. an exogenous change in the value of collateral due to a change in market prices during the course of the credit operation;
- *credit risk associated with the collateral*, i.e. the possibility that the issuer of the collateral asset defaults.

Collateral credit risk is rather small in normal times since the Eurosystem's eligibility criteria are rather stringent and since attention is paid that no close financial relations between collateral issuer and counterparty exist.[23] To reduce market and liquidity risk, the Eurosystem deducts haircuts and makes margin calls when the collateral value falls below a certain trigger.[24]

In general, a necessary precondition for higher liquidity provision by a central bank during a crisis is that it accepts a larger risk exposure. This means that its liquidity measures have to be complemented by an *inert risk management framework*.[25] The *inertia principle* originates with Bagehot (1873) who stressed that,

> "[i]f it is known that the Bank of England is freely advancing on what in ordinary times is reckoned a good security – on what is then commonly pledged and easily convertible – the alarm of the solvent merchants and bankers will be stayed." (p. 198)

The quote states a *minimal requirement* for the central bank to be able to increase its liquidity support during a crisis. Lending against those assets which are *"in ordinary times"* considered good collateral implies that the risk management framework, consisting e.g. of eligibility criteria, risk measurement models, haircut tables or counterparty criteria, has to be left *at least* unchanged when compared to pre–crisis times. If the central bank was not following the inertia principle but rather strengthened its risk management like a private institution, it would obviously need to restrict the

[23]The Eurosystem retains the right to exclude assets from its operations if the credit quality of these assets and the credit risk of the counterparty tend to correlate, see ECB (2011a).

[24]See Chailloux, Gray, and McCaughrin (2008) or Gonzalez and Molitor (2009) for discussions of central bank risk mitigation measures.

[25]See Bindseil (2009) for an extensive discussion of central bank risk management during a crisis.

class of eligible collateral and apply higher haircuts. This in turn would increase the funding pressure in the banking sector and worsen already existing tensions. Moreover, such behavior would prompt banks to engage in potentially large–scale asset management operations to cover funding withdrawals and would thereby enforce a potentially costly immediate deleveraging. The fact that all major central banks behaved like rather conservative risk–takers *prior* to the crisis and decisively expanded their balance sheets *during* the crisis implies that their risk–taking and 'leverage' behave counter–cyclically and thus offset adverse consequences of the strongly pro–cyclical leverage of the financial sector.[26]

The Eurosystem did not only follow the inertia principle, yet it even lowered its risk containment standards at some points during the crisis in order to ensure the liquidity supply of its counterparties. The resulting higher risk exposure was / is then mainly driven by the following general factors:

- The *default probabilities* of counterparties and collateral issuers increase during a crisis. As an example, Standard & Poor's (2013) shows that investment grade debtors (with an S&P rating of at least BBB) experience hardly any default during upswings (not even a single BBB–rated debtor defaulted during 1992 – 1994 or 2004 – 2007), while the default frequency of AA– and A–rated debtors in 2008 moved up to 0.38%.

- The *correlation* between counterparty and collateral issuers' default risk increases because during a crisis common instead of idiosyncratic risks become predominant.

- Liquidity provision becomes biased towards stressed counterparties. This is the immediate consequence of interbank intermediation. Banks which ask for larger recourse to central bank operations during a crisis are generally in a worse condition than the still–sound banks which accumulate excess liquidity. Hence, the asset side of the central bank's balance sheet becomes less diversified and its risk exposure to a particular group of counterparties increases.

- In addition, the extraordinary measures by the Eurosystem, e.g. its outright operations under the SMP and the two CBPP programs, are directed at coun-

[26] See Adrian and Shin (2010) for evidence on the pro–cyclical leverage of the financial sector.

terparties and markets under severe stress which are not targeted by the central bank in normal times. Thereby, additional specific risk factors are added to the Eurosystem's balance sheet.

There seems to be widespread agreement that liquidity support and the complementary risk–taking by the Eurosystem and other major central banks in the aftermath of the Lehman default was unavoidable to prevent a world–wide financial meltdown. There is, however, less agreement with respect to the Eurosystem's preservation of its liquidity support to this date and the additional measures it undertook in response to the balance of payments and sovereign debt crisis that erupted in the euro area since autumn 2009.

The excess liquidity in the post–Lehman period revealed that markets were segmented with less potent banks becoming increasingly reliable on the Eurosystem's support. But what it does not reveal is the fact that since 2009 markets in the euro area became more and more segmented along national borders. This was a consequence of euro area internal asymmetries that rendered the peripheral countries more vulnerable to adverse developments in funding markets, losses of investor confidence and the ensuing reversal of capital flows. These developments, however, are reflected in the strong increase in T2 imbalances.

5.3 TARGET2 Imbalances

5.3.1 Basics of T2

According to article 127 of the Treaty on the Functioning of the European Union (TFEU), the ECB and the European System of Central Banks (ESCB) are charged with the responsibility for maintenance and proper functioning of payment systems in the monetary union. To this end, the ECB operates its own payment system TARGET2.[27] Payments via T2 are settled in central bank liquidity and the settlement accounts of transacting banks are their reserve accounts. Since banks access the monetary policy operations of the Eurosystem only through the NCB of the member state where they

[27] T2 has a market share of around 91% of total payment value in large–value payment systems. According to ECB (2012), in 2011, the total volume of transactions via T2 amounted to around 613 trillion euro with a daily average volume of around 2.4 trillion and around 348 thousand transactions per day.

are incorporated, they also keep their reserve accounts with this particular NCB. To be able to carry out payments via T2, the reserve balances on the account of the sending bank must be sufficiently large.[28] When a payment is made, the reserve account of the sending bank is debited and the account of the receiving bank is credited by the transferred amount. Transfers of reserve balances do not affect the NCBs' balance sheets as long as the involved parties have their reserve accounts with the same NCB. From the perspective of the NCB, the transfer just constitutes a swap within one specific liability item. Yet, as a consequence of the decentralized nature of the Eurosystem, NCBs' balance sheets are affected whenever cross–border transactions between banks with reserve accounts at different NCBs take place. In such cases, transfers of reserve balances give rise to so–called *T2 balances*.

Let us illustrate this by means of an example. Table 5.4 shows the changes on the balance sheets due to a transfer of deposits of amount Θ between banks 1 and 2 *in different euro area member states*. The payment is initiated by sending a S.W.I.F.T. payment message. Upon receipt of the message, NCB 2 debits the reserve account of bank 2 and NCB 1 credits the account of bank 1 by the amount Θ. Thereby the liabilities of NCB 2 decline, although it still records a credit claim against bank 2. Conversely for NCB 1, whose liabilities vis–à–vis its banking sector have increased although no corresponding increase in its asset positions was recorded. This 'exchange of liability positions' due to the settlement of payments is balanced by recording corresponding T2 positions. NCB 2 records a T2 liability and NCB 1 records a T2 claim. At the end of each business day, T2 positions of all NCBs are aggregated and consolidated on the balance sheet of the ECB which acts as the central counterparty. Rather than being settled at some point through a transfer of assets, the T2 positions are continuously rolled forward.

5.3.2 Normal T2 imbalances

If the transfer of liquidity of amount Θ in the last example created a liquidity shortage for bank 2 and excess liquidity for bank 1, then bank 2 may turn to the interbank market in order to borrow amount Θ from bank 1. Whenever bank 1 lends its liquidity

[28] Intra–day overdrafts are allowed but have to be covered by sufficient collateral. The collateral eligibility criteria are the same that apply in Eurosystem monetary policy operations.

Table 5.4: Changes on balance sheets due to deposit shift Θ between banks in different euro area members.

	Bank 1		**Bank 2**		**NCB 1**		**NCB 2**	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
reserve account	$+\Theta$	—	$-\Theta$	—	—	$+\Theta$	—	$+\Theta$
deposits	—	$+\Theta$	—	$-\Theta$	—	—	—	—
T2	—	—	—	—	$+\Theta$	—	—	$-\Theta$
total changes	$+\Theta$	//	$-\Theta$	//	$+\Theta$	//	± 0	//

surplus to bank 2, the intra–system positions immediately reverse. One may therefore conclude that, in normal times, when liquidity surpluses are quickly re–allocated via the market, T2 positions inhibit a tendency to re–balance automatically. Hence, the occurrence of T2 imbalances would signal funding stress and liquidity problems of the banking sector in those member states which record T2 liabilities. This interpretation of imbalances is largely correct with respect to the unusually high positions that accumulated in the course of the crisis. But the re–balancing was, even prior to the crisis, seldom complete and small imbalances persisted although the interbank market was fully operational.

Development of T2 positions prior to the crisis

Figure 5.4 shows T2 positions of crisis countries' NCBs and the German Bundesbank (currently recording the largest T2 asset position). T2 positions are considered henceforth as net asset positions, i.e. whenever a T2 position of a particular NCB is negative, it reflects the fact that the NCB of the respective country is a net T2 debtor and records a net T2 liability on its balance sheet.

The Figure illustrates the incomplete re–balancing and the heterogeneous developments of T2 positions in normal times. The largest T2 liability in the pre–crisis period of amount 48.41 bn euro was recorded by the National Bank of Belgium in the second quarter 2007 (not shown), while the largest net T2 asset position of 47.57 bn euro was recorded by the Banca d'Italia in the same quarter (Panel (vi)). Italy and Spain were T2 creditors during the entire period. The position of Germany fluctuates around zero, while Greece, Portugal and Ireland record persistent negative positions.[29]

Figure 5.7 shows the evolution of aggregate T2 claims for the period 2003 to 2013 (first quarter). The series exhibits a slight upward trend even in the pre–crisis period. This trend, however, vanishes when the aggregate T2 position is normalized by the aggregate liquidity needs of the euro area banking sector.

This is further depicted in Figure 5.8 together with the ratio of excess liquidity to aggregate liquidity needs. The normalized aggregate T2 position (shown with inverted sign) behaves stationary in the pre–crisis period and fluctuates around a mean of 20% with a standard deviation of around 2.2%. It appears that, for a given distribution of euro area autonomous factors, under the aggregate liquidity management model the creation of overly large aggregate T2 positions were also prevented.

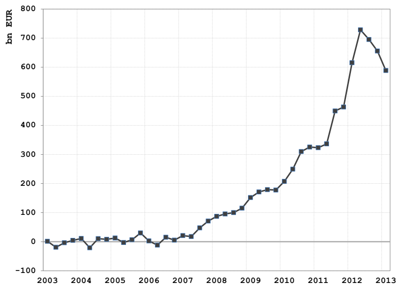
The differences in the patterns of T2 positions of different member countries prior to the crisis can be largely attributed to (i) differences in payment habits, for example when agents in one country pay imports by using banknotes while its exports are paid by using electronic transfers; (ii) transactions involving one leg in foreign currencies; (iii) centralized liquidity management; (iv) settlement of cross–border transactions via other payment systems that do not settle in central bank liquidity; (v) euro–denominated transactions of banks outside the monetary union which hold an account with a particular NCB. In what follows we will shortly discuss the most important factors (i)–(iii). The remaining factors (iv) and (v) are considered further in European Central Bank (2011b).

Electronic versus cash payments: The role of banknotes

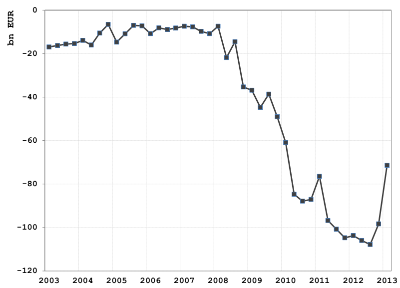
Reserve balances and banknotes are the ultimate means of settlement. T2 positions due to cross–border flows of liquidity arise only because reserve balances are transferred electronically via the payment system. But cross–border transactions can equivalently be settled by using banknotes. Returning to the example in section 5.3.1, suppose that the outflow Θ at bank 2 occurs because depositors withdraw banknotes. Suppose that these banknotes are paid into a deposit at bank 1. There is obviously

[29] With respect to the positions not shown, the Dutch position also fluctuated around zero, while Luxemburg's was constantly positive since 2003. Belgium and Austria recorded persistently negative positions.

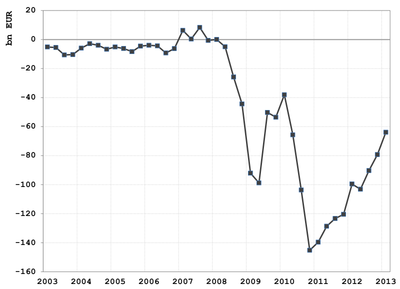
Figure 5.4: T2 positions of crisis countries NCBs and German Bundesbank.
(Source: Euro Crisis Monitor, University of Osnabrück).



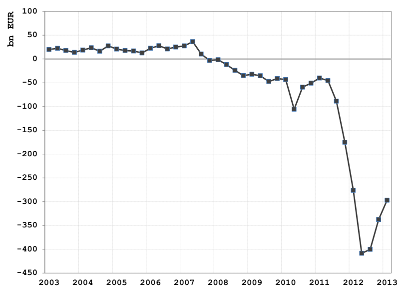
Panel (i): Bundesbank



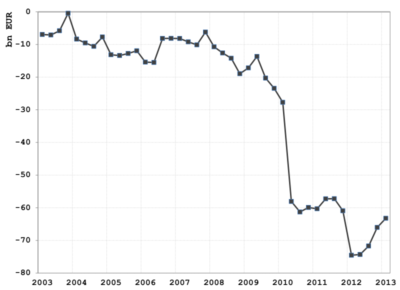
Panel (ii): National Bank of Greece



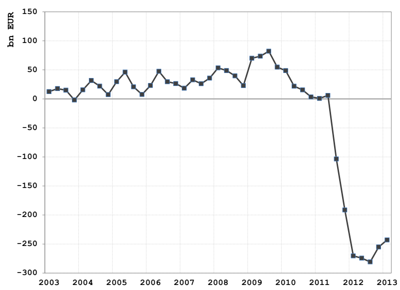
Panel (iii): Central Bank of Ireland



Panel (iv): Banco de España



Panel (v): Banco de Portugal



Panel (vi): Banca d'Italia

Figure 5.7: Aggregate T2 claims and number of T2 creditor NCBs *(Data Source: Euro Crisis Monitor University of Osnabrück; own calculations)*

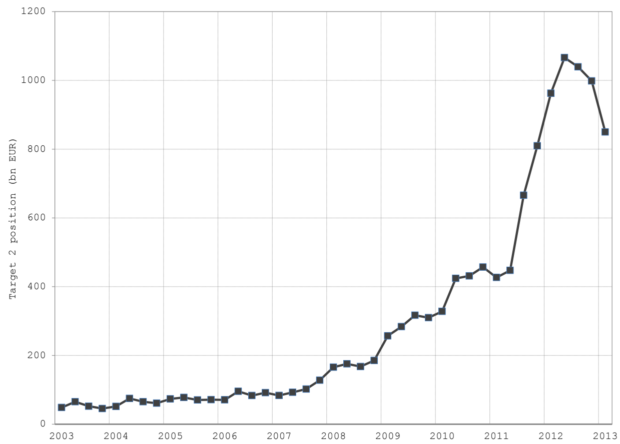
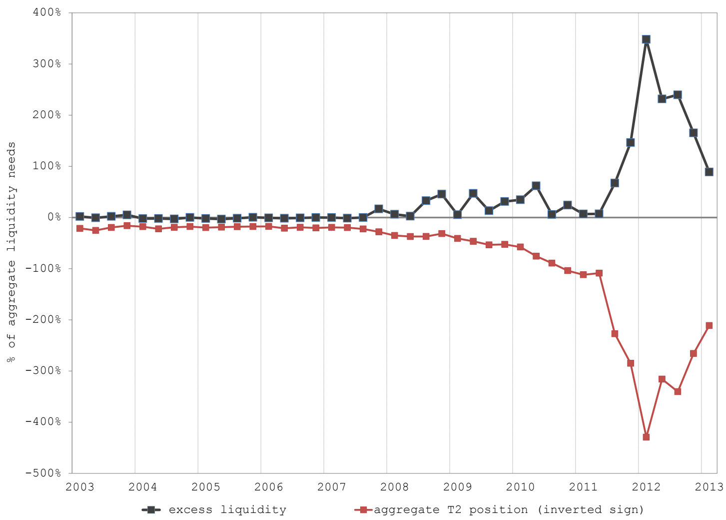


Figure 5.8: Aggregate T2 liabilities and aggregate excess liquidity (normalized by aggregate liquidity needs) *(Data Source: Euro Crisis Monitor University of Osnabrück, ECB Website; own calculations)*



no big economic difference between a transfer of liquidity in the form of an electronic payment or in the form of a cash–based payment. However, the ordinary T2 imbalances arise only in the former case. The Eurosystem treats banknote issuance in a slightly different way, yet also banknote issuance can give rise to intra–system positions on NCBs' balance sheets.

