Essays on banking and financial markets

Inaugural-Dissertation
zur Erlangung des Doktorgrades
des Fachbereichs Wirtschaftswissenschaften
der Johann Wolfgang Goethe-Universität
Frankfurt am Main

vorgelegt von
Björn Hilberg
aus Kassel

GOETHE
UNIVERSITÄT
FRANKFURT AM MAIN

Mannheim 2012

Contents

Acknowledgement

I would like to take the opportunity to thank those people who contributed to the successful completion of this thesis.
First of all I am indebted to Thomas Laubach for supervising this thesis and providing me with financial support during my Ph.D. studies. Moreover, I thank him for giving me the opportunity to gain teaching experience in several tutorials at both the undergraduate and graduate level.
In addition, I would like to thank Ester Faia for advising me in the process of completing this thesis and acting as a second advisor in my thesis committee.
Second, I would like to thank Michael Binder for providing me with financial support during the first two years of my Ph.D. studies.
Finally, two of the three chapter of this thesis profited from joining forces with co-authors. Thus, I would like to thank Josef Hollmayr and Barbara Meller for the cooperation and the fruitful discussions during the research process which led to the successful completion of the first and third chapter.

Abstract

In this thesis the behavior of banks in financial markets which banks frequently use to obtain short-term as well as long-term financing is studied. In the first chapter we incorporate an interbank market for collateralized lending among banks into a dynamic, stochastic, general equilibrium (DSGE) framework to analyze the impact of variations in the expected value of the collateral on the interbank lending volume. We find that a central bank which decides to lower the haircut on eligible collateral in repurchase agreements is able to stimulate interbank markets. In the second chapter a microeconomic model of bank behavior on the interbank market is set up to analyze the impact of risk-taking behavior of interbank borrowing banks and uncertainty about their balance sheet quality on the lending behavior of interbank lending banks. It is found that the disruptions on the interbank market are the result of optimal behavior on the part of interbank lending banks in response to the uncertainty about the balance sheet quality of an interbank borrowing bank. In the third chapter we use monthly data on German bank bond spreads and regress it on bank-specific risk factors to assess the degree of market discipline in the German bank bond market. The regression results for the whole German bank bond market indicate that the bond spread does not show signs of market discipline. However, a structural break analysis uncovers that since the beginning of the financial crisis the German bank bond market exhibits at least a weak form of market discipline for bonds issued by medium-size and large banks.

Summary

In this thesis the interbank market and the bank bond market which banks frequently use to obtain short-term as well as long-term financing is studied. In the first chapter we examine the market for secured interbank lending and analyze the effects of unconventional monetary policy on the behavior of banks in the interbank market.

In the twenty years preceding the current financial crisis all major economies have witnessed an environment with low macroeconomic volatility also known as the "Great Moderation" where central banks in industrialized countries were using the interest rate at which banks can obtain liquidity on the interbank market as its instrument to anchor the inflation expectations around a specified level.[1] However, the way central banks conduct monetary policy changed with the onset of the financial crisis. Central banks no longer rely exclusively on traditional interest rate policy but also prolong the maturities for repurchase agreements ("Repos"), widen the set of collateral accepted in Repo transactions, and reduce the haircut applied to specific types of assets. All these measures aim at reviving the interbank market and stabilizing the financial system as a whole. The interbank market is important for a central bank because it is the market which is most directly affected by monetary policy decisions and hence is the preferred transmission channel to implement the monetary policy strategy of a central bank. However, to enable economists to analyze the macroeconomic consequences of a central bank resorting to a richer set of monetary policy tools that are targeted to change the liquidity situation among banks requires to implement an interbank market in modern macroeconomic models. In models of Bernanke, Gertler, and Gilchrist (1999) or Markovic (2006) banks are financial intermediaries who channel funds between borrowers and lenders. Although they do exhibit profit maximizing behavior, banks in these models are assumed to break-even each period. Only in recent times a couple of DSGE models emerged which explicitly incorporate an active banking sector (Gerali, Neri, Sessa, and Signoretti (2009), DeWalque, Pierrard, and Rouabah (2009), Dib (2009)).

Our model features a heterogenous financial sector that consists of two different types of banks whose behavior is the outcome of explicit optimization problems and which trade central bank

[1] The term "Great Moderation" goes back to a paper by Stock and Watson (2003) to describe the decline in the output volatility in the United States since the early 1980s.

reserves amongst each other on the interbank market. By assumption an interbank borrowing bank can only offer risky assets as collateral in return for interbank liquidity. Because we restrict the amount of interbank lending by introducing a collateral constraint, the volume of interbank lending depends on the expected value of the collateral in the next period. If the value of the underlying collateral is expected to rise an interbank lending bank accepts the risky asset as collateral for an interbank loan independent of the collateral policy of the central bank. However, if the collateral value is expected to decline and the central bank is unwilling to accept this risky asset as eligible asset in a main refinancing operation, the volume of interbank lending will decline. Hence, within this model the central bank faces a situation where the decline in interbank lending activity is not caused by concerns about direct counterparty risk but due to concerns about the value of the collateral pledged by a commercial bank in return for an interbank loan.

We allow for unconventional monetary policy in our model by introducing a haircut rule in addition to the interest rate rule to allow for the re-use of collateral in repurchase agreements with the central bank. To differentiate between different qualities of collateral the central bank applies a haircut to eligible collateral. Within our framework we analyze the impact of such haircut policy on the lending activity on the interbank market. Because a central bank can vary the haircut on certain asset classes in our model, it is in the position to increase or decrease the liquidity supply to the banking sector even if the interest rate is at or near the zero lower bound. This measure is an alternative to providing liquidity to commercial banks directly and has the advantage that it does not completely crowd out the lending activity on the interbank market.

Another feature that distinguishes our study from other studies mentioned above is the distinction between the fundamental price of capital which is equivalent to Tobin's q and the market price of capital which is used to determine the value of the collateral a borrowing bank can offer to an interbank lending bank in return for an interbank loan or to a central bank as eligible collateral in repurchase agreements. If these two values are different we consider it to be a bubble. The effect of such a bubble is an increase in the amount of collateral available for borrowing on the interbank market. In terms of modeling these two variables we rely on the setup introduced by Bernanke and Gertler (1999) who extend the framework of Bernanke et al. (1999). By including an exogenous bubble process we try to contribute to the ongoing debate in the literature whether central banks should respond to asset prices as well.

Another aspect referred to in our paper contributes to the ongoing research on the exit strategy of a central bank engaged in unconventional monetary policy. In our model the central bank is assumed to reduce the haircut on eligible collateral in Repo transactions after the burst of an asset price bubble took place. In this context we simulate the effects of different exit strategies from such unconventional monetary policy on the economy and give recommendations about the preferable strategy based on the variances computed across different exit scenarios.

Our results confirm the results of Dib (2009) who shows that a financial sector helps to dampen monetary policy shocks to the real economy. In addition, we can show that if bubbles inflate the prices used to assess the collateral value in interbank lending and eligible collateral in repurchase agreements, the financial sector amplifies shocks to the real economy. We can show that a lower haircut has a significant and positive impact on the whole economy in the short run. The only drawback is an increase in inflation after the liquidity supply has increased. Moreover, we are able to confirm the result of Bernanke and Gertler (1999) in our model framework and suggest not to include asset prices in the interest rate rule. But this does not mean that the central bank should not react to asset prices at all. In fact instead of incorporating asset prices in the interest rate rule a central bank should rather use the instrument of a haircut rule to react to supposed asset price deviations from their fundamental value. We show that the incorporation of asset prices in the haircut rule significantly reduces the macroeconomic volatility in a simulated boom-bust cycle. Based on the variances of output, inflation, and financial market variables computed from a simulation of the effects of different exit strategies from a haircut rule, our model recommends to communicate the exit date in advance and stick to the announced exit date.