According to current practice, the Eurosystem records 92% of all banknotes in circulation on the balance sheets of NCBs, while the remaining 8% are recorded on the balance sheet of the ECB. The share of banknotes booked by an NCB is determined by the ECB capital key (which reflects GDP and population size). The amount of euro–banknotes in circulation is not only determined by the payment preferences and habits of euro area residents but also by the preferences for euro–banknotes of agents outside the euro area. Since banknote issuance is fully demand–determined, it is therefore likely that a particular NCB issues more or less banknotes than stipulated by its respective capital share. The difference between what the NCB can issue according to the capital key and what it actually issued is booked as an intra–system position. If the difference is positive it is recorded as an intra–system liability, and if it is negative it is recorded as an intra–system asset.[30]

Figure 5.9 exemplifies the importance of intra–system positions due to banknote issuance by comparing intra–system positions of the German Bundesbank and the National Bank of Greece for the period 2002 to 2012. As can be seen from the growing red area, the Bundesbank issues more banknotes than declared by the allocation key. Since the beginning of the monetary union, its intra–system liabilities related to banknote issuance constantly increased. Bartzsch, Rösl, and Seitz (2011) estimate that only about one third of banknotes issued by the Bundesbank circulate in Germany with the remaining part being 'exported' mostly to non–euro area countries and also to some other euro area countries. Prior to the crisis, only a fraction of Germany's intra–system liability due to banknote issuance was offset by T2 claims. As Jobst, Handig, and Holzfeind (2012) point out, differences in payment habits can explain this pattern. As an example, consider trade between Austria and Germany. Austria is a preferred destination for German tourists and exports tourism services to Germany.

[30]The respective subitems on the balance sheet are *A*9.2 and *L*9.2. The technically correct term for the items are *"Assets / liabilities related to the allocation of euro banknotes within the Eurosystem"*. For more details, see Krsnakova and Oberleithner (2012).

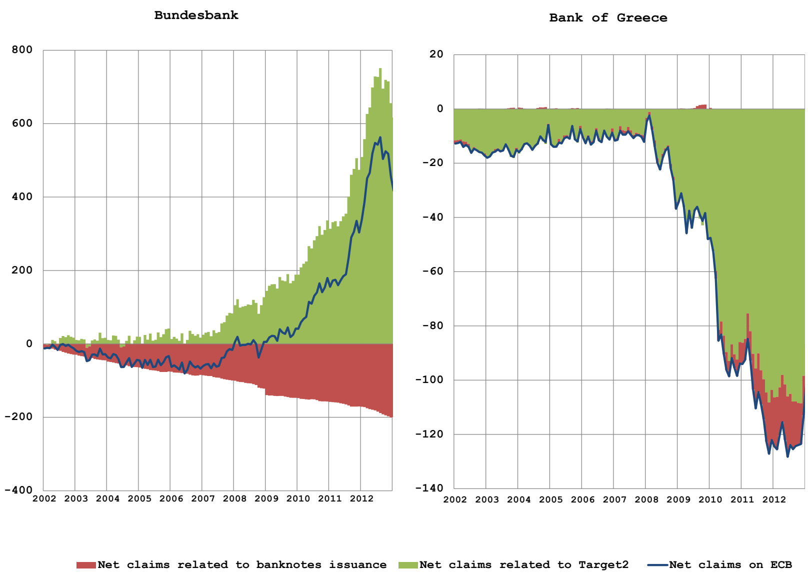


Figure 5.9: Intra–system positions of Bundesbank and Bank of Greece
Source: Graph taken from Boeckx and König (2012, p. 492) which is based on data from IMF IFS.

Tourists often pay their holiday bills with banknotes issued in Germany. Austrian service providers pay these banknotes into deposits at Austrian banks which thereby experience an increase in central bank reserves. If, for example, the additional liquidity is lent further to German banks or if Austrians pay for imports of German machinery and industrial equipment by using electronic transfers, T2 positions build up (a claim for Germany and a liability for Austria). These positions in turn compensate for the intra–Eurosystem positions related to banknote issuance (a liability for Germany and a claim for Austria).

In contrast to Germany, Greece shows a persistent T2 liability even prior to the crisis, but negligible intra–system positions due to banknote issuance. Only recently, with the crisis in full swing, did the Bank of Greece record intra–system liabilities due to over–proportional banknote issuance. It is rather likely that Greek agents, faced with the threat of their country leaving the EMU, preferred to hold more banknotes rather than deposits with their tattered banks.

Foreign currency transactions

T2 imbalances can also occur whenever banks in different euro area countries enter into transactions where one leg is denominated in a foreign currency. In such cases, only the euro–leg is recorded in T2. Suppose that in the example from section 5.3.1 bank 2 pays Θ euros to bank 1 and receives dollars in return. Only the currency composition of the banks' balance sheets has changed. Moreover, the transfer does not lead to a funding gap of bank 2 and does probably not create the need to borrow additional euro–liquidity on the interbank market. However, the balance sheets of NCBs change since only the euro–leg is recorded in T2. In fact, the changes in NCBs' balance sheets are observationally equivalent to those presented in Table 5.4 which occurred due to a funding outflow away from bank 2.

Centralized liquidity management

Large banking groups may centralize their liquidity management in one particular member country in order to exploit economies of scale. Consider the following example in Table 5.5. A banking group has centralized its liquidity management at a subsidiary in country 2. Both, the parent bank in country 1 and the subsidiary in country 2 are subject to minimum reserve requirements. The subsidiary borrows the liquidity for the whole group from NCB 2 and then distributes it via T2 to the other group members. In the example, the liquidity–managing subsidiary transfers amount Θ to the parent bank. The offsetting position is called 'intra–group'. As a result, NCB 2 records a T2 liability while NCB 1 records a T2 asset. This change in T2 positions is again observationally equivalent to a case where banks in the jurisdiction of NCB 2 face funding outflows and the need to obtain liquidity on the interbank market.

Table 5.5: T2 imbalances due to intra–group transactions.

	Parent bank in country 1		**Subsidiary in country 2**		**NCB 1**		**NCB 2**	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
reserve account	$+\Theta$	—	$-\Theta$	—	—	$+\Theta$	—	$+\Theta$
intra–group	—	$+\Theta$	—	$-\Theta$	—	—	—	—
T2	—	—	—	—	$+\Theta$	—	—	$-\Theta$
total changes	$+\Theta$	//	$-\Theta$	//	$+\Theta$	//	± 0	//

5.3.3 Abnormal T2 imbalances

Development of T2 positions during the crisis

As pointed out, the segmentation of interbank and funding markets during the crisis prompted the Eurosystem to take over the role of the market and to intermediate funding flows between banks. This led to an unprecedented build–up of aggregate excess liquidity in the euro area banking sector. The development of excess liquidity alone, however, would not necessarily entail the occurrence of large and persistent T2 imbalances. If stressed and sound banks were more or less evenly distributed across euro area member states, net deposit flows from weaker to stronger banks would not exert a disproportional and persistent effect on T2 positions. The existence of large T2 imbalances is rather a sign that stressed and sounds banks are located in different euro area member states and that financial markets became segmented along national borders.

This is visible from Figures 5.4 and 5.7. Aggregate T2 claims began to increase with the onset of the crisis. At the same time, individual positions began to develop unidirectionally (see e.g. the Bundesbank in Panel (i)) and the number of T2 creditor NCBs declined, implying that liquidity flows in the euro area were directed to a select group of countries. Accordingly, the banks in these countries (essentially Germany, Luxemburg, Finland and the Netherlands) could reduce their recourse to Eurosystem refinancing operations as they were able to satisfy their liquidity needs from the large liquidity inflows via T2. The increase of T2 claims at the beginning of the crisis is muted when claims are normalized by the aggregate liquidity needs of the euro area banking sector (Figure 5.8). As a percentage of liquidity needs, aggregate T2 claims slightly increased after the Lehman collapse and continued to increase during 2009 and 2010 due to the problems faced by the Greece and Ireland, albeit at a rather small rate. Yet, by the end of June 2011, driven by the massive increase of Spanish and Italian T2 liabilities, they spike upwards and eventually peak at a value of around 400% during the first quarter of 2012. Similarly, although excess liquidity was considered large by conventional yardsticks after the Lehman default in 2008 it was small when compared to the large build–up during 2011 and 2012 when the capital flight from Spain and Italy came to the fore.

The evolution of T2 positions went hand in hand with a larger recourse of banks

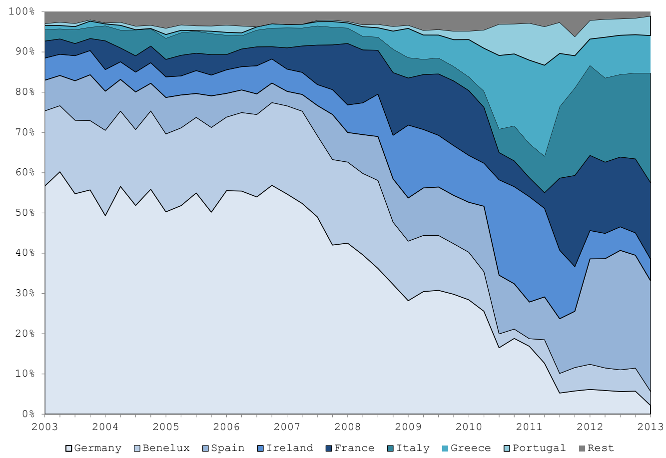


Figure 5.10: Shares in Eurosystem credit on a country level.
Source: Monthly balance sheets of NCBs; own calculations.

in T2 debtor countries to Eurosystem credit facilities and a reduction in Eurosystem credit by banks in creditor countries. This is illustrated in Figure 5.10 which shows the shares of countries in overall Eurosystem credit operations. German banks, usually the largest borrowers in Eurosystem operations (with shares of around 55%), now take out a meager 2%, while Spanish and Italian banks account for around 27% each.

The strong increase in T2 imbalances and the accompanying change in the pattern of Eurosystem credit recourse reflects the consequences of the Eurosystem intermediating the interbank market between core and peripheral countries. This, however, begs the question, why the strong geographical segmentation between core and periphery occurred and why the latter experienced such a massive reversal of capital flows. At the root of these reversals are, essentially, unsustainable external imbalances within the euro area that had been built in the years preceding the crisis.

Roots of the euro area balance of payment crisis

External Imbalances. Since its inception, the euro area as a whole showed rather moderate current account surpluses and deficits vis–à–vis the rest of the world.[31] Internally, however, persistent current account imbalances have been recorded which accumulated to large net external claim and liability positions. Spain recorded large current deficits which had accumulated to net foreign liabilities of around 975 bn EUR or 93% of GDP by the end of 2009. Similarly, Portugal and Greece steadily recorded current account deficits between 6% – 11% of GDP. Germany and the Netherlands in contrast continuously recorded surpluses between 3% and 7% of GDP. Due to its role as a financial center, Ireland was a special case. While its current account deficit and the resulting net investment position were rather small when measured against GDP, it experienced massive capital in– and outflows which peaked at a level of around 250% of GDP prior to the crisis in 2006.[32]

External imbalances within the monetary union were neglected in the union's design and did neither enter the pre–union convergence criteria, nor the Maastricht criteria (Giavazzi and Spaventa, 2010). Yet, there were reasons for this neglect. For example, as noted by Ingram (1973, pp. 14), the "traditional concept of a deficit or a surplus in a member nation's balance of payments becomes blurred" in a monetary union. Economic implications of balance of payments surpluses or deficits are likely to be less meaningful since own–currency market financing to cover short–term funding gaps should always be readily available. In a similar vein, founding fathers of the monetary union must have believed that once exchange rate risk was eliminated, countries' access to funding was assured. The occurrence of damaging balance of payments crises seems to have been associated with exchange rate pegs only and the single currency mechanism was seen as the means to shield individual countries from such crises. In addition, after the introduction of the common currency, the occurrence of euro area internal current account imbalances was largely interpreted as reflecting a catching–up of peripheral countries which had entered the monetary union with relatively lower output–per–capita ratios. Indeed, the evidence put for-

[31] The euro area's average current account balance between 1999 and 2012 amounted to around −110 million Euro.

[32] See Boeckx and König (2012) for the development of the Irish financial account relative to GDP.

ward by Blanchard and Giavazzi (2002) was reassuring in this respect. They find that current account balances of EMU members were increasing with per–capita–income, implying that capital flowed to the less advanced member states. Other studies, e.g. Ahearne, Schmitz, and von Hagen (2007), confirm this finding.

But the convergence narrative looses plausibility under closer scrutiny. Berger and Nitsch (2010) show that intra–euro area capital movements had the tendency to flow where the distortions in labor and product markets were most pronounced. Giavazzi and Spaventa (2010) report results of growth accounting exercises by the European Commission and the ECB which reveal that the conventional convergence story could at most be tailored to the Greek economy, but neither to the Spanish and Portuguese nor to the Irish one.[33]

Moreover, capital inflows to Spain and Ireland were largely channeled to the real estate sector where they fueled a housing bubble (Figures 5.11 and 5.12). The overall share of foreign direct investment into these economies was small (Figures 5.13, 5.14), implying that foreign capital providers did not purchase real estate directly (Giavazzi and Spaventa, 2010). Rather, the domestic banks stuffed their balance sheets with domestic mortgages and related assets which they went on to refinance with the banking sector in the euro area core countries (Eichengreen, 2010). This rendered the respective countries particularly vulnerable to sudden reversals of foreign capital inflows.[34]

Yet, Giavazzi and Spaventa point out that the Ireland / Spain explanation of foreign–funded housing booms does neither fit to Greece, Portugal nor Italy. Neither of these economies exhibited a housing boom and while Portugal and Italy were rather stagnant, at least productivity growth in Greece was more favorable. However, Jaumotte and Sodsriwiboon (2010) point out to the long–term decline of savings rates in these countries (Figure 5.15) and the accompanying increase in indebtedness as an alter-

[33]This is reminiscent of the ‘allocation puzzle’ found by Gourinchas and Jeanne (2009). It states that for developing countries, in stark contrast to neoclassical growth theory, capital inflows and productivity growth tend to be negatively correlated and capital tends to flow to countries that invest and grow less.

[34]See Calvo (1998) for an explanation why the vulnerability to sudden stops of capital inflows increases when countries’ maturity structure becomes shorter. European Commission (2006) and especially European Commission (2012) provide a discussion of the foreign funding composition of euro area countries.