Chapter two concentrates on the interaction between banks which demand interbank liquidity and banks with excess liquidity on the interbank market. At the time the house prices in the United States plummeted financial institutions held large exposures of mortgage-related securities as they seemed to offer an attractive risk-return profile. As losses in those securities accumulated in the balance sheets of banks worldwide, the trust in the stability of financial institutions began to vanish and refinancing started to become an issue for banks. Especially as the liquidity on the important interbank market where banks with excess liquidity used to lend to banks with liquidity demand dried up.

Interbank markets in economics have been introduced by Bhattacharya and Gale (1987) who show that an interbank market where banks can borrow and lend liquidity is optimal to cope with idiosyncratic liquidity shocks. This emphasizes the importance of the interbank market for the liquidity management of banks. This paper focuses on a specific form of market failure which has been observed in the market for interbank liquidity since the beginning of the financial crisis, namely liquidity hoarding. This liquidity hoarding on part of banks has been confirmed empirically by Heider, Hoerova, and Holthausen (2009) for the unsecured Euro interbank market, for the US Federal Funds market (Ashcraft, Mcandrews, and Skeie (2011), Afonso, Kovner, and Schoar (2011), and Taylor and Williams (2009)) and by Acharya and Merrouche (2010) for the

UK Sterling money market.
However, while liquidity hoarding by banks is confirmed by the data, there are two competing theoretical explanations why individual behavior of banks jointly led to disruptions on the interbank market. One strand of the literature argues that the observed liquidity hoarding by banks is the result of concerns about its own future liquidity needs, that is, banks show precautionary behavior which can be explained by an internal motive for holding liquidity. In a model of incomplete markets Allen, Carletti, and Gale (2009b) show that the price volatility due to the lack of hedging completely against aggregate and idiosyncratic shocks leads to the holding of excess reserves by banks. In contrast, Freixas and Jorge (2008b) or Heider et al. (2009) argue that it is rather an external motive, namely, that each bank is concerned about the balance sheet conditions of other banks which leads to the tensions on the interbank market. As the balance sheet quality of a bank declines, the counterparty risk incurred by lending to this bank increases as the probability of default rises. Freixas and Jorge (2008b) show that interbank market imperfections results in an equilibrium with credit rationing and a study of Heider et al. (2009) confirms that asymmetric information about the counterparty risk can lead to a breakdown of the interbank market.
In this paper a model with a heterogenous banking sector is developed where some of the banks possess excess liquidity while others lack sufficient funds to finance a risky portfolio investment. The model developed in this paper is based on Rajan (1994). However, in the model of Rajan (1994) it is assumed that a bank possesses sufficient own funds to implement the desired policy. This assumption no longer holds in this model where a bank is required to obtain liquidity on the interbank market to be able to make a portfolio decision. Hence, the interbank market in the model allows for a transfer of liquidity from banks with a liquidity surplus to banks with a liquidity deficit. It is due to the introduction of an interbank market that the impact of the lending policy of banks in the interbank market on the riskiness of the balance sheet of banks with a liquidity demand can be analyzed.
The counterparty risk in this model depends on the quality of the balance sheet and the portfolio choice made by a bank. It is assumed that the counterparty risk involved in interbank lending is not directly observable. But interbank lending banks possess a costless technology which allows them to imperfectly assess the quality of a bank's balance sheet. The interbank market functions smoothly if interbank lending banks are sufficiently confident to be able to correctly assess the counterparty risk involved in providing liquidity on the interbank market. However, it is shown that the liquidity on the interbank market can dry up if the reliability of the technology used by interbank lending banks to assess the counterparty risk involved in interbank lending falls below

a certain threshold. As banks are then unable to differentiate between high and low counterparty risks they find it optimal not to lend on the interbank market even if their analysis signals that the true counterparty risk is low. Moreover, the model implies that if lending banks in the interbank market care about counterparty risk they are able to exert control on the risks taken by banks. Moreover, this model allows one to analyze the effect of a central bank's liquidity policy on the interbank market. The conclusion is that the central bank is able to reduce the liquidity risk but the level of counterparty risk remains unaltered as banks are reluctant to actively reduce their exposures. Another result of the model is that due to the fact that the central bank supplies liquidity to banks inelastically it is unable to control the risk-taking behavior of banks.

In the third chapter we examine if investors in the German bank bond market exert market discipline on bond issuing banks by continuously processing information on bank risk and incorporating this information in their investment decision. If such a channel exists, the bond yield in the German bank bond market correctly reflects the risk information about each individual bank. The third pillar introduced by the Basel Committee on Banking Supervision in the second Basel accords ("Basel II") was intended to strengthen the market discipline by imposing specific disclosure requirements on banks to help market participants in their assessment of a bank's capital adequacy and other risk parameters of an individual bank. The rationale for the introduction of a third pillar was to reduce the asymmetric information between the bank and potential investors and to ensure a continuous monitoring by the market in addition to a less frequent evaluation of a bank by the national supervisory authority. Given the information about a bank's capital adequacy and its exposure to several kinds of risk it is expected that investors' required return is higher the higher the reported risks and the lower the capital which is able to absorb losses stemming from those risks. The idea that the supervision by market participants can be used to complement the efforts by the supervisory authority has been empirically assessed first by Flannery and Sorescu (1996) and Berger, Davies, and Flannery (2000). Bliss and Flannery (2001) emphasize that market discipline is a combination of "monitoring" and "influence". The aspect of monitoring by market participants requires that investors are perfectly informed about bank risk and use this information to determine the fair market price of a debt or equity instrument issued by an individual bank. The second component of market discipline requires that a bank adjusts its level of bank risk given that it is monitored by market participants to avoid an increase in its future funding costs.

Most empirical studies examine market discipline with a focus on monitoring, that is, the first component of market discipline and have a focus on the banking industry in the United States. For example, Flannery and Sorescu (1996), Jagtiani, Kaufman, and Lemieux (2002), and Covitz,

Hancock, and Kwast (2004) examine how market discipline was affected by a change to the setup of the Federal Deposit Insurance Corporation introduced by the Federal Deposit Insurance Corporation Improvement Act ("FDICIA"). As a result of this change in the legal framework in 1991 where the US government basically committed itself to a "no bail-out"-strategy, studies which examine US data of the post-FDICIA period find that bondholders are effectively monitoring bank risk. An assessment of the degree of market discipline in the European banking industry has been done by Sironi (2003).
To answer the question if the market participants assume the role meant for them by the supervisory authorities and monitor the banks closely to ask for higher spreads if banks increase their risk-taking we construct a rich data set which contains bond-specific and bank-specific information to study the extent of market discipline in the German bank bond market. In a first step we analyze if the German bank bond market as a whole shows signs of weak or strong market discipline by means of a fixed effects regression. In a second step we split up the sample into three groups according to a bank's size and examine if market discipline is more important for a subsample of banks. In the last step of our empirical analysis we allow for two structural breaks to examine if the market discipline within each of the subsamples has been subject to variations over time. The results of our paper suggest that it is important to distinguish between small, medium and large banks and at the same time to allow for structural breaks in order to uncover market discipline in the German bank bond market. The regression results for the whole German bank bond market indicate that the bond spread in the German bank bond market does not show signs of market discipline. In addition, for neither of the subsamples the existence of market discipline can be confirmed for the whole sample period. However, the structural break analysis uncovered that since the beginning of the financial crisis the German bank bond market exhibits at least a weak form of market discipline for bonds issued by medium-size and large banks.

List of Figures

List of Tables

List of Original Papers

1. Asset Prices, Collateral and Unconventional Monetary Policy in a DSGE Model, Co-author: Josef Hollmayr, August 2011, ECB Working Paper 1373.

2. Interbank Refinancing Conditions and Bank Risk-taking, July 2012.

3. Market Discipline in the German Bank Bond Market: An Empirical Analysis, Co-author: Dr. Barbara Meller, August 2012.

Chapter 1

Asset Prices, Collateral and Unconventional Monetary Policy in a DSGE Model

"What appears to be in substance a direct transfer of mortgage and mortgage-backed securities of questionable pedigree from an investment bank to the Federal Reserve seems to test the time honored central bank mantra in time of crisis-"lend freely at high rates against good collateral"-to the point of no return"
(Remarks by Paul Volcker at a Luncheon of the Economic Club of New York on April 8, 2008)

1.1 Introduction

In the twenty years preceding the current financial crisis all major economies have witnessed an environment with low macroeconomic volatility also known as the 'Great Moderation'.[1] During this time the central banks in industrialized countries set the policy rate to anchor the inflation expectations around a specified level. Although the twenty years before the Great Recession is by and large attributable to good policy some studies (see for example the studies Primiceri (2005) and Justiniano, Primiceri, and Tambalotti (2010)) argue that central banks were fortunate as well. Hence, it comes not as a surprise that the way central banks conduct monetary policy changed with the onset of the crisis. Central banks no longer rely exclusively on traditional interest rate policy but also prolong the maturities of repurchase agreements ("Repos"), widen the set of collateral accepted in Repo transactions, and reduce the haircut applied to specific types of assets. Those measures can be subsumed under the heading of unconventional monetary policy.

[1] The term 'Great Moderation' goes back to a paper by Stock and Watson (2003) to describe the decline in the output volatility in the United States since the early 1980s.

So far these measures have been confined to crisis times and were aimed at reviving the interbank market and stabilizing the financial systems as a whole.
The interbank market is important for a central bank because it is the market which is most directly affected by monetary policy decisions and hence is the preferred transmission channel to implement the monetary policy strategy of a central bank. To enable economists to analyze the macroeconomic consequences of a central bank which resorts to a richer set of monetary policy tools that are targeted to change the liquidity situation among banks, requires to implement an interbank market in modern macroeconomic models. In models of Bernanke et al. (1999) or Markovic (2006) banks are financial intermediaries which channel funds between borrowers and lenders. Although they do exhibit profit maximizing behavior banks in these models are assumed to break-even each period. Only in recent times a couple of DSGE models emerged which explicitly incorporate an active banking sector (Gerali et al. (2009), DeWalque et al. (2009), Dib (2009)).
Our model features a heterogeneous financial sector which consists of two different types of banks whose behavior is the outcome of explicit optimization problems and which trade central bank reserves amongst each other on the interbank market. The way the interbank market is modeled in the literature is different from our setup. Dib (2009) for example splits up the responsibilities of a bank by assuming two separate entities: a savings and a lending bank. The "interbank market" in Dib (2009) is represented by the commercial bank in our model setup. A setup similar to Dib (2009) is employed by DeWalque et al. (2009) but here both banks are assumed to operate in a competitive environment and not in a monopolistic competitive environment as in Dib (2009). While Gerali et al. (2009) claim to model an interbank market, in their model in equilibrium no interaction among wholesale banks takes place. Other studies that examine interbank liquidity flows are, for example Ewerhart and Tapking (2008), Allen, Carletti, and Gale (2009a) and Freixas and Jorge (2008a), however, these do not incorporate their microeconomic model into a DSGE framework.
By assumption an interbank borrowing bank can only offer risky assets as collateral in return for interbank liquidity and the volume of interbank lending depends on the expected value of the collateral in the next period. If the value of the underlying collateral is expected to rise, an interbank lending bank accepts the risky asset as collateral for an interbank loan independent of the collateral policy of the central bank. However, if the collateral value is expected to decline and the central bank is unwilling to accept this risky asset as eligible asset in a main refinancing operation the volume of interbank lending will decline. Hence, within this model the central bank faces a situation where the decline in interbank lending activity is not caused by concerns

about direct counterparty risk but due to concerns about the value of the collateral pledged by a commercial bank in return for an interbank loan.

Only recently Gertler and Karadi (2009) and Gertler and Kiyotaki (2010) incorporate unconventional monetary policy into their models to assess the effects of these policies on the macroeconomy.[2] We allow for unconventional monetary policy in our model by introducing a haircut rule in addition to the interest rate rule to analyze the role of collateral in repurchase agreements with the central bank. To differentiate between different qualities of collateral the central bank is able to apply different haircuts to the securities within the set of eligible collateral. Recent papers which incorporate a haircut into their model set are Ashcraft, Garleanu, and Pedersen (2010), Gorton and Metrick (2009), Adrian and Shin (2009), Curdia and Woodford (2010), and Schabert (2010). Within our framework we analyze the impact of such a haircut policy on the lending activity of banks on the interbank market. Because a central bank can vary the haircut on certain asset classes in our model, it is in the position to increase or decrease the liquidity supply to the banking sector even if the interest rate is at or near the zero lower bound. This policy is an alternative to providing liquidity to commercial banks directly and has the advantage that it does not completely crowd out the lending activity on the interbank market.

Another feature that distinguishes our study from other studies mentioned above is the distinction between the fundamental price of capital which is equivalent to Tobin's q and the market price of capital which is used to determine the value of the collateral a borrowing bank can offer to an interbank lending bank in return for an interbank loan or to a central bank as eligible collateral in repurchase agreements. If these two values are different we consider it to be a bubble. The effect of such a bubble is an increase in the amount of collateral available for borrowing in the interbank market. To model these two variables we rely on the setup introduced by Bernanke and Gertler (1999) who extend the framework of Bernanke et al. (1999). By including an exogenous bubble process we try to contribute to the ongoing debate in the literature whether central banks should respond to asset prices as well.

Our results confirm the results of other studies with an interbank market that a financial sector helps to dampen monetary policy shocks to the real economy. In addition, we exemplify that if bubbles inflate the prices used to determine the value of the collateral a bank can offer to an interbank lending bank in return for an interbank loan or to a central bank as eligible collateral in repurchase agreements, the presence of a financial sector amplifies shocks to the real economy. By lowering the haircut which is equivalent to a central bank's reaction to enlarge the set of admissible collateral, the central bank has a significant and positive impact on the whole economy

[2] A study of unconventional monetary policy which also places a big emphasis on the central bank's balance sheet has recently been conducted by Curdia and Woodford (2010).

in the short run. The only drawback is an increase in inflation after the liquidity supply on the interbank market has increased.

In addition, we examine if central banks should target asset prices. First, we know that this is a decision which has to be taken by politics. Nevertheless in the line of a pure economic argumentation we deem it appropriate to lean-against the wind. As market prices amplify the volatility, both the interest rate rule as well as the collateral policy can be used to dampen a boom-bust cycle. According to our metric, however, the haircut rule is more appropriate for this task.

Within this model setup we analyze the long run effects of a "leaning-against-the wind"-policy and contribute to the ongoing research on the exit strategy of a central bank engaged in unconventional monetary policy measures. Conditional on a reduction in the haircut on eligible collateral in Repo transactions we simulate the long run effects from such unconventional monetary policy for the economy and give recommendations about the preferable strategy based on the variances of output, inflation and financial market variables computed across different exit scenarios. Based on this metric our model recommends to communicate the exit date in advance and stick to the announced exit date. If the central bank reacts to asset price movements all variables can be stabilized with the important exception of inflation which is positive throughout. This is due to the fact that keeping the haircut low for a prolonged time period, the amount of liquidity allocated to the interbank market is rising considerably over time.

This paper is structured in the following way. In Section 1.2 the model setup is explained. The calibration to the data is shown in Section 1.3. We proceed in Section 1.4 by stating important results such as impulse response functions, comparative statics and the long run effects of asset price targeting. Section 1.5 finally concludes.