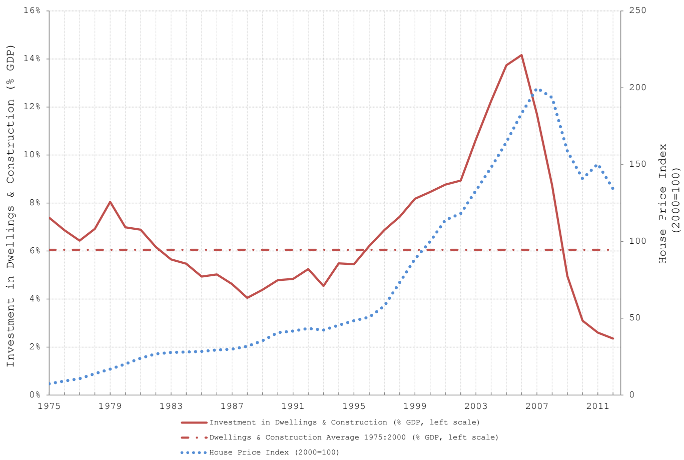


Figure 5.11: The Irish housing bubble. Shown are investment in construction and dwellings relative to GDP against its long–run average (taken to be average for the period 1975 to 2000) and the development of house prices where 2000 = 100. *(Data: Investment data from Ameco database, house prices from BIS property price statistics; own calculations.)*

native explanation. Saving rates began to decline during the mid–90ies, largely as a result of greater financial liberalization. The introduction of the euro, the fast financial integration and the steep decline of interest rates further helped to fund expenditures which otherwise would not have been possible to finance. Portugal and Greece had consumption rates far above euro area average, financed to a large extent through domestic bank credit. With savings low and consumption demand picking up, the current account necessarily worsened and external debt rose. Similar to what Spanish and Irish banks did with their mortgage–related assets, banks in Portugal and Greece re–financed domestic credit at quite favorable conditions in international capital markets. Thus, the current crisis countries strongly increased their private sector indebtedness and some of them also saw an additional deterioration of public sector debt. This in turn rendered these economies heavily dependent on foreign capital inflows and, given the financial landscape in the euro area, rather reliant on their domestic banking sector and its ability to tap intra–euro area capital markets.

Figure 5.12: The Spanish housing bubble. Shown are investment in construction and dwellings relative to GDP against its long–run average (taken to be average for the period 1975 to 2000) and the development of house prices where 2000 = 100. *(Data: Investment data from Ameco database, house prices from BIS property price statistics; own calculations.)*

The roots behind the build–up of these imbalances can be traced to the early days of the monetary union. In a well–known critique of the common currency, Walters (1990) stressed that the establishment of a common bond market in the course of the monetary unification must lead to real interest rate differentials. Countries with an initially higher inflation would exhibit lower real interest rates while low–inflation countries should face higher rates. Walters suspected that, given a common monetary policy, this would bring about unstable Wicksellian dynamics and ever growing inflation differentials between the two groups of countries. Expressed in modern lingo, Walters feared that a unit root would be induced into the inflation differentials.

However, in contrast to Walters' prediction, albeit inflation rates in different euro area regions are still quite pronounced, differentials did not continue to grow further.[35] Wicksellian dynamics from too low real interest rates did not unfold to the full extent as the real appreciation (given a fixed nominal exchange rate) exerted a counteracting effect. The protracted inflation differential undermined the ability of

[35] See Angeloni and Ehrmann (2007), Wyplosz (2010, 2013) or Mongelli and Wyplosz (2009).

high–inflation peripheral countries to compete with euro area core countries (Mongelli and Wyplosz, 2009). This worsened the current account position of peripherals and exerted a contractionary and opposing effect. In other words, the unit root that was suspected to occur in inflation differentials actually appeared in the current account positions which heavily diverged (Angeloni and Ehrmann, 2007; Wyplosz, 2010). Rather than pushing inflation differentials farther apart, low real interest rates supported an unsustainable level of consumption, and, as recently pointed out in a study by Wyplosz (2013), this drove the current account positions of most crisis countries far into negative territory.[36]

In addition, governance mechanisms for capital flows were insufficient. A disciplining exchange rate mechanism, which could have helped to prevent peripheral countries from over–borrowing was absent (Hellwig, n.d.). Otherwise, with a national currency, countries would have faced a limited capacity to borrow in their own currency and a large portion of capital inflows would have been denominated in foreign currency. This in turn would have forced borrowers to acknowledge the risk inherent in their borrowing. It is therefore unlikely that capital inflows would have fueled the housing bubbles in Spain and Ireland or continued to finance stagnant Portugal or high consumption rates in Greece.

Warnings by Ingram (1973, p. 22), that "to avoid the problem of an ever increasing burden of external debt" requires to invest borrowed funds into productive endeavors, remained largely unheard. Thus, with hindsight, the believe that external imbalances within the monetary union were irrelevant, proved wrong.

The property booms in Spain and Ireland reached their peaks in 2006. Since then, the share of investment in construction in GDP was falling (Figures 5.11 and 5.12). Although house prices went on increasing for some time until 2007 (Ireland) and 2008

[36] It is sometimes suggested that Harrod–Balassa–Samuelson effects led to the euro area inflation differentials. This explanation builds upon the assumption that catching–up countries reaped productivity gains in the tradable goods sector and the resulting wage increases spilled over to the non–tradables sector. In light of the evidence provided by Giavazzi and Spaventa (2010), it seems questionable whether this was indeed the case. Wyplosz (2013) provides an empirical test for the Harrod–Balassa–Samuelson hypothesis based on Ricci, Lee, and Milesi-Ferretti (2008) and rejects it. He also points out that this effect is completely silent about and thus not very helpful in explaining developments leading to current account deficits.

(Spain), the US subprime crisis and the Lehman default considerably worsened the funding tensions for banks and financial integration within the monetary union deteriorated. As pointed out by Milesi-Ferretti and Razin (1996), what matters for the sustainability of a country's current account position are the funding composition of external deficits, the domestic saving and investment behavior, private and public sector debt, financial market environment, as well as productivity and openness. In this light, the external imbalances in the euro area could not be sustainable: Low domestic saving rates (especially in Greece and Portugal), bank–biased funding structures, a fragile composition of financing (Ireland, Greece) and low productivity (Portugal, Spain) with production geared mainly towards the production of non–tradables. The major turn thus began in autumn 2009. Among investors the perception was spreading that

> "(...) the pattern followed by some countries in the last decade, with growth driven by domestic demand and financed with foreign borrowing, was unsustainable, and that the heavy imbalances which had accumulated were not the unavoidable outcome of healthy convergence processes but signaled the existence of solvency problems.
> (Giavazzi and Spaventa, 2010, p. 12)

As the largest part of domestic risks was sitting on domestic banks' balance sheets, the capital reversal led to the exclusion of peripheral banks from the interbank market and to the segmentation of markets across national borders. These developments were further aggravated by the strongly interlinked problems of banks and governments in these countries. This is often referred to as the *diabolic loop* problem of the euro area (Euronomics Group, 2011) and it implied that suddenly not only individual banks but rather nations and national banking sectors went underwater.

Diabolic Loop. There are three main reasons that contributed to the creation of the diabolic loop problem.

1. *Sovereign debt.* As the Euronomics Group (2011) points out, sovereign debt of all different euro area members was in most instances treated alike by regulators, market participants, policy makers, and the Eurosystem. Sovereign bonds

were by and large considered as safe assets. The yield differences for sovereign bonds converged after the introduction of the common currency and remained negligible until the beginning of the crisis. The perceived safety of sovereign debt implied that regulators attached a zero risk weight on sovereign portfolios, no matter how they were composed, when calculating the banks' capital requirements. Moreover, the Eurosystem did hardly discriminate between euro area sovereign bonds with different provenance and accepted all bonds as collateral in its operations. Although different haircuts were sometimes applied, these did certainly not fully reflect underlying structural and risk differences. The diverse euro area sovereign bonds were almost perfect substitutes in terms of serving as safe assets and with respect to the central bank liquidity they commanded. There were thus little reasons for banks to diversify their sovereign bond portfolios. This in turn contributed to the build–up of a *home bias* in sovereign debt portfolios and created a strong exposure of banks to the financial situation of their respective host countries.[37]

2. *Resolution of insolvent banks.* Banking regulation and the resolution of stressed banks in the euro area is left to national authorities. This is particularly problematic since many euro area countries host overly large banking sectors. On average, euro area banks hold assets roughly equal to three times the GDP of their resident country. Moreover, the balance sheet size of larger banks, e.g. ING or Santander, easily dwarfs the respective domestic GDP.[38] For comparison, no single bank in the United States has assets in excess of one eighth of US GDP.[39] Most bank resolution mechanisms, e.g. bad bank schemes, injection of equity, or debt guarantees, require at least a minimum involvement of the government and their implementation may therefore induce an additional fiscal burden. These costs increase in the size of the banking sector, which can make

[37] See also DIW (2012) or Merler and Pisany-Ferry (2012).

[38] See IMF (2013, p. 7).

[39] Total assets of the euro area banking sector amount to over 300% of euro area GDP, while for the US this ratio is below 100%, see Shambaugh (2012, p. 162). Shambaugh points out that this comparison does not reflect the shadow banking sector which is much larger in the US than in Europe. Including the shadow banking sector would probably show that relative to GDP, euro area and US banking sectors are of similar size.

it at some point prohibitively costly or even impossible for the respective national authorities to carry out an effective and long–lasting banking sector rescue plan. Comparing bank balance sheets to tax revenues of resident governments illustrates this point. In 2010, the ratio of bank assets to resident country tax revenues was nowhere in the euro area below 5. For a number of countries (including Germany, Greece, Belgium and Portugal) it exceeded 10, or even 15 (France, Netherlands, Spain) and reached a peak for Ireland at an astonishing ratio of 45.[40] According to Mody and Sandri (2012), one of the key driving forces of the euro area crisis was the close connection between banks and sovereigns caused by the implied costs of bank rescue measures. The perception of a high cost burden acted like a trigger for the regime shift in yield differentials of governments. Mody and Sandri point out that shortly after the Bear Sterns rescue in the United States, investors all over the world started to shift attention to the state of factors such as health of banking sector or the financial situation of the government. This caused government bond yield spreads in the euro area to widen. With the default of Anglo Irish, these considerations became even more pressing, despite the fact that Anglo was a rather small bank.

> "Suddenly, the ability of sovereigns to prop up the financial sector was in doubt. In this sense, Anglo Irish crystallized the public finance implications of global banking tensions. Thereafter, not only did the weakness of the financial sector raise sovereign spreads, but shocks to a sovereigns fiscal strength compromised the scope of financial sector support. Banks and the sovereign, at this point, were joined at the hip." (Mody and Sandri, 2012, p. 7)

3. *Lender of last resort responsibility.* A third cause, rather a subitem of the second point, is the national responsibility for lender–of–last–resort support in the euro area. The reason for stating it separately is that banking resolution rather pertains to *insolvent* banks, whereas a lender of last resort should, ideally, deal with *illiquid, but still solvent* banks. Therefore a lender of last resort function falls into the realm of the central bank. The ECB, however, does not assume a

[40] See Merler and Pisany-Ferry (2012).

de jure responsibility to carry out lender of last resort support.[41] Article 127 of the Treaty does not specify any concrete objective to sustain financial stability or to support troubled financial institutions. The only lender of last resort facility employed by the Eurosystem is therefore the *emergency liquidity assistance* (ELA) facility. Under current arrangements, ELA provision is within the discretion of the NCB to which the candidate financial institution is assigned and conditional on approval by the decision making bodies of the ECB. As losses due to ELA provision are borne entirely by the providing NCB, it has discretion with respect to the collateral it demands in exchange for its support. Given that banks can access the standing lending facility of the Eurosystem at their own discretion, ELA provision would not be necessary if the bank still possessed sufficient eligible collateral. Hence, the collateral in ELA operations is likely to be of minor quality and associated with higher credit and liquidity risks. Therefore ELA has often been made available only against an additional guarantee by the government. Yet, with or without such guarantees, the burden for ELA provision falls completely onto the shoulders of the respective national government, provided that the government would balance capital losses of the NCB in any case.

The Eurosystem was therefore designed such that *de jure* the risks and costs for any individual bank rescue measure, independent of whether a bank is already insolvent or whether it is just (highly) illiquid, are attributed exclusively to national governments. Although the size of ELA provision in the few publicly known cases[42] was never significantly high, in view of the relatively large bal-

[41]The question whether the ECB has *de facto* assumed the lender–of–last–resort role by steeply increasing its liquidity support during the crisis is beyond the scope of this chapter. Most scholars refer to central bank actions as 'lender of last resort' when liquidity support to individual is considered, e.g. Freixs et al. (2002) or Goodhart (1999). However, the original lender of last resort doctrine, dating back to Thornton (1802) or Bagehot (1873), is sometimes interpreted as referring to enhanced liquidity support to the market, see e.g. Humphrey and Keleher (1984) or Humphrey (2010). Henceforth, we will follow the former and use the term 'lender of last resort' only with respect to discretionary rescue measures directed at particular institutions.

[42]The rare cases where ELA provision has become known to the public include the case of BAWAG bank in Austria in 2006, the cases of Belgian bank FORTIS, or German Hypo Real Estate in 2008, see Manna (2009) for a discussion of the BAWAG case and Unicredit Research (2012) for remarks on FOR-

ance sheets of many euro area banks, this cannot serve as a guidepost for the expected burden of possible future interventions.[43]

The two–way linkages between banks and sovereigns described under the three points above created a diabolic feedback loop and gave way to a self–fulfilling and self–aggravating spiral: Bank debt portfolios suffer from tensions in sovereign bond markets as higher sovereign risk premia induce valuation losses and a decline in the value of banks' collateral. Given the home bias in sovereign portfolios, this loss increases disproportionately with tensions in markets for debt of banks' resident countries. The market liquidity of sovereign bonds declines and the likelihood of funding illiquidity and bank default for all banks in the respective country increases. Investors become increasingly suspicious and averse to lend to the banks and the sovereign. As a consequence of the funding dry–up, banks have to deleverage and curtail lending to the private sector. This in turn depresses domestic growth and worsens the fiscal situation of their resident government even further. Bank rescue measures, be it through re–capitalizations, guarantee schemes or ELA, exert an additional negative impact on the sovereign's financial position and, because of the large relative size of banking sectors, induce strong upward pressure on sovereign yield spreads. The latter feeds back into the sovereign debt position of banks, thereby completing the diabolic loop and validating investors' initial doubts. These close linkages between banking and government sector, in particular, created the breeding ground for the loss of confidence by investors and domestic depositors which in turn spurred the outflow of capital away from crisis countries towards banks in countries considered as safe havens with fiscally more potent governments that seemed capable to stem potential banking stress.

TIS and Hypo Real Estate.

[43]ELA has recently been used as a substitute for regular monetary policy operations in Greece, Cyprus or Ireland. In these cases, the size of ELA intervention was probably (as it is not known publicly) considerably high. A rough approximation for the Greek and Cypriot intervention can be given from the Eurosystem's consolidated balance sheet. Early in 2012, the ECB announced a switch in its accounting practices and declared to record ELA under balance sheet item 6. The change in this, otherwise not so frequently used item, allows to obtain ballpark figures for ELA provision. The highest level of ELA provision was therefore reached in calender week 46, 2012. During this week, an amount of EUR 235 bn was recorded under item 6. Subtracting the amount recorded under item 6 in calendar week 15 (before the accounting change was introduced), gives the ELA approximation of EUR 173 bn.