1.2 Model

The model economy consists of three major blocks: the real sector, the financial sector, and the central bank. The real sector comprises the households and the production sector and is very similar to Bernanke et al. (1999) and Christensen and Dib (2008). Each household consumes a final good sold by the retailer and supplies labor to entrepreneurs. Entrepreneurs combine household labor with capital bought from capital good producers to produce an intermediate good which is sold to retailers. To transfer wealth across periods, households save by holding identical amounts of deposits both with the interbank borrowing bank and the interbank lending bank. The former uses these deposits together with interbank liquidity obtained from the interbank lending bank to grant loans to entrepreneurs. In the relationship between the commercial bank and the en-

trepreneur a demand side friction is incorporated, which results in an external finance premium that depends on the net worth an entrepreneur has accumulated.
The financial sector consists of two types of commercial banks which lend and borrow to the private sector. Independent of the type they have access to central bank liquidity if they possess eligible collateral to participate in the main refinancing operations of the central bank. It is assumed that the commercial banks are heterogeneous with respect to their balance sheet structure. One type of commercial bank has highly liquid assets on its balance sheet while the other type of commercial bank contains less liquid, risky assets.[3] In case the latter bank has a liquidity need they prefer to demand additional liquidity from the interbank market and offer the illiquid, risky asset as collateral to avoid having to reduce their loans to the private sector. In the following we will refer to the former group as interbank lending banks and to the latter group as interbank borrowing banks. In the following subsections the model setup and the optimization problems faced by each agent are explained. First-order conditions are completely delegated to Appendix 1.B.1.

1.2.1 Household

Households are infinitely lived and maximize consumption and leisure subject to a budget constraint. Throughout the model h is attached to variables and parameters to denote an individual household variable. The instantaneous utility function has the following form

$$U_t = \frac{C_t(h)^{1-\gamma_c}}{1-\gamma_c} + \frac{(1-L_t(h))^{1-\gamma_l}}{1-\gamma_l} \tag{1.1}$$

The infinite sum of discounted utility is maximized by the households under the following budget constraint which is expressed in real terms

$$C_t(h) + D_t(h) = W_t L_t(h) + \frac{R^D_{t-1}}{\pi_t} D_{t-1}(h) + P_t(h) - T_t(h) \tag{1.2}$$

The household's savings are transferred across periods by depositing it with commercial banks. The gross return paid on household's deposits is denoted by R^D_t. W_t is the wage in real terms that the household gets from the entrepreneur in exchange for its labor supply. Finally, $P_t(h)$ denotes transfer payments stemming from profits made by commercial banks, the central bank,

[3] This balance sheet structure is the result of some of the commercial banks having the opportunity to invest in an additional loan to the private sector, while other banks which lack this opportunity invest their remaining liquidity in a liquid asset like a government bond.

and retailers. $T_t(h)$ are the lump sum taxes that the government collects from household h.

1.2.2 Entrepreneur

Entrepreneurs are perfectly competitive and produce output that is sold to retailers. As input factors in production they use homogenous labor supplied from households and capital purchased from capital producers. The production function is assumed to be of the Cobb-Douglas type

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \tag{1.3}$$

Technology A_t follows an AR(1) process.
Each period the entrepreneur purchases capital K_{t+1} to be used in production in the next period. The difference between the value of capital $Q_t K_t$ and the net worth N_t needs to be financed by a loan B_t taken out from the commercial bank.

$$B_t = Q_t K_{t+1} - N_t \tag{1.4}$$

The interest rate charged on loans is R_t^B.
Bernanke et al. (1999) show that an external finance premium results from the financial contract signed between a bank and the firm. Dib (2009) implements this financial contract in a model with a banking sector. The expected external marginal financing costs are defined as a mark up over the lending rate. The size of the markup depends on the ratio of the market value of capital S_t over the net worth N_t and is given by the following function

$$R_{t+1}^S = \frac{R_t^B}{\pi_{t+1}} \left(\frac{S_t K_{t+1}}{N_t} \right)^{\psi} \tag{1.5}$$

The external finance premium $(S_t K_{t+1}/N_t)^{\psi}$ depends on the entrepreneur's leverage ratio which is defined as $S_t K_{t+1}/N_t$. If the leverage ratio increases, the borrower increasingly relies on debt financing which increases the probability of default of the entrepreneur and hence increases the interest rate charged by a bank.[4] The aggregate net worth position of entrepreneurs is evolving

[4] The size of the elasticity parameter ψ that has originally been calibrated by Bernanke et al. (1999) to be 0.05 depends on the standard deviation of the distribution of the entrepreneurs idiosyncratic shocks, agency costs, and the entrepreneurs' default threshold. If the parameter ψ is set to zero, the financial accelerator vanishes and the mark up is zero.

as

$$N_t = \nu \left[R_t^S S_{t-1} K_t - \left(R_t + \frac{\mu \int \omega \mathrm{d}F(\omega) R_t^S S_{t-1} K_t}{S_{t-1} K_t - N_t} \right) (S_{t-1} K_t - N_t) \right] + (1-\alpha)(1-\Omega) A_t K_t^{\alpha} H_t^{(1-\alpha)\Omega} \quad (1.6)$$

with ν and ω being the survival probability of the entrepreneur and the default probability of the project the entrepreneur invests in, respectively. Moreover, $1 - \Omega$ denotes the share of entrepreneurial labor in the amount of total labor and μ is the parameter of the supervising costs of the bank.

Note that the loan contract between the entrepreneur and the commercial bank is conditioned on the market price of capital S_t and not on the fundamental price Q_t. The distinction between the market price S_t and the fundamental price Q_t has been proposed by Bernanke and Gertler (1999) in an extension of the model by Bernanke et al. (1999) and allows to model exogenous asset price bubbles.[5]

If a unit of capital is valued at the fundamental price Q_t, optimal demand for capital guarantees that the marginal external financing costs equal the marginal return on capital

$$R_t^Q = \frac{\left(R_t^k + (1-\delta) Q_t\right)}{Q_{t-1}} \quad (1.7)$$

Analogously, if a unit of capital is valued at the market price S_t and $S_t \neq Q_t$, optimal demand for capital satisfies

$$R_t^S = \frac{\left(R_t^k + (1-\delta) S_t\right)}{S_{t-1}} \quad (1.8)$$

The fundamental return and the market return on capital are related as follows

$$R_t^S = R_t^Q \left(b + (1-b)(1-(1-a) \frac{(S_{t-1} - Q_{t-1})}{S_t} + \varepsilon_t^{SQ} \right) \quad (1.9)$$

The parameter a determines the speed of convergence back to the fundamental price Q_t and b is given by $b \equiv a(1-\delta)$.[6] The shock to the fundamental value ε_t^{SQ} is normally distributed with variance σ_S^2. In the absence of shocks the market price S_t moves in line with Q_t.

[5] For an introduction on asset price bubbles we refer to the seminal paper by Blanchard and Watson (1982).
[6] In the case of rational bubbles this value would be one, see Blanchard and Watson (1982).

1.2.3 Capital Producer

Capital producers provide the capital purchased by entrepreneurs. They use a linear technology to produce capital and maximize the following objective function

$$\max_{I_t} E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \left[Q_t \left[I_t - \frac{\kappa_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] - I_t \right]. \tag{1.10}$$

The aggregate capital stock evolves according to

$$K_{t+1} = (1-\delta) K_t + \left(1 - \frac{\kappa_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t \tag{1.11}$$

where δ determines the depreciation rate and investment is subject to quadratic adjustment costs with κ_i denoting the parameter of those costs. This maximization problem is standard and a detailed description can be found for example in Dib (2009).

1.2.4 Retailer

To introduce sticky prices we assume that retailers are Calvo (1983) price setters. This is a common assumption in the New-Keynesian literature and implies that each period there is an exogenous probability of $1 - \xi_p$ that a retailer is able to adjust its price. The rest of the retailers index their prices to current inflation. As in Bernanke et al. (1999) monopolistic retailers buy the product of the entrepreneur, transform it into final output at no cost and sell it to households or capital goods producers. The expected discounted profit function that the retailer maximizes takes the form:

$$\Pi_t^R = \sum_{k=0}^{\infty} \xi_p^k E_{t-1} \left[\Lambda_{t,k} \frac{P_t^* - P_{t+k}^w}{P_{t+k}} Y_{t+k}^*(R) \right] \tag{1.12}$$

where $\Lambda \equiv \beta \frac{C_t}{C_{t+k}}$ denotes the stochastic discount factor of households as those benefit from the profits of the retailer. Finally $P_t^w \equiv \frac{P_t}{Z_t}$ is the nominal price of wholesale goods with Z_t as the gross markup.

1.2.5 Interbank Borrowing Bank j

A commercial bank j maximizes over both the interest R_t^D and R_t^B and takes the interest rate prevailing on the interbank market R_t^{IB} as given. The liability side of commercial bank j comprises deposits $D_t(j)$ and interbank loans $IB_t(j)$. These funds are invested in loans to entrepreneurs

$B_t(j)$. A commercial bank j has only risky loans to entrepreneurs on its balance sheet which are assumed to be less liquid. Moreover, securities backed by collateral from the lending relationship of a commercial bank j and the entrepreneur are usually not accepted as collateral in repurchase agreements with the central bank. The balance sheet of a commercial bank j is given by

Assets	Liabilities
Loans to Entr. $B_t(j)$	Deposits $D_t(j)$
	Interbank Loans $IB_t(j)$

Table 1.1: Balance Sheet of an Interbank Borrowing Bank j

Each commercial bank *j* maximizes its profit which is given by the following equation

$$\Pi_t(j) = \frac{R^B_{t-1}}{\pi_t}B_{t-1}(j) - \frac{R^D_{t-1}}{\pi_t}D_{t-1}(j) - \frac{R^{IB}_{t-1}}{\pi_t}IB_{t-1}(j) \tag{1.13}$$

$$- \frac{\kappa_d}{2}\left(\frac{R^D_{t-1}}{R^D_{t-2}} - 1\right)^2 \frac{R^D_{t-1}}{\pi_t}D_{t-1}(j) - \frac{\kappa_b}{2}\left(\frac{R^B_{t-1}}{R^B_{t-2}} - 1\right)^2 \frac{R^B_{t-1}}{\pi_t}B_{t-1}(j) \tag{1.14}$$

with κ_b and κ_d being the adjustment cost parameter for both interest rates. As deposits and loans of different commercial banks j are imperfect substitutes for households, the maximization is subject to the following demand functions for household deposits and entrepreneurial loans.

$$D_t(j) = \left(\frac{R^D_t(j)}{R^D_t}\right)^{\epsilon_d} D_t \tag{1.15}$$

$$B_t(j) = \left(\frac{R^H_t(j)}{R^H_t}\right)^{-\epsilon_h} B_t \tag{1.16}$$

In return for the loan $B_t(j) = Q_tK_t - N_t$ to the entrepreneur a commercial bank j obtains collateral worth Q_tK_t. It is assumed that a commercial bank j possesses a technology to transform the illiquid capital stock into a marketable security. In the following we will refer to the financial instrument generated in this process as asset-backed security. In contrast to the value of the capital stock Q_tK_t, the value of the asset-backed security portfolio of bank j is given by

$$ABS_t(j) = S_tK_t(j) \tag{1.17}$$

The assumption that the risky asset $ABS_t(j)$ depends on the market price S_t and not on the fundamental price Q_t allows us to consider the effect of asset price movements on the behavior of banks in the interbank market where these securities serve as collateral.

Our model also features a borrowing constraint in a borrower-lender relationship in the form proposed by Kiyotaki and Moore (1997). However, in our model the financial friction arises between the commercial bank j and an interbank lending bank k. In order to obtain interbank liquidity the commercial bank j is able to offer its asset backed securities as collateral. The commercial bank's ability to obtain interbank liquidity is limited by the expected value of the asset portfolio in the next period. An interbank lending bank k encounters transaction costs which are proportional to the collateral value, $(1 - m_t)S_{t+1}K_t(j)$. These transaction costs comprise the time to find a buyer for the collateral and legal fees paid in the process of liquidating the pledged assets. Hence, to ensure full repayment in the case of a default of the commercial bank j, the maximum amount of interbank liquidity granted by a commercial bank k is given by $m_t\mathbb{E}_t S_{t+1}K_t(j)$. As $m_t < 1$ is assumed, the size of the interbank loan to a bank j will always be strictly lower than value of the asset portfolio in the next period. The borrowing constraint of a commercial bank vis-a-vis an interbank lending bank takes the following form[7]

$$R_t^{IB} IB_t \leq m_t \mathbb{E}_t S_{t+1} K_t \tag{1.18}$$

where m_t is the loan-to-value ratio which responds to deviations of the market price of capital from the fundamental price, u_t, to incorporate the reluctance of an interbank lending bank to provide interbank loans in the presence of asset price bubbles. In log-linearized terms m_t is assumed to follow an AR(1) process[8]:

$$m_t = \rho_m m_{t-1} - 2 \cdot u_t + \epsilon_t^m \tag{1.19}$$

Finally, the balance sheet identity has to hold in all periods t.

$$B_t(j) = D_t(j) + IB_t(j) \tag{1.20}$$

1.2.6 Interbank Lending Bank k

The activities performed by a commercial bank vis-a-vis the private sector are identical to those of a commercial bank j. However, compared to a commercial bank j, a commercial bank k by assumption invests its funds in liquid assets. Thus, the balance sheet depicted in Table 1.2

[7] We assume that the borrowing constraint is satisfied with equality because the size of the shock is sufficiently small such that the economy remains in the neighborhood of the steady-state. See Iacoviello (2005)

[8] In section 4.3 we assume that the loan-to-value ratio is controlled by a supervisory authority and therefore the deviation of the market price from its fundamental value has to be included

contains liquid assets in the amount G_t. The liquid assets G_t can be always exchanged against central bank liquidity if a commercial bank k is willing to supply liquidity on the interbank market.

Assets	Liabilities
Liquid Assets $G_t(k)$	Deposits $D_t(k)$

Table 1.2: Balance Sheet of an Interbank Lending Bank k

Because the funding structure is identical across commercial banks the interest rate paid on deposits will be the same across commercial banks. Moreover, we assume that the difference between the interest rate paid on deposits and the interest obtained from the investment in the liquid asset G_t is negligible and we are able to ignore it in the optimization problem of the commercial bank k.
The interest rate on the interbank market R_t^{IB} is endogenously determined by the profit-maximizing behavior of interbank lending banks and interbank borrowing banks. Hence, a commercial bank k which considers lending to a commercial bank j takes the policy rate R_t set by the central bank as given and decides optimally about the amount of liquidity supplied on the interbank market. Each commercial bank k maximizes its profit function which has the following form

$$\Pi_t^{IB}(k) = R_t^{Spread}\big(IB_t(k) + M_t^D(k) - X_t(k)\big) + R_t IB_t(k) - R_t^{IB} M_t^D(k) + R_t^{IB} X_t(k) \tag{1.21}$$

which is mathematically equivalent to $R_t^{IB} IB_t(k) - R_t(M_t^D(k) - X_t(k))$ but emphasizes that the commercial bank k not only cares about the absolute interbank rate but also about the spread between the interbank interest rate and the policy rate set by the central bank[9].

$$R_t^{Spread} = R_t^{IB} - R_t \tag{1.22}$$

We assume that commercial bank k's demand for central bank liquidity depends on the optimally chosen value for interbank lending and excess reserves as follows[10]

$$M_t(k) = IB_t(k)^{\zeta} X_t(k)^{1-\zeta} \tag{1.23}$$

[9] Compare also Graph 2 with the interbank rate fluctuating around the policy rate
[10] Excess reserves can be interpreted as a riskless investment opportunity for a commercial bank k.

Unlike the Cobb-Douglas production function that takes labor and capital as input factors and yields goods as output, here the only input factor is the supply of central bank liquidity M_t whose division among interbank funds and excess reserves is governed by the parameter ζ. If ζ is equal to one, there is a one-to-one relationship between the additional liquidity supply of the central bank and the supply of interbank liquidity on the interbank market. But ζ is assumed to be smaller than one to account for the effect of the money multiplier.
The commercial bank k faces the following collateral constraint which limits the volume of central bank liquidity it can obtain in a main refinancing operation of the central bank

$$M_t(k) = G_t(k) + (1 - h_t)ABS_t^{PD}(k) \tag{1.24}$$

The liquidity obtainable by each individual commercial bank k is denoted by $M_t(k)$. The right hand side shows the two types of collateral accepted by the central bank: liquid assets G_t and asset-backed securities ABS_t. However, if the latter can be used as collateral in repurchase agreements depends on the decision of the central bank. If $h_t = 1$ the central bank does not accept asset-backed securities.[11] The lower the haircut, the lower the discount of those risky securities applied by the central bank and hence the higher the volume of liquidity obtainable per unit of asset-backed securities.