Adjustment to Capital Reversals

The exclusion of peripheral banks from financial markets and the resulting market segmentation forced the respective banks to increase their reliance on Eurosystem refinancing. Consider again Figure 5.10 which shows the shares in Eurosystem credit on a country–level. These developments are the mirror images of the developments of T2 positions. The shares of T2 surplus countries have deteriorated since banks in these countries do not need to take any recourse to the Eurosystem's facilities because they can easily cover their liquidity needs from the liquidity that flows in via the T2 system from banks in crisis countries which borrow the liquidity from their NCBs in order to match their funding gaps.

The Eurosystem's role as an interbank market maker is thus considerably enlarged to an intra–country–intermediator. An important consequence of its liquidity support has been to buffer adverse consequences of the massive capital outflows from euro area peripherals. In this respect, the T2 system played a significant role as it allowed banks in crisis countries to harness the liquidity they borrowed from the Eurosystem's various facilities.

To appreciate the mechanics behind the *adjustment buffer* function of the Eurosystem's liquidity support and the T2 system, let us firstly consider the general mechanics of the adjustment to a sudden reversal of capital flows. This can be illustrated by using the balance of payments and national income identities.

From the balance of payments identity follows

$$CA \equiv FA + V,$$

where CA denotes the current account deficit, FA stands for the financial account (capital imports) and V abbreviates the sum of errors and omissions, capital account and reserve changes. By abstracting from changes in V, a sudden reversal of capital inflows (a sudden reduction of FA) requires an equivalent contraction in the current account deficit CA. By the national income identity,

$$CA \equiv X - GNP, \tag{5.1}$$

where $X \equiv C + I + G$ stands for domestic absorption (domestic spending on tradable and non–tradable goods) and GNP abbreviates gross national product. A contraction in the current account deficit can either be achieved through an increase in GNP or through a reduction in domestic absorption. The former is rather unlikely to occur during an episode of capital reversals. Hence, the more plausible and relevant case is that adjustment is brought about by a reduction in domestic spending. This gives rise to an excess supply of both tradable and non–tradable goods in the economy. Any excess supply of tradable goods can be exported, thereby helping to reduce CA. But how can the excess supply of non–tradable goods be eliminated? Non–tradable goods cannot be exported and the demand reduction is therefore likely to give rise to a price decline and a real depreciation. Moreover, in a Keynesian or in a Fisherian world, output and employment losses may result (Reinhart and Calvo, 2000). In the former, prices and wages are rigid in the downward direction and their decline is likely to be too small. As a consequence, additional quantity adjustments have to occur which cause higher unemployment and lower output. In the latter, the real depreciation gives rise to a debt–deflation spiral. In particular, when the production of non–tradables is financed through loans at fixed nominal interest rates, a real depreciation raises the ex post real interest rate of producers of non–tradable goods and gives rise to a situation where the real value of their output falls short of the real value of their debt. Loans may become non–performing, producers default and financial intermediaries and other lenders incur losses. To compensate for these losses, financial intermediaries tend to reduce the supply of loans and cut down credit lines, thereby exacerbating deflationary pressure. This in turn is associated with worker layoffs and a sharp decline in production. Clearly, if the government or the monetary authority were able to nominally devalue the currency, the damaging Keynesian or Fisherian consequences could be mitigated and would probably be less pronounced.

As members of the EMU, nominal devaluations were not an option for euro area crisis countries. Moreover, across–the–board, these countries featured characteristics which are regarded either as creating a particularly fertile ground for a sudden stop, or as being rather problematic during episodes of capital reversals. Firstly, as already mentioned, capital flows largely went into the non–tradable goods sector. This implied that once capital stopped flowing in, there was hardly any overhang of tradable goods that could have been exported in order to dampen the required adjustment. Secondly, the inflowing capital came often in the form of bank debt with rather short maturity, which provided an especially ‘fertile breeding ground’ for the sudden stop (Reinhart and Calvo, 2000). In contrast to other forms of capital inflows, e.g. FDI, (short–term) debt is usually much more fragile as maturity is limited and lenders hold a financial claim instead of being a direct stakeholder. Thirdly, wages across southern peripherals were quite rigid in the downward direction, implying that the adjustment gave rise to a large number of worker layoffs and production cuts. Fourthly, whenever capital inflows were used to finance consumption rather than investments into productive enterprises, the adverse effects of a sudden stop would be expected to be more hefty (Calvo, 1998).

Given these characteristics, peripheral countries' adjustment to the capital reversal could have been expected to cause adverse consequences for their economies. The Eurosystem's liquidity support and the T2 system helped to smooth these, thereby acting as an *adjustment buffer*. The mechanics behind this buffer function can be seen immediately by writing out the financial account for a euro area country as

$$FA = -\Delta T2 + FA^o,$$

where $\Delta T2$ denotes the change in the T2 position (netted on the asset side) and FA^o stands for the financial account excluding T2 claims. The latter can be further written as

$$FA^o = \Delta A - \Delta A^*,$$

where ΔA denotes *(foreign purchases - foreign sales) of domestic assets*, and ΔA^* denotes *(domestic purchases - domestic sales) of foreign assets*.

Hence, using equation (5.1), we can further write

$$\begin{aligned} FA &= \Delta A - \Delta A^* - \Delta T2 \\ &= X - GNP \\ &= CA. \end{aligned} \tag{5.2}$$

The latter equation illustrates how the Eurosystem's liquidity support and the T2 system reduce the impact of the capital reversal. As sketched above, in the absence of additional liquidity support, the reduction of FA requires CA to contract. Given the fixed–rate full–allotment policy of the Eurosystem, any reduction in, say, ΔA, could be met without immediately adjusting X, but by an offsetting increase in $\Delta T2$, i.e.

by accommodating the capital outflow. Thus, the ability of peripheral banks to resort to Eurosystem facilities to borrow liquidity at their own discretion (given eligible collateral) which could be shifted through the T2 system, lent crisis countries greater stability and allowed them to smooth adjustment and to deleverage at a slower pace. In its role as the interbank market maker, the Eurosystem substituted for the pre–existing private contractual relations. It provided funding to previous debtors, at rather favorable conditions, and allowed previous creditors to deposit the received funds at small but risk–free rates. Private sector creditors could thereby shift credit risk onto the Eurosystem's balance sheet and transform their private claim into a claim against the public sector.

Figures 5.13 and 5.14 exemplify the discussion by showing the evolution of the financial account of Ireland and Spain for the period 2005 until the third quarter of 2012.[44]

For the entire period, Ireland shows a rather small current account deficit as capital inflows and outflows largely match. Up to the crisis, Ireland exports FDI and imports portfolio investments and other assets (largely bank debt). Beginning with the second quarter 2008, a significant fraction of capital imports take the form of T2 liabilities. The corresponding capital exports are mainly debt and portfolio investment. The last quarter of 2010 (the quarter when Ireland took refuge to the IMF programme) records the largest outflow of almost 150 bn EUR, mostly in debt assets. The largest fraction is matched by portfolio investments, but also by T2 liabilities of around 40 bn EUR. Since 2011, the Irish T2 position improves and private capital flows back.

The Irish situation contrasts with the Spanish one. Until recently, Spain records large and protracted current account deficits. Prior to the crisis, the financing capital imports mostly take the form of portfolio investments, while also Spain exports FDI. If we make the plausible assumption that portfolio investment is more liquid and easier to liquidate than FDI, the Spanish funding structure exhibits a considerable liquidity mismatch. With the onset of the crisis, the share of other investment assets in Spain's overall funding composition increases and its T2 positions become negative. Outflows peak between the second and the third quarter 2011 and continue to remain high until the second quarter 2012. Large outflows of portfolio and other

[44] Diagrams for Italy, Greece and Portugal are provided in the Appendix.

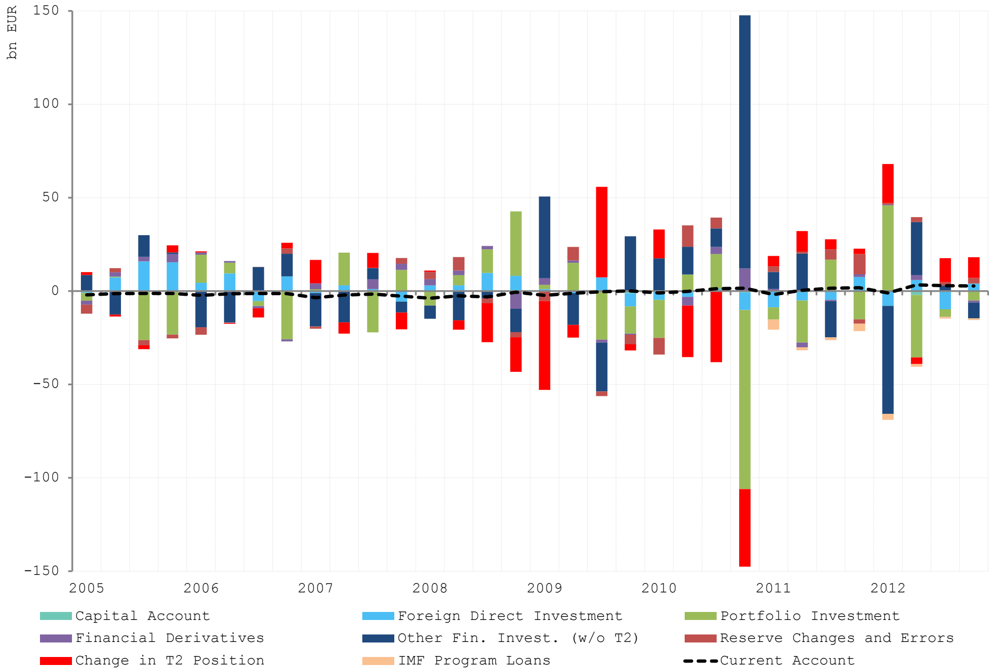


Figure 5.13: Financial account development of Ireland. Capital exports are shown with positive sign, and capital imports with negative. *(Data: Balance of payments data from IMF IFS database, T2 data from Euro Crisis Monitor; own calculations.)*

investment assets occur during this period but hardly any private capital flows in. As a consequence, the T2 positions increase strongly.

The diagrams clarify the adjustment buffer function of the Eurosystem's support. In the absence of additional central bank financing and a dry–out of private capital flows, the current account positions would had to switch into positive territory at a rather fast rate. Due to the availability of central bank liquidity, the actual adjustment took place at a slower pace. From this perspective, the T2 system enhanced stability and provided the time to undertake needed reforms to resolve the distortions that caused the external imbalances in the first place.

There are, however, objections to the unconstrained large provision of Eurosystem liquidity. Sinn and Wollmershäuser (2011, p. 27) stress that this financed the current

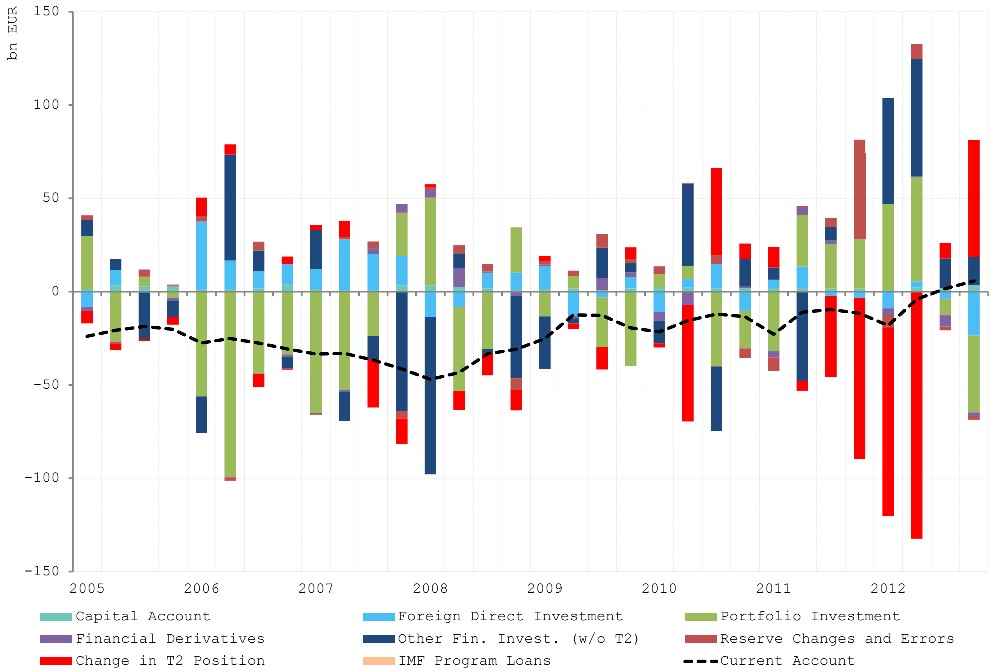


Figure 5.14: Financial account development of Spain. Capital exports are shown with positive sign, and capital imports with negative. *(Data: Balance of payments data from IMF IFS database, T2 data from Euro Crisis Monitor; own calculations.)*

account deficits and may have actually caused funding outflows in the first place. It is worth quoting their comment in full.

> "While it is clear that the (...) rescue operations have financed the current account deficits and the capital flight, they may, in fact, even have caused or supported them. After all, had the public credit channels not been available, there would have been an even stronger credit squeeze in the GIIPS countries, which would have made it impossible for them to finance their current account deficits. A rapid nominal contraction of the economy would have depressed the nominal incomes and hence imports, avoiding the current account deficits. Moreover, private capital owners would not have been able to flee if the banking sector had been unable to buy their assets with the newly printed money it was able to borrow from its NCB. Asset prices would have fallen rapidly, and an equilibrium would have emerged which would have made it again sufficiently attractive for capital to stay or for new capital to come from abroad. True, quite a number of investment funds, banks and insurance companies in the rest of the world would have suffered from write-off losses, and states would have had to rescue a number of commercial banks."

In light of the discussion above, we agree with Sinn and Wollmershäuser that, absent Eurosystem support facilities, the capital reversal would have required an immediate contraction in the current account position.[45] Furthermore, we agree that it is not obvious from equation (5.2) whether the current account deficit may eventually be reduced whenever the Eurosystem provides liquidity that can be used to accommodate the capital outflow via the T2 system. This begs the questions whether the liquidity support stalls the underlying adjustment, and how external adjustment can be achieved in a monetary union.

External adjustment in a monetary union is necessarily different from external adjustment under a pegged exchange rate system. Under the latter, the central bank is faced with the threat that the reversal of capital flows exhausts its reserves and enforces the break–up of the exchange rate fixation. On the one hand, this exerts a dis-

[45] However, the claim that the availability of the Eurosystem's facilities has *caused* the capital reversal remains an unprovable counterfactual (to say the least).

ciplining effect on the central bank and its government which may already in the first place implement policies to avoid external imbalances. On the other hand, such a system is also prone to self–fulfilling speculation and balance of payments crisis can occur even in situations where the country's fundamentals are rather favorable.[46]

It is unlikely that a self–fulfilling crisis can occur in the euro area. As long as the Eurosystem stands ready to accommodate capital outflows and as long as the payment system operates without constraints, the T2 positions are limited only by the collateral required for borrowing central bank liquidity and cannot be exhausted. While this increases the monetary union's financial and banking stability, it makes it more difficult to correct the underlying imbalances. Jaumotte and Sodsriwiboon (2010) point out that the policy options left to re–balance external deficits in a monetary union are

- Fiscal measures: Consolidation of public deficits sufficiently large to offset counteracting developments in private saving and investment.
- Structural measures: Policies that foster productivity growth to regain competitiveness in the medium- to long-run, including labour market reforms, investments in education etc.
- Internal devaluation: Reducing labor costs relative to most important competitors. This could in principle be achieved by changing the weight of tax bases (increasing VAT to finance reduction in social security contributions) or by pegging the wage growth rate to the lowest inflation neighbor.
- Regulatory financial policies: Strengthening financial supervision to limit growth of private sector credit and improve overall loan quality.