1.2.7 Central Bank

A central bank sets the monetary policy rate R_t in response to deviations of output and expected inflation. Moreover, we allow for interest rate smoothing on part of the central bank.

$$R_t = \rho_r R_{t-1} + \phi_\pi(\pi_{t+1} - \bar{\pi}) + \phi_y(Y - \bar{Y}) + d(S_t - \bar{S})\epsilon_t^R \tag{1.25}$$

In addition, we assume that the central bank is interested in financial market stability and especially in a liquid interbank market. In this context the central bank decides which assets are eligible as collateral in repurchase agreements and through this device it is able to vary the liquidity supply to the banking sector directly.
The haircut h_t set by the central bank is specified by the following process

$$h_t = \rho_h h_{t-1} + c(S_t - \bar{S}) - \varepsilon_t^h \tag{1.26}$$

[11] This would be the case of the Fed before the crisis. In Europe the haircut was lower than one even before the crisis and were lowered even more during the crisis.

If the central bank decreases the haircut h_t, the liquidity supply increases. The parameter c determines the sensitivity of the central bank to asset price deviations from its fundamental value $\bar{S} = \bar{Q}$. Hence, if the market price of capital S_t is below its steady-state, the central bank will decrease the haircut in case of $c > 0$.
We do not postulate that the haircut rule should substitute the interest rate rule. The haircut rule, however, is suited to fine-tune the liquidity situation on the interbank market once the interest rule policy does not have the desired effect anymore because for example of the zero lower bound. We can show that a decrease in the haircut can stimulate both the interbank market and the real economy.
The profit function of the central bank is as follows

$$\Pi_t^{cb} = \frac{R_{t-1}}{\pi_t} M_{t-1}^{cb} - \frac{R_{t-1}^{DF}}{\pi_t} X_{t-1}. \tag{1.27}$$

The objective function corresponds to the profit that the central bank makes with seigniorage minus the payment on excess reserves a commercial bank k holds in its account with the central bank. Also the profits of the central bank go the household.

1.2.8 Aggregate Conditions

In equilibrium the following aggregate conditions have to hold.
The amount borrowed by an entrepreneur across commercial bank j has to equal the amount of loans granted to the entrepreneur by the commercial bank sector. γ^X denotes the relative mass of agent X.

$$B_t = \gamma^j B_t(j) \tag{1.28}$$

The same holds true for the savings of households and deposits accepted by commercial banks

$$\gamma^j D_t(j) = \gamma^P D_t(h) \tag{1.29}$$

Total interbank lending has to satisfy

$$\gamma^j IB_t(j) = \gamma^k IB_t(k) \tag{1.30}$$

Money provided by the central bank has to equal the total money demand by commercial banks k.

$$M_t^{CB} = \gamma^k M_t^k(k) \tag{1.31}$$

The total supply of asset-backed securities is constrained by the available capital stock K and the market price of capital S.

$$ABS_t = S_t K_t \tag{1.32}$$

The maximum amount of collateral the commercial banks j can offer to commercial banks k is then given by (1.32). Summing across the demand for collateral by commercial banks k and the supply of collateral by commercial banks j the following condition holds

$$ABS_t = \gamma^k ABS_t(k) = \gamma^j ABS_t(j) \tag{1.33}$$

Finally, goods market clearing requires

$$Y_t \;\; = \;\; C_t + C_t^e + Q_t \left(K_t^h - (1-\delta) K_{t-1}^h \right) + G_t + \text{Adj. costs} \tag{1.34}$$

1.3 Calibration

One crucial task of calibrating this model is to deal both with a real sector where one period usually corresponds to one quarter as macroeconomic aggregates like GDP are updated on a quarterly basis and a financial sector where information about financial variables are updated at a much higher frequency. Hence, we decide to calibrate the model to monthly data[12]. So most of the parameters on which the literature agreed on and that are calibrated to quarterly data are adjusted to a monthly frequency. Hence, the discount rate of households β is set to 0.997 which corresponds to a yearly interest rate of 3.6%, which is in line with other studies which assume 4% per year. For the instantaneous household utility we assume log preferences in both consumption and labor. The fraction of capital employed in the production process α is set to 0.33 which is a value commonly found in the literature. With respect to the rate of depreciation that is commonly calibrated to be 10% per year, we set the monthly depreciation rate to a value of 0.8%. The coefficient determining the mark-up ϵ_p is time-invariant and set to 6 as, for example, in Bernanke et al. (1999). However, the fraction of retailers being able to set prices each period is set slightly lower than in the quarterly specification. In a quarterly setting it is usually assumed (as in Bernanke et al. (1999)) that $(1 - \xi_p)$ is equal to 0.25. In our context we set this value to 0.15 to account for the monthly frequency. Both the elasticities of the demand functions for entrepreneurial loans and household deposits and the adjustment cost parameters for both interest

[12] This approach is also often used in the macro-finance literature, see for example Borgy, Mesonnier, Laubach, and Renne (2011)

rates are taken from Gerali et al. (2009) and are multiplied by three as the values used in Gerali et al. (2009) are calibrated to a quarterly model. Thus, the values are 852 and 759 for the deposit and loan demand elasticities, respectively, and 540 and 1125 for the adjustment cost parameter κ_d and κ_b, respectively.
The financial friction parameter ψ which is calibrated by Bernanke et al. (1999) to be 0.05 is recalibrated with our parameters from above and equals 0.0506. Two parameters are important for the development of the bubble process, a and b. Those are exactly set as in Bernanke and Gertler (1999), to 0.98 and 0.97216 (which equals $a(1-\delta)$). The amount of entrepreneurial labor is chosen to be 0.01 as is common in the literature, see Bernanke et al. (1999). The elasticity of Tobin's q with respect to investment is set to 0.5 as in Bernanke and Gertler (2001). The leverage of the entrepreneurs is assumed to be 2. Finally, in line with Bernanke and Gertler (1999) the survival rate of entrepreneurs is set to 0.95.
The values in the interest rate rule are set in accordance with Taylor (1993). With respect to the autoregressive parameters in the AR(1) shock processes we increase all values in comparison to existing studies as those were chosen to match quarterly time series dynamics. Thus, in our study they take on values in the range from 0.95 in the case of government expenditure to 0.99 in the case of the haircut and the policy rate set by the central bank.
The one parameter that is completely unknown in the literature is the intensity of interbank loans or excess reserves in the production function of a commercial bank k denoted by ζ. We set it to $\zeta = 0.9$ which seems reasonable and is in line with most of the banks' balance sheets. In addition, the robustness checks indicate that the results are robust to higher values for this parameter. The haircut is set in steady state to be 0.2, as the ECB paid a little more than 80 percent for BBB ranked assets.
A comprehensive summary of all parameter and imposed steady state values can be found in Appendix 1.C.

1.4 Results

In this section we discuss the results of the model. In the impulse response analysis conducted in Section 1.4.1 we discuss how the model developed in Section 1.2 reacts to a set of shocks. Furthermore, we compare the impulse responses for the same set of shocks both in a model setup with and without an interbank market. In the case without an interbank market we assume that the commercial bank k does not exist. As the commercial bank j is then in direct contact with the central bank in this case[13] no interbank lending occurs in equilibrium and the interbank rate is identical to the policy rate. This enables us to to study the implications of an interbank market on the model dynamics. In Section 1.4.2 we answer the question whether in our model framework central banks should "lean against the wind", that is, if a central bank should react to asset prices or not. A boom-bust cycle caused by market price fluctuations is simulated following the procedure laid out in Bernanke and Gertler (1999). Finally, in Section 1.4.3 three different exit strategies for the central bank are analyzed within the model framework proposed in Section 1.2.

1.4.1 Impulse Response Analysis

In this section we examine the model dynamics in response to four types of shocks: a monetary policy shock, a shock to the haircut h_t applied to risky assets, a shock to technology A_t and to the market price of capital S_t. The impulse responses are expressed in percentage deviations from steady state and one period corresponds to one month. All corresponding figures can be found in Appendix 1.D.1.

Figure 1.2 shows the impulse response functions to an unanticipated 25 bp increase (3% in annualized terms) in the nominal interest rate. As the policy rate rises, liquidity demanded by the commercial bank k declines and the interest rate for interbank loans increases. This in turn lets a commercial bank demand less interbank funds. At the same time a higher interest rate induces the commercial bank k to hold more excess reserves at the central bank. This countercyclical movement of interbank loans and excess reserves is due to the specification of the function assumed for a commercial bank k in splitting up the liquidity obtained from the central bank.[14] The fundamental price of capital Q_t decreases on impact and returns gradually to its steady state. The response of output and inflation is in line with many other New-Keynesian studies. Hence, our model recommends to raise interest rates in response to a boom in asset prices. This is exactly what should have happened in the US where the policy rate has been kept at a too low level for too long.

An interbank market smoothes the responses of the economy to a monetary policy shock compared to the case without an interbank market. Taking for example output and inflation, the impulse responses are all qualitatively the same but the initial impact is much more pronounced. Liquidity decreases more than in the case where an interbank market is not present. Moreover,

[13] Even in the model without an interbank market the results will differ from Bernanke and Gertler (1999) due to the presence of an profit maximizing commercial bank

[14] The percentage increase in excess reserves is much higher because its steady state value is very low.

the decline in the fundamental price of capital and thus the decline in the value of the asset-backed securities is stronger if the interbank market is shut down.

If the central bank lowers the haircut on asset-backed securities Figure 1.3 shows that the liquidity supply increases on impact and converges slowly back to its steady-state. This is due to the fact that the autoregressive parameter of the haircut is chosen to be very close to one and one time period corresponds to one month[15]. As expected both output and inflation increase on impact in response to a 10% decrease in the haircut applied by the central bank. The lowering of the haircut has a positive effect on the fundamental price of capital which then increases the value of the asset-backed securities. As the total value of collateral offered by the commercial banks in return for interbank loans increases, the interbank lending rate decreases which stimulates interbank lending. Besides rising interbank lending excess reserves go up as well. This is the only time that both quantities move in the same direction.[16] In addition output rises on impact. This stimulus, however, comes at a cost of higher inflation. A comparison between the model with and without an interbank market is not very meaningful here as the haircut policy in our setup only works with an interbank market. The assumption hinges on the fact that the commercial bank k gets liquidity from the central bank in exchange for government bonds and asset-backed securities. Once the interbank market is eliminated, the haircut policy is ineffective because a commercial bank j is in direct relation with the central bank to obtain its funding.

In Figure 1.4 technology increases by 1%. As this shock originates in the real sector the responses of the real variables (output, inflation, fundamental price of capital) are in line with other studies that incorporate a financial accelerator (see Bernanke et al. (1999) and Christensen and Dib (2008)). As the technology shock leads to a decrease in the policy rate, the interbank lending rate decreases as well which in turn stimulates interbank lending activity. In the case of a technology shock the two setups deliver similar responses for output and consumption. If the interbank market is missing the price of capital and therefore the asset-backed securities are deviating a bit more from their respective steady states. The same holds true for liquidity. If anything, then a shock to technology is dampened by the presence of the interbank market, although not by as much as in the case of a monetary policy shock.

Finally we analyze a shock which leads to a 10% increase in the market price S_t.[17] In this case, for the first time, the impulse responses of market price and fundamental price are not identical (see Figure 1.5). While both prices increase, the market value rises ten times as much, driving up

[15] In a period of forty months liquidity as well as the other persistent financial variables converge back to their steady states

[16] Compare on the real side the increase of both labor and capital after a technology shock using the same production function specification.

[17] The deviation of the fundamental value Q_t from the market price S_t is denoted by u_t

the value of the asset-backed securities above their fundamental value as their value depends on the market price S_t. Although the liquidity supply by the central bank rises with the value of the asset backed securities, banks are reluctant to increase their interbank lending and rather invest in riskless excess reserves. Hence, in our model banks become more cautious in their investment behavior in response to sharp increases in asset prices. Although the increase in the value of the asset-backed securities results from a shock to the market price and not from an increase in the liquidity supplied by the central bank, the model resembles the behavior of the banks in the aftermath of the financial crisis. Namely, that in response to an increase in liquidity banks are reluctant to lend in the interbank market and rather invest in risk-free assets. A shock to the market price S_t exhibits a significantly different evolution of variables. Without an interbank market the size of the market price increase is only about a third compared to its impact in the setup that features an interbank market. Asset-backed securities and liquidity show similar responses across model specifications. Having only a minuscule but negative effect on the interest rates, the real sector develops a life on its own and behaves counterintuitive if no interbank market is considered. The fundamental value goes down as investment decreases after a slight interest rate decrease. Output and consumption react in the same way. Inflation is increasing but only by very little. After all and despite some counterintuitive results the volatility is nevertheless greatly reduced once the interbank market is eliminated. In this case the interbank market amplifies shocks to the market price of capital S_t.

1.4.2 Boom-Bust Cycle

In this subsection we apply the methodology of Bernanke and Gertler (1999) and Bernanke and Gertler (2001) to a model framework with a micro-founded interbank market and where the central bank has an additional central bank instrument, namely, the haircut rule given in equation (1.25). The question we try to answer is whether central banks should 'lean against the wind', that is, if a central bank should respond to deviations of asset prices from their fundamental value. We plot six variables[18]: Output and inflation to analyze the impact on macroeconomic volatility, interest rate spread and excess reserves to consider financial markets and the fundamental and the market price of capital.

In this subsection we compare eight different cases which are specified in Table 1.3. These cases differ in the central bank's reaction to output deviations, inflation deviations and asset price deviations when deciding about the setting of its policy instruments. Compared to case

[18] Bernanke and Gertler (1999) also plot only six variables: output, inflation, the market price of capital, the fundamental price of capital, the return on capital and the external finance premium

1 in case 2 the central bank reacts much more aggressive to inflation rate deviations. Cases 3 and 4 are identical to case 1 and case 2, respectively but this time asset price deviations let the central bank adjust its policy rate. The coefficients for deviations of output and inflation from their respective steady-state values are identical in cases 5 to 8. Moreover, in case 6 and 8 the the central bank reacts to asset price deviations by adjusting its policy rate. However, in cases 7 and 8 the central bank adjusts the haircut applied to the set of eligible assets if the market price of capital S_t deviates from the fundamental value of capital Q_t.

Cases	Values				Cases	Values			
	ρ_π	ρ_y	c	d		ρ_π	ρ_y	c	d
Case 1	1.01	0	0	0	Case 5	1.01	0.5	0	0
Case 2	2	0	0	0	Case 6	1.01	0.5	0	0.1
Case 3	1.01	0	0	0.1	Case 7	1.01	0.5	0.5	0
Case 4	2	0	0	0.1	Case 8	1.01	0.5	0.5	0.1

Table 1.3: Boom-Bust Cycle Analysis: Cases

Figure 1.6 resembles the analysis of Bernanke and Gertler (1999) and Bernanke and Gertler (2001) within our model setup and compares accomodative and aggressive monetary policy either without (cases 1 & 2) or with (cases 3 & 4) the central bank reacting to deviations of asset prices. In this case the haircut rule is a simple AR(1) process that does not react to asset prices. To assess the quantitative importance of the stability gains we calculate the variances for each of the six variables shown in Figure 1.6.