Usually, the implementation of any of these measures can be achieved only through a lengthy and sometimes complex political process. The adjustment mechanics that come into play in the monetary union are thus constrained by institutional and political forces. Moreover, it takes time until such measures exert an impact on external

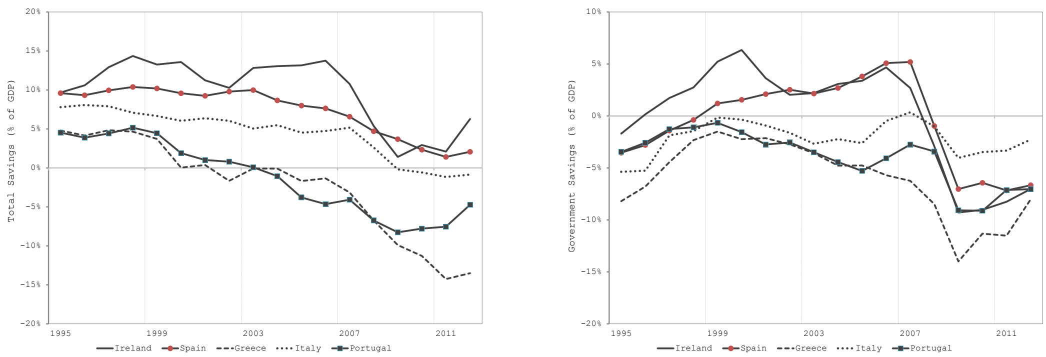
[46] See Obstfeld (1996) for a model of self–fulfilling crises with multiple equilibria. Morris and Shin (1998) or Heinemann and Illing (2002) use the global games approach to derive a unique equilibrium in such a model where the peg may even be abandoned when the fundamentals could, in principle, support the peg.

positions. This can be provided by the liquidity support measures which bridge the waiting period until reforms become effective. But do they forestall the adjustment of the current account deficit as Sinn and Wollmershäuser suspect?

On the one hand, it is certainly correct that the provision of liquidity limits the painful consequences of the capital reversal and thus reduces incentives of crisis countries to immediately implement any of the above mentioned measures to adjust their external positions. Since the costs of adjustment to a capital reversal in absence of additional external support are indeed quite high, one may suspect that crisis countries would have adjusted with more vigor and probably had implemented measures to avoid the external imbalances in the first place, had their banks not been able to rely on aiding measures from the ECB.

On the other hand, it must be noted that the accommodation of capital outflows does not eliminate all adverse consequences of a capital reversal. Not all private entities which experience a funding drain can resort to the Eurosystem's facilities, and neither can they automatically refinance with the banking sector in order to smooth idiosyncratic funding shocks. Even though banks can, at the current operational modes of the Eurosystem, meet capital outflows through additional borrowing, this diminishes their capacity to issue new credit since a larger part of their assets become encumbered in monetary policy operations and are thus not available to secure funding for new investments. As a consequence, the real sector becomes credit–constrained which exerts downward pressure on aggregate demand. The price decline of non–tradable goods is thus not stalled but only mitigated, which implies that there will be additional valuation losses for all different types of agents in the economy. And even though one may doubt whether the institutional structure in the euro area, and in particular in crisis countries, is flexible enough to quickly implement needed reforms, there can be no doubt that at the current juncture, these countries have undergone strong adjustments. Firstly, all of them reduced current account deficits (e.g. Figures 5.13 and 5.14). Secondly, economy–wide savings rates stopped declining and even began to increase in Portugal, Spain and Ireland (see Figure 5.15). This is largely due to households reducing consumption spending and government deficits beginning to rebound because of drastic austerity packages sometimes implemented under the auspices of EU, ECB and IMF (in line with the first

Figure 5.15: Total saving rates and government savings of crisis countries in % of GDP. *(Data: Ameco; own calculations.)*



policy option).

Thirdly, despite the Eurosystem's support, the crisis countries, especially Spain and Greece, experienced strong increases in unemployment and reductions in GDP. Interestingly, except for Ireland, the deleveraging of the banking sector seems to lag behind the real adjustments (see Figure 5.16). Total assets of banks started to decline some time after the peaks in the respective NCBs' T2 positions were recorded. This allows to tentatively conclude that Eurosystem policies seem to have had a strongly mitigating impact on the adjustment of banks' balance sheet without stalling the needed real adjustments.

Hence, even though the effect of any direct economic mechanism (like a price or exchange rate mechanism etc.) that speeds up the external adjustment is mitigated in a monetary union, in the presence of the adverse developments and the adjustments that take place in crisis countries, it is misleading to claim that Eurosystem facilities prevent external re–balancing.

Furthermore, we cannot subscribe to the easiness with which Sinn and Wollmershäuser point out to "asset price deflations" and "rapid nominal contractions". While we can appreciate the theoretical appeal that reference to a 'natural, market–based' solution may have, we believe that besides the existence of Keynesian or Fisherian effects, it would have failed in practice for at least two further reasons. Firstly, given the size of the banking sectors in the euro area, it remains doubtful whether even

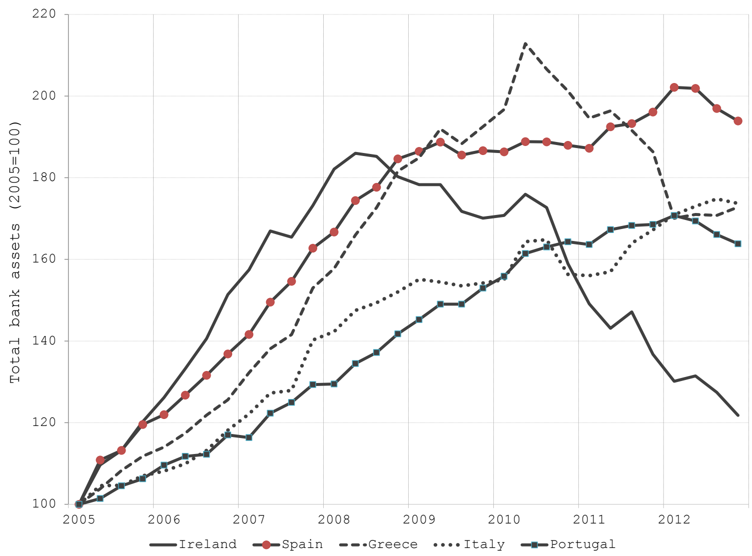


Figure 5.16: Index of aggregate bank assets of crisis countries, 2005 = 100. *(Data: Bundesbank; own calculations.)*

sound governments would have been able "to rescue a number of banks". For example, as shown by Cecchetti, McCauley, and McGuire (2012), German banks reduced their exposure to periphery countries between 2008 and the second quarter of 2012 by around 281 bn EUR. The write–off of only a part of this amount would have had severe repercussions on the respecive banks and any rescue measure would have likely had a severe impact on the German fiscal situation. Secondly, a more fundamental reason for the failure of this argument is the *Lucas critique*. The default on a large fraction of external liabilities would have damaged investor wealth in the remaining euro area. This would have obviously led to a change in expectations and behavior. It is therefore highly questionable whether the equilibrium that the authors have in mind would have been stable or whether the adverse developments would have continued. In Charles Goodhart's words,

> "ex ante one must suspect that crises and panics will disturb and disrupt the prior pattern of statistical relationships. Amidst a flurry of failing banks screaming headlines in news stories, can anyone be confident that the monetary guideposts (weak as they have been) may not shift some considerable way further? How much easier then, how much less disrup-

> tive, how much more efficient to nip the panic in the bud, to prevent the contagion before it gets hold, by organizing a rescue." (Goodhart, 1995, p. 289)

Hedging against exit

Besides capital flow reversals, *hedging against exit* was recently identified by Cecchetti, McCauley, and McGuire (2012) as another important determinant of T2 imbalances. That banking groups from inside and outside the euro area engage in such activities can be seen as a cautionary sign that euro area internal asymmetries and the geographical segmentation persist and that investors attach a non–zero probability on the exit of crisis countries.

The balance sheet mechanics behind exit–hedging are similar to the mechanics behind centralized liquidity management of banking groups that was discussed in section 5.3.2 above. Consider a banking group with two members, one being domiciled in a euro area crisis country and the other in a euro area safe haven. Suppose that on the asset sides of their balance sheets, both banks hold claims against local borrowers. Prior to the crisis, with the likelihood of exit of a country being virtually zero, it was irrelevant for the risk exposure of the overall banking group whether each member bank obtained liquidity at its assigned NCB or whether any of the two members obtained the liquidity for the group as a whole. The ongoing crisis and the economic and political turmoil faced by some countries created the belief that exit from the monetary union had to be considered as a political option. The possibility of exit does not cause a change in the credit risk exposure of each member. But it may give rise to re–denomination risk. The likely devaluation after an exit would produce a currency mismatch on the banking group's overall balance sheet if the liquidity was borrowed from the NCB whose country remains part of the euro area. Cecchetti, McCauley, and McGuire (2012) point out that to hedge this risk, the banking group would shorten its positions in weak and lengthen it in stronger '(proto)–currencies'. To this end, the banking group would take recourse to Eurosystem operations in the crisis country and shift the liquidity via T2 to the group member in the safe haven, thereby giving rise to T2 imbalances.

5.4 Exit Risk

The additional risk–taking due to extended liquidity support under an (at least) inert risk management framework is in no way a special characteristic of the Eurosystem's crisis policies. All major central banks that extensively 'used their balance sheets' during the crisis increased their exposure to market, liquidity and default risks considerably. There are, however, two facets of the its institutional and operational design which directly expose the Eurosystem to the additional risk that one of its members may exit the monetary union. Firstly, the euro area is 'only' a monetary union but it is neither a political nor a fiscal union. Secondly, even the monetary policy system is not completely unionized since NCBs retain responsibility for the counterparties in their jurisdiction and for the monetary operations of their counterparties with the Eurosystem. The direct exposure to exit risk is created by the following two implications of these facts.

1. Since the euro area is a merger of seventeen politically independent countries, every country can leave the euro area at its own discretion. To be precise, under present international law, leaving the European Monetary Union (EMU) without also leaving the European Union (EU) is, at least legally, impossible. However, a withdrawal from the EU is legally conceivable and would also entail exit from the EMU.[47] The politico–economic fallout from a decision to withdraw from EU / EMU may be devastating and the legal complexities involved in such a step are seemingly unsolvable. Yet, economic developments in countries like Cyprus or Greece, the rise of political forces that strongly reject the euro, for example in Italy's latest election, and the current activities of larger banking groups to hedge against a potential exit (see section 5.3.3 above) all present evidence that such a scenario is not as hypothetical anymore as it may have been a few years ago when the crisis began. Even ECB president Mario Draghi admitted this freely in 2012 when he said with respect to the risk premia in sovereign debt markets, "[t]hese premia have to do, as I said, with default, with liquidity,

[47] The authoritative view is by Athanassiou (2009), which is one of the few legal in–depth discussions of this issue. He also points out that the likelihood of expulsion from the EMU is almost zero, given the legal, conceptual and practical problems.

but they also have to do more and more with convertibility, with the risk of convertibility".[48] Thus, market participants and policy makers seem to believe that it is in general possible, at least with a certain small probability, that a country may decide to leave EU / EMU at its own discretion.

2. Under present arrangements, any monetary policy operation between the Eurosystem and a counterparty gives in fact rise to a contractual relationship between the counterparty and the respective NCB to which it is assigned (and *not* between the counterparty and the ECB or the Eurosystem as a whole).[49] Therefore only the respective NCB has the legal right to seize the collateral that is pledged in the course of a monetary policy credit operation.[50] Hence, while the collateral which it requires in its lending operations indeed insures the Eurosystem (partially) against the risk of a counterparty default, the decentralized nature of monetary policy operations and the fact that only NCBs can access the collateral imply that the Eurosystem is not insured against the potential losses that may occur because one of its members withdraws from the monetary union.

Points (1) and (2) together imply that the exit of a country from EU / EMU may create a loss for the remaining member countries.[51] The Eurosystem's regulations and the various treaties regulating the institutional structure of EU and EMU do not contain specific provisions that govern a withdrawal from EU / EMU. It is therefore difficult to speak with certainty about any losses that may or may not occur in the course of an exit. Moreover, the history of sovereign defaults and financial crises is crystal clear

[48] Quoted from Cecchetti, McCauley, and McGuire (2012, p. 9).

[49] See e.g. Deutsche Bundesbank (2013, Section V).

[50] In case of a counterparty default, the NCB seizes the collateral and sells it in order to make good any potential loss. If the liquidation value of the posted collateral falls short of the value of the credit claim, the NCB incurs a loss. Any losses arising from regular monetary policy operations are shared among the NCBs according to the ECB capital key. The loss shares are attributed via intra–system balance sheet positions. See Boeckx and König (2012) for a simple example of the balance sheet mechanics of loss sharing. Given harmonized collateral eligibility criteria, the risk–sharing does not come at the expense of any particular NCB. Loss sharing does not apply in case the loss arises under ELA provision. As mentioned in section 5.3.3, in this case only the responsible NCB incurs the loss.

[51] We are not concerned here with potential losses due to contagion or spill–over effects. These indirect losses are much harder (or even impossible) to quantify than the direct losses.

on one fact: Even sovereign defaults on explicit contractual obligations were usually associated with long lasting negotiations between creditors and debtor. Since the exit of a country from EU / EMU would most likely not be a 'wild exit', the plausible scenario is that an 'exit agreement' may be negotiated and that negotiations may even continue after a country has already created precedents and left.[52] Such negotiations may be a rather lengthy complex political and legal process. In the end, the resulting exit agreement is most likely to contain a compromise about the positions that have to be written off by the remaining euro area countries and the compensations and redemptions that have to be covered by the exiting country. Since the outcome of these negotiations is highly uncertain, given the lack of guiding principles and Treaty provisions, we cannot explicitly calculate the expected 'exit loss' for the Eurosystem. However, we can narrow down the Eurosystem's *position at risk* due to the exit of a member. We define this to be the net sum of balance sheet items that are neither covered by collateral nor by offsetting balance sheet items and thus become subject to negotiation between the exiting country and the remaining euro area. Put differently, the *position at risk* is equal to the amount that would need to be written off in case the exit country would disappear completely without leaving any recovery value. As will be illustrated by means of balance sheet examples, the *position at risk* can be calculated as the *sum of net T2 liabilities and banknotes in circulation on the balance sheets of the NCB of the exiting country.*

We begin by considering banknotes in circulation. This case is presented in Table 5.6, which shows the aggregated balance sheets of NCBs that remain part of the euro area, the balance sheet of the NCB of an exit country and the consolidated balance sheet of the Eurosystem. The table is drawn for the period *before* the exit occurs when also 'NCB exiting' is still a member of the Eurosystem. Aggregate liquidity is equal to $M_1 + M_2$. In the exiting country, a fraction $\beta \in [0, 1]$ of liquidity M_2 is held in banknotes and we assume for simplicity's sake that no banknotes circulate in the remaining euro area countries.

[52] Athanassiou (2009) points out that on the one hand, the exit clause in the Lisbon treaty recognizes a *unilateral* right to leave, but on the other hand makes references to an exit agreement. The exit clause does not differentiate whether an EU member is also member of EMU or not.

Firstly, set $\beta = 0$ and suppose that the country leaves the euro area and introduces a new currency.[53] What happens on the consolidated balance sheet of the remaining Eurosystem? On the asset side, the Eurosystem holds credit claims of amount M_2 against banks in the exiting country. On the liability side it recorded reserves of these banks. When the country exits, both items are decreased by the same amount M_2: Since the exiting NCB, which holds the claims of M_2 against the banks in the exiting country, is not a member of the Eurosystem anymore, the Eurosystem looses these claims and therefore its assets have to be decreased by M_2. This also entails that the Eurosystem does not have any liability anymore to provide these counterparties with euro central bank liquidity. Hence, liabilities are also decreased by M_2 and no position on the Eurosystem's balance sheet is put directly at risk due to the exit.

Suppose now that banknotes circulate in the exiting country, i.e. $\beta > 0$. After the withdrawal from the union, the exiting NCB again re–denominates all positions on its balance sheet.[54] As in the previous example, the Eurosystem has to reduce its claims by M_2. But now it can decrease the reserves to banks only by the amount $(1-\beta)M_2$. The banknotes outstanding in the exiting country of amount βM_2 are not covered by an offsetting position and cannot be removed automatically from its balance sheet. Amount βM_2 is the Eurosystem's position at risk due to the exit.

There may, of course, be ways to reduce this position ex post exit. The imprinted country code allows to trace the origin of euro banknotes which makes it possible to withdraw the respective notes from circulation. Moreover, the exiting country may draw in euro notes or exchange euro notes for newly issued currency. It can then hand over the euro notes to the Eurosystem (it is quite doubtful whether agents would be willing to exchange their euro notes against the probably less valuable domestic notes). Alternatively, the Eurosystem could withdraw all notes from circulation and issue newly designed coins and notes in the remaining member states.[55]

[53] We deliberately ignore any problems that may arise for the banks or the central bank in the country due to currency mismatches etc. on their balance sheets.

[54] This may be a little bit more involved than in the previous case because the NCB has to find a way to deal with the euro banknotes on its balance sheet. However, this is a minor problem. Even if the resulting procedure would cause the capital of the NCB to become negative, it would still be operational.

[55] With respect to the first alternative, the euro area could exchange banknotes originating in the exit country against notes produced in the remaining euro area until a deadline. After the deadline

But such solutions require additional actions and regulations that can only be implemented with help from the executive in the euro area. We want to emphasize here that there exists neither an accounting, nor an economic mechanism that reduces the position at risk to zero. Whenever banknotes and coins circulate in the exit country, there is no back–up that allows the Eurosystem to automatically contain any potential losses in full.[56]

Table 5.6: Example of exit *without* $T2$ balances

	NCBs remaining		**NCB exiting**		**Eurosystem**	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
CB credit	M_1	–	M_2	–	M_1+M_2	–
bank reserves	–	M_1	–	$(1-\beta)M_2$	–	$M_1+(1-\beta)M_2$
banknotes	–	–	–	βM_2	–	βM_2
T2	–	–	–	–	–	–
total	M_1	//	M_2	//	M_1+M_2	//

What we have just explained with respect to banknotes in circulation carries over to T2 liabilities. The corresponding example is presented in Table 5.7. For simplicity, we set $\beta = 0$ and assume that prior to the exit, the NCB in the exiting country lent M_2 to its counterparties. However, banks have moved a fraction $\tau \in [0,1]$ of borrowed liquidity via the payment system to banks in the remaining euro area. After the exit, the Eurosystem writes off claims of M_2, but it can only reduce its liabilities by the amount $(1-\tau)M_2$, which is the amount that remained on the reserve accounts of banks in the exiting country. The remaining portion, τM_2, was already moved to accounts of banks in the remaining euro area and now constitutes a claim of these banks against the Eurosystem. Moreover, since the collateral pledged by banks in the exit country can only be accessed by the exiting NCB, there is no collateral coverage for this position either. Before the exit, T2 liabilities were a mere accounting item. But because of the exit they become euro–denominated liabilities of the exiting country.

the notes originating in the exit country are declared illegal. However, as long as notes issued in the remaining euro area are circulating in the exit country, the only way to fully eliminate the exit loss is by strict border controls to prevent agents in the exit country from re–importing these notes.

[56] If we suppose that the exit becomes known in advance the amount of banknotes in the exit country is most likely to rise because depositors will try to convert their claims into euro notes before they get re–denominated in the new weaker currency.

From the perspective of the Eurosystem, both T2 claims against and banknotes circulating in the exit country constitute liabilities of the Eurosystem, unbacked by off–balance sheet collateral or on–balance sheet assets.

Table 5.7: Example of exit *with* $T2$ balances

	NCBs remaining		**NCB exiting**		**Eurosystem**	
	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
CB credit	M_1	–	M_2	–	$M_1 + M_2$	–
bank reserves	–	$M_1 + \tau M_2$	–	$(1-\tau)M_2$	–	$M_1 + M_2$
banknotes	–	–	–	–	–	–
T2	τM_2	–	–	τM_2	–	–
total	M_1	//	M_2	//	$M_1 + M_2$	//

5.5 Insuring Against Exit and Re–Balancing of T2 Positions

Can the Eurosystem insure itself against exit risk? Are there any adequate risk control measures that can be implemented to mitigate or even eliminate the position at risk *without* endangering the coherence of the monetary union? Furthermore, insofar as the imbalances may be associated with excessively large external imbalances, are there measures that may not only mitigate the exit risk but also provide incentives for the respective countries to enact policies that reduce external imbalances?

As indicated in the previous section, there may be ways of mitigating, ex post exit, losses arising from banknote circulation. Yet, potential losses arising from T2 liabilities cannot be addressed by measures such as strict border controls or issuance of newly designed notes. Therefore, this section provides a critical assessment of various proposals that have been made to insure against the exit risk associated with T2 positions. We classify measures to reduce T2 imbalances into *preventive* and *curative measures*. The former prevent the build–up of overly large imbalances, while the latter seek to re–balance T2 positions (or at least the inherent risk) but do not restrict their build–up in the first place. The *preventive measures* to be discussed are (i) the centralization of monetary policy at the ECB, i.e. the transfer of responsibility for counterparties and the management of counterparties' reserve accounts from the level of NCBs to the ECB; (ii) direct limits on the size of T2 liabilities (Sinn, 2011b); (iii) surcharges for any T2 liabilities above a certain trigger level (Bindseil and Winkler, 2012; Schlesinger, 2011). The *curative measures* discussed are (iv) the regular settlement of T2 positions by means of asset transfers (Sinn and Wollmershäuser, 2011b; Sinn, 2013); (v) providing only the liquidity that the banking sector needs in aggregate, i.e. returning to the aggregate liquidity management model.

Point (v) is, in our opinion, key to resolve the misunderstandings surrounding the T2 controversy. Excessively large T2 imbalances cannot build up in the euro area whenever the Eurosystem restricts its liquidity provision to the amount of liquidity needed in aggregate, i.e. if it follows the aggregate liquidity management model described in section 5.2.1. Obviously, for the reasons outlined in section 5.2.2 this is not the best operational mode during a period of dysfunctional financial markets, since it relies on a well–functioning market mechanism to ensure the provision of liquidity to all banks. But if the Eurosystem was returning to this operational mode, a large part of T2 imbalances would vanish. We refer to this as the *natural re–balancing* of T2 positions. The claim that *hysteresis imbalances* will persists even after an end of the crisis (Fahrholz and Freytag, 2012; Sinn, 2013) is probably based on the (implicitly made) assumption that the fixed–rate full–allotment procedure is continued. We show that no hysteresis imbalances prevail once the aggregate liquidity deficit is allocated in the same way as prior to the crisis. However, since this is a rather unlikely scenario, it is possible that T2 imbalances prevail which differ from the imbalances seen prior to the crisis. This, however, is the result of the re–allocation of the aggregate liquidity deficit and structural changes that may have taken place in the euro area banking sector during the crisis and not the result of current account transaction that took place during the crisis as suspected by Fahrholz and Freytag (2012).

Moreover, most proposals to limit T2 liabilities, in particular those made by Sinn and Wollmershäuser (2011b) or Sinn (2013), are also motivated by the desire to provide incentives to countries to keep their current account deficits in check, and thereby to prevent the occurrence of balance–of–payments disequilibria within the euro area. In this respect, the arguments supporting point (v) as well as the observed pre–crisis patterns of current account deficits and T2 positions disprove the claim that measures taken against T2 imbalances are sufficient to delimit current account deficits. Notably, Italy and Spain showed large current account deficits in the run–up to the crisis. Yet, both of them persistently recorded positive T2 positions. Addressing macroeconomic imbalances by addressing T2 imbalances is therefore a futile exercise as it easily 'misses the target'.

One may, of course, argue that measures to address T2 imbalances are not intended to prevent external imbalances, but should rather enforce the actual adjustment of the current account and the deleveraging of the private sector. Again, this can be achieved more easily than by limiting T2 positions, as it requires only the full–allotment policy to be quitted. This fact illustrates the role of the T2 system for the Eurosystem. They do not constitute a loan or a credit on their own, but reflect the usage of previously borrowed liquidity which is obtained from the Eurosystem's various facilities. The strong focus on discussing T2 positions all too easily neglects that there exist various possibilities to bypass any regulations of T2 imbalances, simply because such regulations would only restrict one, albeit an important, way of harnessing previously borrowed liquidity.

5.5.1 Preventive Measures

(i) Centralizing the monetary policy implementation at the ECB. T2 imbalances could be immediately eliminated by fundamentally changing the institutional arrangements of the Eurosystem and transferring the full responsibility for counterparties to the ECB. If the ECB, on behalf of the members of the Eurosystem, concluded the borrowing contracts with counterparties and administered their reserve accounts, cross–border transfers of liquidity would not appear on NCBs' balance sheets anymore. Obviously, this would neither prevent nor limit cross–border capital flows and it would not provide incentives for countries to keep current account deficits low.

As the contractual partner of counterparties, the ECB would receive access to the collateral. In case of an exit, the remaining NCBs could take recourse to the pledged assets and sell them to make good any potential exit losses. While this provides some insurance against the exit risk, the potential losses may not be contained in full, however, since collateral may have been issued under domestic law and therefore may become subject to re–denomination in case a new currency is introduced after the exit.

Whether or not a full centralization of monetary policy constitutes a feasible option is a completely different matter. As the Eurosystem chose the present decentralization of monetary policy from its start, there may have been political, legal or organizational constraints that inhibited a further centralization.

(ii) Direct limits on T2 positions. Sinn (2011b) proposes to limit T2 accounts; he writes,

> "[t]ight national caps on Target balances could provide the right incentive to comply. Such a cap would not eliminate current–account deficits, but it would reduce deficits to the flow of private capital willing to finance them. Setting a cap on Target accounts is a fundamentally more appropriate policy to keep current–account deficits in check than the wage policies contemplated by the new Pact for the Euro. Wage policies are appropriate only for centrally planned economies."

Firstly, Sinn proposes to limit T2 positions in order to reduce current account deficits. As already pointed out, there is no one–to–one relationship between the current account and T2 positions that could be exploited for such a purpose.

Secondly, even if there were a one–to–one relationship and if it was true that a net T2 liability would be necessarily associated with a current account deficit, the proposal to limit T2 positions begs the question of how and at which level the limit should be set. A balanced current account is not a 'natural outcome' in an open economy. As pointed out by Blanchard and Milesi-Ferretti (2009), there are 'good' imbalances, reflecting an optimal allocation of capital over time and space, as well as 'bad' imbalances, reflecting distortions in goods, labor and asset markets. Even if we acknowledge the evidence put forward by Berger and Nitsch (2010) and others that capital flows in the euro area gravitated towards those countries where distortions in goods and labor markets were most pronounced, we cannot say with certainty which portion of the current account deficit should be classified as 'bad'. Conversely, we can never say up to which point current account deficits should be allowed. Such a limit is arbitrary because no matter how much econometric evidence we accumulate to prove that past capital flows were of the 'bad' type, we can never use this evidence to infer about the quality of future flows. A policy of introducing an arbitrary limit on T2 positions or current accounts, determined by the ECB's or the European Commission's experts, can therefore be equivalently judged to be "appropriate only for centrally planned economies" (Sinn, 2011c).

Thirdly, a limit may be legally problematic as it could be interpreted as a direct violation of Article 26 (2) TFEU, "the internal market shall comprise an area without internal frontiers in which the free movement of (...) capital is ensured" and Article 63 (TFEU), "(...) all restrictions on the movement of capital between Member States and between Member States and third countries shall be prohibited". Sinn's proposal requires nothing less than changing fundamentally a core–constituting element of the EU. Impeding capital flows in this way furthermore impairs the monetary transmission mechanism and thereby endangers the *singleness* of monetary policy in the euro area. Banks, which otherwise could freely participate in the interbank market to borrow and lend central bank liquidity, now face the threat of not being able to move liquidity freely in and out of the country. Premia would be charged on interbank loans reflecting the T2–leeway of the borrowing bank's NCB. The transmission of the common monetary policy cannot be guaranteed with a sufficient degree of accuracy and at market rates close to the policy rate. The limit bears the potential to create interbank market segmentation. While present T2 imbalances are a consequence of geographical market segmentation, limiting imbalances would, a fortiori, cause and aggravate segmentation along national borders.

Fourthly, to exert any effect on national policies and incentivize governments to keep current account deficits moderate, the limit must be binding. Yet, if it was binding, a country which comes closer to the limit is threatened of being de facto not be a member of the EMU anymore. If the limit were reached, the tenet of the monetary union – a euro is equal to a euro – is jettisoned. It is therefore quite likely that a country whose limit is reached and which would be unable to negotiate additional inflows of liquidity to widen its T2 leeway would also *de jure* opt out of the union. Hence, the introduction of a binding limit transforms the monetary union to something akin to a system of fixed–exchange rates or a gold standard system where the T2–liability–leeway is the equivalent of the stock of foreign currency (gold) reserves used to sustain the exchange rate fixation. It is highly questionable whether such a system works. The possibility that the buffer could be exhausted implies that foreign funding, if at all, would be available only against high premia. Domestic agents, threatened by the possibility that their euros could cease to be euros that could be used everywhere in the monetary union, would possibly try to move their money out. Capital flows within the euro area would turn towards countries with larger T2 buffers and thereby depleting T2 buffers in others. In addition, self–fulfilling speculation against the limit and the exit would likely occur.[57] Therefore, a limit would pose a threat to the stability of the common currency and contribute to undermine its credibility rather than providing more stability.

Fifth, it is doubtful whether a limit would be politically feasible and whether any country would accept the imposition of a limit. When they decided to become members of the monetary union, countries solved the macroeconomic trilemma in favor of fixed exchange rates and free capital flows, and thereby gave up domestic monetary independence. Since a limit on T2 imbalances hampers the free flow of capital, any country would find it relatively more costly to stay in the monetary union. It is therefore possible that countries, even current T2 claimants, find it more preferable to switch back to a system of domestic monetary policy, free capital movements and floating exchange rate.

Finally, the proposal to limit only T2 positions completely ignores that such regulation could be easily bypassed by withdrawing banknotes. Agents could simply ship banknotes to other euro area countries to pay for import goods. Clearly, such a procedure would be costly and time–consuming, but it shows that a limit on T2 accounts is not even sufficient to prevent current account deficits from growing. Instead of increasing its T2 position, the respective NCB would increase its intra–system position due to the allocation of banknotes. And since also banknotes are counted in the position of risk, the limit would,

[57] Bindseil and König (2011) provide an example for a speculation strategy that involves also betting on the respective country's sovereign default.

not even in the most favorable scenario without runs and speculative attacks, be sufficient to prevent an increase in the position at risk.

(iii) Surcharges on overly large imbalances. T2 positions are remunerated at the marginal rate in the ECB's MROs. According to Schlesinger (2011), Bindseil and König (2012) or Bindseil and Winkler (2012), an incentive to reduce T2 liabilities could be created by imposing penalty rates or surcharges, starting from a particular level of T2 liabilities. Bindseil and Winkler (2012, p. 45) write,

> "for TARGET2 balances up to e.g. 25% of GDP, the normal MRO rate would apply, but then for each subsequent 25%, it would increase by say 0.5 percentage points. As the remuneration would be paid by the central bank, and hence be at the expense of the profits transferred to the Government, this would create economic incentives for the Government to address the reasons for the capital flight."

Under present arrangements for income distributions in the Eurosystem, a surcharge is without any effect on monetary income distribution, implying that a surcharge mechanism would be ineffective. Monetary income in the euro area is distributed according to the ECB's capital key. At the end of each financial year, NCBs receive a fraction of the total amount of monetary income, where their share is determined by their share in the paid up ECB capital. The total amount of monetary incomes is the sum of individual NCBs' monetary incomes. According to current regulations, NCBs' monetary incomes are *reduced* by the amount of interest accrued on, among other things, T2 claims. Conversely, monetary income is increased by the amount of interest paid on T2 liabilities.[58] Hence a penalty rate on T2 liabilities would have no effect whatsoever on the monetary income received by each NCB. Interest payments simply cancel out.[59]

Suppose that regulations are indeed changed such that at least surcharges on 'excessive' T2 liabilities would not be included in the monetary income calculation. This causes the paradoxical situation that once T2 liabilities pass the

[58] See OJ L 35, 9.2.2011, p. 17.

[59] See also Jobst, Handig, and Holzfeind (2012) or Burgold and Voll (2012a).

surcharge trigger level, they tend to increase even further. The settlement of accumulated surcharges has to be transferred via T2 to those NCBs with T2 surpluses. But any such transfer causes again a net T2 liability.

Could the NCB settle the surcharge burden by sending cash (physically) to the other NCBs? Such a settlement would increases its intra–system liability due to over–issuance of banknotes (or reduce its intra–system assets due to under–issuance).[60]

Apart from these issues, it is also not clear how accurate a surcharge framework would perform the task of reducing imbalances because it does not exert incentives directly on the banks (which may have some leverage over the control of liquidity in– and outflows). Surcharges could not be passed on to the NCB's counterparties as a reason for overly large usage of the T2 system because such a policy would constitute a violation of the above mentioned articles in the TFEU and a restriction on the free movement of capital.[61] Therefore, as pointed out by Bindseil and Winkler, surcharges would need to be paid by the governments directly. But governments can at most indirectly reduce the use of T2 imbalances through financial sector reforms or measures to reduce current account deficits. This policy is subject to the same caveats as the limit proposal since there are no one–to–one relationships that could be efficiently exploited. While the surcharge framework may indeed impose incentives for governments to implement policies that limit capital imports and current account imbalances, it is highly questionable whether it can be calibrated in a way that eliminates only excessive imbalances but otherwise promotes the build–up of "good" imbalances.

[60] See Boeckx and König (2012) for the balance sheet mechanics of income distribution.

[61] One may counter that, in a similar vein, also Eurosystem collateral requirements impose a direct violation of free capital movements. However, there is a subtle difference between the two issues. A surcharge explicitly imposes a restriction on the use of liquidity in cross–border transactions, whereas collateral requirements restrict the general access of banks to liquidity but do not constrain particular uses once liquidity has been obtained. While the former explicitly constrains capital movements in the monetary union, the latter constrains only the access to central bank borrowing but given the free market principle can be bypassed by resorting to market finance.

5.5.2 Curative Measures

(iv) Settlement through asset transfer. The most famous proposal to keep the 'exit risk' of T2 positions in check and to provide incentives to prevent T2 liabilities from growing is an annual settlement of positions across NCBs. Sinn and Wollmershäuser (2011b) or Sinn (2013) view the Federal Reserve's procedure to annually settle balances in the so–called *Interdistrict Settlement Accounts* (ISAs) as the role model for such a settlement and propose its introduction in the euro area. The Federal Reserve System consists of twelve so–called *Reserve Districts.* The regional central banks are called district *Reserve Banks.* The Reserve Banks' ISAs record the inter–district flows of liquidity. The yearly settlement procedure is a rather complicated procedure which is essentially inherited from the time of the gold standard when each reserve bank had to back a certain portion of the banknotes in circulation in its district by gold holdings.[62] The settlement consists of an adjustment of gold certificates and a re–allocation of district reserve banks' shares in a common pool of securities which originates from the Federal Reserve System's monetary policy operations (SOMA portfolio).

The SOMA portfolio is managed by the Reserve Bank of New York which is also solely responsible for conducting regular monetary policy operations. In the settlement procedure reserve banks with an ISA liability reduce their shares in the SOMA at the benefit of reserve banks with an ISA claim. The settlement is not based on the actual ISA balance at settlement date but rather on the average position during the preceding year. This implies that the settlement is not complete. Moreover, the settlement procedure does not restrict inter–district capital flows. The Federal Reserve's official documentation does not specify the procedure for the case when a reserve bank would lack the SOMA shares necessary to comply with the settlement. The missing regulation of how a Reserve Bank is treated that cannot settle its liabilities implies that the ISA settlement does not induce a binding limit to interdistrict balances. This renders the claim by Sinn and Wollmershäuser (2011, p. 43) dubious that the introduction of an ISA–style settlement prevents that "huge capital flows will run through the Tar-

[62] See Federal Reserve (2013, pp. 136) which also contains an example calculation. A detailed description of the Fed's settlement procedure can be found in Cour-Thimann (2013).

get system".

Given the extensive discussion in the literature and the vigor with which Sinn (2013) promotes the adoption of the ISA settlement procedure for the Eurosystem to the general public, it is worth analyzing whether the introduction of ISA–style settlement in the euro area would be feasible. Although the T2 and the ISA positions share a common denominator (both are not subject to a limit and both originate from asymmetric payment flows between NCB / Reserve Bank counterparties in different jurisdictions of the respective monetary area as well as from the disproportional issuance of banknotes and coins by NCBs / Reserve Banks), there are two key differences which stem from differences in the institutional structure of the Eurosystem and the Federal Reserve System and from the operational procedures of monetary policy implementation.

Firstly, monetary policy implementation in the US is largely centralized at the Reserve Bank of New York and other Reserve Banks obtain far less direct income from monetary policy operations. The ISA–settlement then serves to attribute seignorage income from New York to the different districts. This is actually of no consequence since all Reserve Banks distribute their seignorage to the same fiscal authority, i.e. to the US treasury. Monetary income is also shared under the Eurosystem's arrangements but the sharing rule is not related to intra–system positions. In fact, it is even neutral with respect to intra–system positions. Each NCB receives a share of distributable monetary income based on its share in the ECB's capital. As the EMU is not a fiscal union, NCBs distribute their seignorage gains to different fiscal authorities. The introduction of an ISA–style settlement in the euro area would therefore lead to distributional effects which would conflict with current arrangements of income sharing.

Secondly, and more fundamentally, the introduction of an ISA–like settlement procedure is not feasible under the present rules of Eurosystem monetary policy implementation. The functioning of the ISA settlement in the US depends crucially on the availability of a sufficiently large pool of assets that can be redistributed among the different reserve banks. The pool of assets is available because the Federal Reserve conducts monetary policy largely by means of outright transactions in US treasuries and bills. The value of the pool of assets is therefore approximately equal to the total liquidity in the system. Since the Federal Reserve also adhered to the aggregate liquidity management model prior to the crisis, the ISA balances were, similar as in pre–crisis Eurosystem, rather small relative to the banking sector's aggregate liquidity needs. The available pool of assets was therefore sufficiently large to cover the settlement of net inter–district liquidity flows. Moreover, the Federal Reserve System ensures that each Reserve Bank has sufficient assets to comply with the settlement. During the settlement in April, each Reserve Bank's SOMA share is calculated and then, until the next settlement, the SOMA assets are allocated on a daily basis between the Reserve Banks in order to make sure that the ratio is always satisfied.[63]

A pool of assets that can be easily re–distributed between NCBs is not available in the Eurosystem. In particular, because open market operations are conducted in the form of reverse transactions and not as outright transactions. Therefore, the only assets available for settlement in the EMU are gold holdings, foreign exchange reserves and portfolio investments unrelated to monetary policy on the balance sheets of NCBs. Some individual NCBs' holdings of these assets were not even prior to the crisis sufficient to completely settle accumulated imbalances. A fortiori, present holdings of debtor NCBs are not large enough to cover current liabilities. Hence, if a settlement procedure was implemented and based on the available stocks of assets, already at the first settlement date, T2 imbalances could only be partially settled before the asset stocks of T2 debtors were depleted. Thus, given the complete exhaustion of settlement assets, the respective countries would face the same consequences as if they had reached the a binding limit.

In order to prevent this scenario but nevertheless settle T2 positions, EEAG (2012) proposes to *create* a pool of settlement assets by issuing so–called *European Standard Bills* (ESBs). ESBs are intended to be standardized govern-

[63] One can calculate the ratio immediately from Table 9 of the Federal Reserve's Balance Sheet by dividing an individual Reserve Bank's holdings of 'Securities held outright' by the total 'Securities held outright'. The last settlement took place between 10 April 2013 and 17 April 2013 and the current ratios apply until April 2014.

ment debt securities with highest seniority, covered either by government assets (e.g. real estate) or tax revenues, that would be issued by governments and which NCBs could use to settle any T2 imbalances. This begs the question of how NCBs could obtain ESBs in the first place. If NCBs were acquiring ESBs issued by member states' governments other than their own, they would have to transfer the purchase price via T2. This would cause a paradoxical situation: Acquisition of the settlement asset would give rise to a T2 liability of an amount equal to the purchase price of the settlement asset, which, in turn, could only be settled by using the newly acquired settlement asset. It is therefore not possible to obtain the initially needed ESBs in foreign markets in order to settle T2 imbalances. The only possibility for NCBs to build up their initial ESB stock is to purchase them domestically. But NCBs could not acquire ESBs on the primary market directly from the government because this would violate the monetary financing prohibition in Article 123 of the Treaty.[64] Therefore, the government would have to sell ESBs to domestic banks and these in turn could sell them to the domestic NCB. To induce banks to sell the needed amount of ESBs, the NCB would have to offer a sufficiently high price. This would create adverse incentives for banks. By moving liquidity out of the country via T2, domestic banks could drive up the price for their ESBs because the larger the T2 liability from moving liquidity out of the country, the larger the NCB's demand for ESBs which it can only acquire from the domestic banks. The situation becomes particularly problematic during a crisis. When a capital reversal takes place, the NCB would probably exhaust its ESB buffers. It could then either stop processing cross–border payments (thus creating the same consequences as under a binding limit), or it could accommodate outflows by purchasing more ESBs. But as these could only be issued by the respective national governments, the need for new ESBs has the potential to create additional government debt. The perverse consequence: A domestic liquidity crisis would either cause (fire–)sales of assets to agents located abroad or it would entail greater government indebtedness, thus exacerbating the 'diabolic loop'.

Can at least the collateral that is pledged under monetary policy credit opera-

[64] See also Burgold and Voll (2012b).

tions be transferred in case of cross–border transactions? Also collateral transfers are not possible under present arrangements. The majority of NCBs in the Eurosystem uses a *pooling / pledge* procedure in their lending operations. This means that counterparties provide a large collateral pool and the central bank obtains a security interest in the whole pool. This allows for so–called *over–collateralization*, whereby counterparties pledge more assets than are actually needed to cover the borrowed amounts. The ownership of the collateral, however, stays with the counterparties. Hence, under present arrangements it would also not be possible to transfer assets in order to collateralize cross–border transactions. Indeed, the only possibility to obtain settlable collateral would be to switch to repurchase agreements in monetary policy operations where also a transfer of ownership occurs. In these cases, the Eurosystem could collateralize any cross–border transaction. This may, however, impose practical difficulties since assets are earmarked and once the counterparty wants to repurchase the asset at maturity, the Eurosystem has to stand ready to provide it with the same asset. Thus, the question arises how a transfer of only a fraction of the liquidity that the counterparty obtained should be collateralized. Should only security interests be transferred or should the asset physically be transferred?

The introduction of a settlement procedure *à la* ISA would be feasible once the Eurosystem would conduct its monetary policy in the form of outright transactions like the Federal Reserve rather than as reverse transactions. In normal times, the Federal Reserve usually purchases US government bonds with relatively short maturity in its liquidity providing outright transactions. Would a similar procedure be feasible in the euro area? At the current juncture, it is difficult to imagine the Eurosystem regularly buying a somehow–weighted basket of euro area government debt. The euro area consists of seventeen members with independent fiscal authorities and the decision over the right basket ultimately has distributional implications and a political dimension that may imperil the independence of the central bank.[65] Moreover, since government debt is largely issued under domestic law, the bonds purchased outright would also

[65] The same holds with respect to the creation of a euro area safe asset backed by all governments.

be subject to re–denomination risk in case of a member's exit. Alternatively, the Eurosystem could confine itself to only acquire the various other asset classes that it also accepts in its credit operations. While this would build up a stock of settlement without creating a conflict–laden political situation, the Eurosystem would thereby steeply increase its risk–exposure. As pointed out in section 5.2.2, under collateralized lending, the Eurosystem becomes subject to credit– and liquidity–risk associated with the collateral only in case the counterparty defaults. In contrast, by acquiring assets outright, the Eurosystem immediately exposes itself to the underlying risks.

The switch to outright transactions would neither constrain the flows of goods, services and capital. It implies that the total liquidity outstanding would be fully backed by assets. Since any NCB with a net T2 liability must have provided the liquidity that was transferred across borders to its counterparties in the first place, it must have acquired assets of similar amount so that it could always cover its T2 liabilities and would not face the risk of being caught up from the payment system. Hence, the settlement would neither limit the flow of capital nor create incentives to reduce external balances.

To summarize, none of the above discussed measures (i)–(iv) limits intra–euro area capital flows effectively or efficiently and therefore these measures have hardly any effect on governments to exert stronger control on current account imbalances. With respect to the possibility of backing T2 positions by assets, the current implementation procedures do neither give rise to a stock of assets usable for settlement, nor do they allow for the transfer of collateral in cross–border transactions. While it is generally conceivable that the Eurosystem switches to a different mode of implementation, the gains from being able to insure against the exit risk have to be carefully traded off against the higher exposure to credit and liquidity risk. Moreover, given that the euro area does not have a single fiscal authority, the switch to outright transaction may be associated with political and distributional conflicts about the asset classes the Eurosystem should purchase.

(v) Returning to aggregate liquidity management – 'natural re–balancing'. If the Eurosystem follows the aggregate liquidity management model explained in section 5.2.1, the evolution of T2 positions is determined by the factors that were described in section 5.3.2. Indeed, prior to the crisis, the imbalances were rather small and of no concern. Some countries, notably Austria and Belgium ran larger imbalances which were basically attributable to differences in payment habits, e.g. if their export goods were paid in cash, while they paid for their imports using an electronic transfer via T2. The imbalances of concern, however, arose as a consequence of the funding outflows accommodated under the full–allotment mode, which gave rise to large excess liquidity in the euro area banking sector. A large part of these imbalances will automatically vanish once the Eurosystem returns to the aggregate liquidity management model.

How is this possible? Are not the T2 positions *stock variables* and would it not take much more than just a return to normal *flows* of goods, services and capital to decrease these stocks? The answer to this question is straightforward once one recognizes that T2 positions are primarily clearing items in a payment system. They reflect the *usage* of liquidity, previously borrowed *from Eurosystem facilities.* The largest part of liquidity transferred through T2 originated with a credit operation by the Eurosystem.[66] Independent of whether the counterparty kept the liquidity on its account, whether it transferred the liquidity via T2 to another bank or whether the liquidity ended up in the form of banknotes in circulation with some private households, the Eurosystem retains a claim against the borrowing counterparty. When the credit contract matures, the counterparty has to obtain liquidity to cover its liability with the Eurosystem. Under the fixed–rate full–allotment procedure, a distressed bank most likely rolls its Eurosystem credit forward as long as possible. If the Eurosystem returns to the aggregate liquidity management model, it only accommodates reserve requirements and desired excess reserves. Currently, the outstanding

[66]Alternatively, liquidity could be injected via outright transactions and not only via reverse transactions. In case of outright transactions, the NCB does not retain a claim against a counterparty. However, the mechanism described in the text is not changed since the outright transaction reduces the liquidity deficit. This means that after quitting the full–allotment procedure, the benchmark amount that is allotted in the regular operations will be lower. Whenever the Eurosystem has injected so much liquidity that the liquidity position of the banking sector changes sign, then, instead of conducting credit operations, it would need to steer the interest rates by means of absorbing operations.

liquidity is roughly twice the needed liquidity, and it is largely borrowed by distressed banks in crisis countries. Whenever current outstanding credit expires and is *not* replaced in full, the debtor banks need to obtain liquidity to redeem their Eurosystem credit. They can either return to the interbank market and borrow from surplus–banks (i.e. those that experienced inflows via T2), or, if market access is not restored, they can sell off earning assets at a price sufficiently low enough to attract liquidity surplus banks to buy these assets.

This gives rise to three different scenarios which we consider in succession subsequently. The first scenario is labeled *confidence–liquidity–scenario.* It assumes that the Eurosystem's return to the aggregate liquidity management model ends the crisis and all banks which were previously excluded from the interbank market immediately re–gain access as if nothing had happened. The second scenario, the *no–confidence–liquidity–scenario* assumes that the distressed banks do not re–gain market access. In order to pay off their central bank credit they sell earning assets, but the losses from these fire–sales are not large enough to wipe out their capital. Finally, the third scenario is the *no confidence–insolvency–scenario.* It is basically equivalent to the previous one but assumes that the fire–sale losses become too large, they completely erase banks' capital and lead to their default. We will then show that in the first two scenarios the abnormal T2 positions vanish. In the last one, some imbalances may prevail on NCBs' accounts, determined by to the respective NCBs' share in the Eurosystem's net loss due to the bank default. None of these three scenarios, least the first one, provides a realistic description of how current events may come to an end. However, they constitute useful benchmarks and it is likely that the ECB's exit from its current implementation mode may be described as a convex combination of these three scenarios.

The basic situation under full–allotment and excess liquidity is presented in Tables 5.8 and 5.9. In this example we set the aggregate liquidity needs equal to 0. Bank 1 has accumulated excess liquidity of amount Θ and left this idle on its reserve account. The liquidity inflows came from bank 2 which is associated to a different NCB. Therefore NCB 1 records a T2 asset and NCB 2 records a T2 liability. Bank 2 was subject to a deposit outflow and NCB 2 stepped in and provided liquidity Θ in order to close bank 2's resulting funding gap. The central banking system, consisting of NCB 1 and NCB 2, intermediates the interbank market. In contrast to previous examples, we introduce asset prices p_1 (assets of bank 1) and p_2 (assets of bank 2) in order to be able to speak about fire–sale losses.

Table 5.8: Basic financial accounts of liquidity–surplus banks and their NCB

Bank 1				**NCB 1**			
Assets		Liabilities		Assets		Liabilities	
loans	$p_1 A_1 \equiv E_1 + D_1$	deposits	$D_1 + \Theta$	credit banks	–	bank reserves	Θ
bank reserves	Θ	CB credit	–	T2	Θ	T2	–
		equity	E_1				

Table 5.9: Basic financial accounts of liquidity–deficit banks and their NCB

Bank 2				**NCB 2**			
Assets		Liabilities		Assets		Liabilities	
loans	$p_2 A_2 \equiv E_2 + D_2$	deposits	$D_2 - \Theta$	credit banks	Θ	bank reserves	–
bank reserves	–	CB credit	Θ	T2	–	T2	Θ
		equity	E_2				

Scenario 1: *Confidence–Liquidity–Scenario*, presented in Tables 5.10 and 5.11. Suppose that the central bank returns to the aggregate liquidity management model. In our example, the allotment amount is then equal to 0. Bank 1 cannot roll over its central bank credit and has to repay Θ to NCB 1. Under the confidence–liquidity–scenario, we assume that bank 2 can return to the interbank market and easily obtain a credit of amount Θ from bank 1. As liquidity Θ is transferred via the payment system in the reverse direction than before, offsetting T2 positions occur such that T2 imbalances vanish (note that for a better understanding, we do not consider netted T2 positions in the scenarios).

Scenario 2: *No–Confidence–Liquidity–Scenario*, presented in Tables 5.12 and 5.13. Next, consider the scenario where the full–allotment mode is switched off, but the distressed bank 2 has not yet regained access to the interbank market. To pay off its central bank credit, it has to sell some of its assets. Denote the

Table 5.10: Confidence–liquidity–scenario for bank 1 and NCB 1

Bank 1				**NCB 1**			
Assets		Liabilities		Assets		Liabilities	
loans	$p_1 A_1 \equiv E_1 + D_1$	deposits	$D_1 + \Theta$	credit banks	–	bank reserves	–
bank reserves	–	CB credit	–	T2	Θ	T2	Θ
interbank credit	Θ	equity	E_1				

Table 5.11: Confidence–liquidity–scenario for bank 2 and NCB 2

Bank 2				**NCB 2**			
Assets		Liabilities		Assets		Liabilities	
loans	$p_2 A_2 \equiv E_2 + D_2$	deposits	$D_2 - \Theta$	credit banks	–	bank reserves	–
bank reserves	–	CB credit	–	T2	Θ	T2	Θ
		equity	E_2				
		interbank credit	Θ				

fire–sales price by q. To obtain liquidity of amount Θ, bank 2 has to sell Θ/q of its assets. In a closed system with sound and stressed banks, the only way how the stressed banks can obtain the liquidity that they need is from the sound banks (if the central bank gives up its support), i.e. the assets sold by bank 2 must ultimately end up on the accounts of bank 1. In order to avoid any complications with respect to particular accounting standards, we assume that both banks use historic–cost accounting, i.e. bank 1 books an asset it obtains from a fire–sale of bank 2 at per–unit value q, while bank 2 books the same asset at a per–unit value p_2. After the transfer of the purchase price, bank 1 records assets of total value $p_1 A_1 + q\Theta/q = p_1 A_1 + \Theta$, while bank 2 records an asset value of $p_2 A_2 - p_2 \Theta/q$. The fire–sale loss is given by $(p_2/q - 1)\Theta$ and cuts into bank 2's equity. In the present scenario, we assume that $E_2 > (p_2/q - 1)\Theta$ so that the fire–sales do not drive bank 2 into default. As a consequence of the transfer of the purchase price, the T2 imbalances vanish. With respect to this outcome, the scenario is equivalent to the previous one. The difference is, however, that the fire–sales induce a loss for the bank. Sooner or later, the bank would need to be recapitalized, but in the present scenario it can still survive without additional capital.

Table 5.12: No–confidence–liquidity–scenario for bank 1 and NCB 1

Bank 1				NCB 1			
Assets		Liabilities		Assets		Liabilities	
loans	$p_1 A_1 + \Theta$	deposits	$D_1 + \Theta$	credit banks	–	bank reserves	–
bank reserves	–	CB credit	–	T2	Θ	T2	Θ
interbank credit	–	equity	E_1				

Table 5.13: No–confidence–liquidity–scenario for bank 2 and NCB 2

Bank 2				NCB 2			
Assets		Liabilities		Assets		Liabilities	
loans	$p_2 A_2 - \frac{p_2}{q}\Theta$	deposits	$D_2 - \Theta$	credit banks	–	bank reserves	–
bank reserves	–	CB credit	–	T2	Θ	T2	Θ
		equity	$E_2 - \frac{p_2 - q}{q}\Theta$				

Scenario 3: *No–Confidence–Insolvency–Scenario*, presented in Tables 5.14 and 5.15. The following no–confidence–insolvency–scenario is equivalent to the previous one, except that we now assume that the fire–sale loss drives bank 2 into insolvency. Bank 2 fire–sells all its assets but the proceeds qA_2 fall still short of the needed liquidity Θ. The assets all end up on the balance sheet of bank 1, which transfers amount qA_2. Due to the transfer, NCB 1 records a T2 liability and NCB 2 records a T2 asset of amount qA_2. NCB 2 makes a loss of amount $\Theta - qA_2$. We assume that the loss sharing rule between the central banks states that NCB 1 bears a fraction $1-\zeta$ of the losses and NCB 2 a fraction ζ. The losses are attributed via T2, where NCB 1 incurs a liability equal to the loss it takes, with the offsetting position cutting into its capital.[67] Similarly, NCB 2 records a T2 asset equal to the loss attributed to NCB 1. The net T2 position of NCB 1 is then given by $\zeta(\Theta - qA_2)$. This position is increasing in the total loss $\Theta - qA_2$ and in the fraction of allocated to NCB 2, i.e. to the T2–debtor NCB. Clearly, whenever NCB 2 does not participate in the loss, $\zeta = 0$, NCB 1 has to ‘transfer’ via T2 the amount that reduces NCB 2’s loss. Conversely, whenever $\zeta = 1$ and only NCB 2 bears the losses, then the full loss remains as a persistent

[67] Even if the capital was becoming negative, the central bank would still be fully operationable, since it can never go bankrupt.

T2 position.

Table 5.14: No–confidence–insolvency–scenario for bank 1 and NCB 1

Bank 1				**NCB 1**			
Assets		Liabilities		Assets		Liabilities	
loans	$p_1 A_1 + qA_2$	deposits	$D_1 + \Theta$	credit banks	–	bank reserves	$\Theta - qA_2$
bank reserves	$\Theta - qA_2$	CB credit	–	T2	Θ	T2	$qA_2 + (1-\zeta)(\Theta - qA_2)$
interbank credit	–	equity	E_1			Capital	$-(1-\zeta)(\Theta - qA_2)$

Table 5.15: No–confidence–insolvency–scenario for bank 2 and NCB 2

Bank 2				**NCB 2**			
Assets		Liabilities		Assets		Liabilities	
loans	–	deposits	$D_2 - \Theta$	credit banks	–	bank reserves	–
bank reserves	–	CB credit	–	T2	$qA_2 + (1-\zeta)(\Theta - qA_2)$	T2	Θ
		equity	$E_2 - (p_2 - q)A_2$			Capital	$-\zeta(\Theta - qA_2)$

One further remark has to be made with respect to the influence of the assumption that autonomous factors, minimum reserve requirements and thus the aggregate liquidity deficit are equal to zero. This assumption was made for the sake of clarity of the balance sheet mechanics, yet it blurs the crucial distinction between relative and absolute central bank intermediation that we alluded to in section 5.2.2. When, as a consequence of market segmentation, the central bank intermediates the banking sector, the first stage of intermediation consists of relative central bank intermediation, meaning that a re–allocation of the existing liquidity deficit between the banks in different countries takes place *without* causing an expansion of the consolidated central bank's balance sheet. Only, in the second stage, when funding outflows continue and the banking sector which receives liquidity inflows starts to build up excess liquidity, will the consolidated central bank balance sheet expand. Funding outflows at both stages are moved via T2 and create T2 positions. Yet, it is rather unlikely that a return to the aggregate liquidity management model will also be associated with an immediate adjustment of the aggregate liquidity deficit to its pre–crisis allocation. Rather, it is more likely that the banking sectors in current crisis countries will continue to take out the largest part of refinancing credit from the Eurosystem even when exit from the full–allotment procedure has been carried out. This can be illustrated by Figure 5.8 which shows aggregate excess liquidity and total T2 liabilities relative to the aggregate liquidity deficit. The last observations (end of first quarter 2013) amount to excess liquidity of around 89% and T2 positions of around 210% of the aggregate liquidity deficit. Hence, if we suppose that the Eurosystem would return today to the aggregate liquidity management model and the crisis countries would borrow all liquidity allotted, then total T2 positions could be reduced by 89% of the aggregate liquidity deficit, which amounts to roughly 317 bn Euro. This constitutes the lower bound to the reductions that may be enforced through the return to the aggregate liquidity management model.

Finally, the balance sheet mechanics of the three natural re–balancing scenarios allow to draw the following conclusions.

- The Eurosystem can enforce the external adjustment by returning to the aggregate liquidity management model. This would immediately release those economic forces, namely asset price deflation and liquidity spirals, that the Eurosystem tried to avert by making full–allotment liquidity support available in the first place. Whenever the results would be in line with the no–confidence–insolvency scenario, T2 imbalances (beyond those that prevailed prior to the crisis) could occur. These, however, would be determined solely by the loss sharing rule of the Eurosystem and by the re–allocation of the aggregate liquidity deficit and not by any current account transactions as suspected by Fahrholz and Freytag (2012).
- The Eurosystem cannot solve the crisis and it cannot implement any measures to speed up external adjustment. It can only provide time through the full–allotment policy such that fiscal and regulatory policies are enacted to bring about the external adjustment and to resolve any banking sector problems. As long as these measures fail, the return to the aggregate liquidity management model is likely to be associated with bank defaults and pressure on the Eurosystem to re–install its support measures.
- Returning to the aggregate liquidity management model does not insure

the Eurosystem against the exit risk inherent in T2 positions, but it would reduce the position at risk by at least the amount of excess liquidity outstanding.

- Given that the Eurosystem followed the aggregate model prior to the crisis when large external imbalances were built up, the impact on future euro area imbalances by returning to this implementation model are not clear. But then, addressing external imbalances does not fall into the realm of the Eurosystem. In the monetary union, this has to be achieved by political efforts along the four points emphasized in section 5.3.3.

5.6 Conclusion

This chapter has provided a discussion of two aspects of the Eurosystem's crisis policies. Firstly, the switch from the aggregate liquidity management model to the fixed–rate full–allotment liquidity provision. Secondly, the unconstrained use of liquidity borrowed under Eurosystem facilities via the T2 system. Our aim was to propose a consensus view on the issue of T2 imbalances. We conclude as follows. To mitigate the consequences of market breakdowns during the crisis, the Eurosystem substituted for the market mechanism and switched to a demand–determined liquidity provision. In addition, as became visible from the occurrence of T2 imbalances, markets became segmented along national borders, reflecting a reversal of capital flows from peripheral to core countries. In absence of the Eurosystem's liquidity support, this reversal would have probably caused even more dramatic declines in aggregate demand, asset price deflations and severe debt–deflation spirals. The T2 system allowed to accommodate the capital outflows and thereby mitigated the adverse consequences of outflows. However, we emphasized that this did not stall the underlying adjustment mechanisms, but rather bought the time to implement those measures which are feasible in a monetary union. We then pointed out to the possibility of a member country leaving the monetary union and to the resulting exit risks. As these are largely reflected in the T2 positions, we discussed preventive and curative measures that have been proposed to limit the T2 positions and therefore the inherent exit risk. None of these measures was found to be a particularly convincing instrument with respect to containing the exit risk. What can, however, reduce the T2 imbalances and enforce the adjustment that is currently delayed (or stretched) is the switch back to the aggregate liquidity management model.

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