	Output	Inflation	Fundamental Price Q	Market Price S	Spread	Excess Reserves
Case 1	0.0102	0.012	0.0622	0.1226	0.1537	13.7149
Case 2	0.0047	0.0038	0.0252	0.0675	0.1494	16.1308
Case 3	0.0101	0.0071	0.065	0.127	0.1606	14.988
Case 4	0.0048	0.0027	0.0284	0.073	0.1549	16.8067

Table 1.4: Stabilization Gains I

The results for cases 1 and 2 resemble the results in Bernanke and Gertler (1999), namely, that a higher response coefficient on inflation dampens both output and inflation. Cases 3 and 4 deliver similar results compared to the cases without the central bank reacting to asset price movements. As expected the prices for capital are less diverging from the steady state once the interest rate rule incorporates a response to asset price deviations. In its decision to react to asset price movements or not, the central bank faces a trade-off. Setting $d > 0$ allows a central bank to better stabilize inflation and output but at the cost of more volatility in the financial variables. Hence, according to this model it is the weight put on financial market stability relative to output and inflation stabilization that is important in the decision of incorporating asset prices in the interest rate rule or not. This is different from the position of Bernanke and Gertler (1999) who claim that the interest rate should not respond to asset price deviations.

In Figure 1.7 we come to the core of the debate between Bernanke and Gertler (2001) and Cecchetti, Genberg, and Wadhwani (2002). The latter argue that once the interest rate rule contains a non-zero response coefficient to output as well the argumentation of Bernanke and Gertler (1999) no longer holds. If this is true a central bank which reacts to deviations of output and asset prices (case 6) should be more successful in stabilizing the macroeconomic variables than a central bank which does not respond to asset prices at all (case 5). To assess the quantitative importance of the stability gains we calculate the variances for each of the six variables shown in Figure 1.7.

	Output	Inflation	Fundamental Price Q	Market Price S	Spread	Excess Reserves
Case 5	0.01	0.0046	0.0576	0.1167	0.1653	15.7312
Case 6	0.0082	0.0026	0.046	0.0999	0.165	17.0213
Case 7	0.0009	0	0.0022	0.0215	0.0058	3.134
Case 8	0.0007	0	0.0015	0.0191	0.0088	3.7898

Table 1.5: Stabilization Gains II

Based on the results in Table 1.5 which depicts the variances of the variables plotted in Figure 1.7 we can confirm the result of Cecchetti et al. (2002). But the overall performance can be dramatically improved if the haircut rule is allowed to respond to asset prices either without (case 7) or with (case 8) the interest rate exhibiting ‘leaning again the wind’-behavior.

As a result, our model predicts that macroeconomic stability is primarily achieved by the liquidity management of the haircut rule and not by the the interest rate policy of the central bank.

1.4.3 Exit Strategies

In the aftermath of a crisis exit strategies and primarily the timing of the exit are very important questions for central banks. We are not able to determine the optimal exit date within our model. Nevertheless we are able to analyze the response of the economy to an exit. Methodologically we follow Angeloni, Faia, and Winkler (2010) who examine exit strategies at the government level in a deterministic environment. However, we perform this exercise in connection with exit strategies of the monetary authority. In our scenario we examine three cases: (1) the exit from a haircut policy where risky assets are purchased at lower haircuts than normal and (2) the simultaneous exit from both the above mentioned haircut policy and an interest rate policy that keeps the interest rate close to its zero lower bound and (3) an exit from a policy that keeps the loan-to-value ratio at a level above normal.[19]

In Figure 1.8 we depict four variables and their reactions if the market price is shocked negatively. One path shows how the economy evolves if the central bank can credibly commit not to exit from its haircut policy ("no exit"). Given a negative shock to the market price, the haircut rule decreases constantly keeping output stable and inflation and the prices of capital close to their steady state values. Another path exemplifies how the variables evolve if agents are surprised by the fact that the central bank ignores deviations of the market price of capital from period twenty-five onwards ("unanticipated exit") and the haircut returns back to its steady-state value at a pace governed by the AR-coefficient. Obviously until the time of the unanticipated exit the economy's response is identical to the "no exit"-case. Afterwards, given that the haircut is no longer responding to asset price movements, output and inflation drop immediately and considerably, as liquidity is reduced sharply. In addition, the prices of capital reduce unexpectedly before returning gradually to the steady state value. The last path depicted in Figure 1.8 belongs to a situation where the agents anticipate correctly from the very beginning that after twenty-four periods the central bank is no longer stimulating the economy with its haircut instrument ("anticipated exit"). Hence, for all variables this path has to differ from period one onwards as the expectation of the central bank's reduced liquidity provision drives up output after a few periods and lets inflation fall from the very beginning. Once the haircut rule is actually shut down, the prices of capital and output experience a sudden but only slight dip before returning fast to their steady states. Only inflation takes longer to adjust. Table 1.6 shows the variances of the four variables plotted in Figure 1.8. The variances are lowest for the case of a constant haircut. Moreover, the variances are significantly lower if the central bank exits its constant haircut policy as anticipated by the agents in the model.

	Output	Inflation	Fundamental Price Q	Market Price S
No Exit	0.0039	0.0014	0.0191	0.0335
Anticipated Exit	0.0484	0.0052	0.0552	0.0779
Unanticipated Exit	0.2622	0.0032	1.1972	1.3867

Table 1.6: Exit from Haircut Policy

Figure 1.9 shows the same analysis when the central bank exits its haircut policy after twenty-

[19] One could assume that the loan-to-value is controlled by a supervisory authority whose only objective is to keep excesses on the interbank market at bay. Note that both the haircut rule and the loan-to-value ratio respond to asset price deviations.

four periods and simultaneously increases the interest rate to a level implied by the Taylor-rule. The results are more mixed in this example. For output and inflation the anticipated response is much closer to the unanticipated one. Unlike in the previous case where only an exit to the haircut rule was examined the response to inflation looks much smoother with an initial spike in the beginning as the interest rate is fixed close to its zero lower bound. Output and also the price of capital experience more pronounced downturns if the policy rate is held simultaneously at zero. The conclusion drawn from the variances in Table 1.7 is that less volatility in inflation

	Output	Inflation	Fundamental Price Q	Market Price S
No Exit	8.2629	10.2129	2.8563	3.4686
Anticipated Exit	9.3231	8.5345	4.9132	5.7406
Unanticipated Exit	8.0824	10.7364	10.8665	11.9479

Table 1.7: Exit from Haircut Policy plus Taylor-Rule

comes at the cost of more volatility in the other variables. Again the anticipated exit is preferable to an unanticipated exit.

Finally, in Figure 1.10 we assume that the central bank is able to control the loan-to-value ratio and acts as a supervisory authority. The setup is the same as in the previous cases with the instrument being shut down after twenty-four periods and letting it return to its steady-state value at a speed governed by a pure AR(1) process afterwards. In the “no exit”-case the loan-to-value ratio would be constantly above its steady-state value which leads to very little macroeconomic volatility as can be seen in Figure 1.10. After a shock to the market price output decreases and inflation increases slightly. In the case of an anticipated exit, the reaction of output and inflation is stronger. After the exit, output as well as the prices for capital increase sharply whereas inflation drops considerably because we assumed that the loan-to-value ratio runs countercyclical to the development in the asset-backed securities. Once the loan-to-value ratio returns to its normal level, the value of asset-backed securities increases and overall demand in the real sector drives up the price of capital and output. If the exit is unanticipated by the agents, output and the price of capital increase even stronger. This is confirmed by the variances produced by the simulation and which are depicted in Table 1.8.

	Output	Inflation	Fundamental Price Q	Market Price S
No Exit	0.0039	0.0014	0.0191	0.0335
Anticipated Exit	0.0442	0.006	0.066	0.0726
Unanticipated Exit	0.0484	0.0045	0.1742	0.1437

Table 1.8: Exit from constant Loan-to-Value Ratio

1.5 Conclusion

The financial crisis has changed the way economists have to think about modeling and explaining monetary policy. This paper tries to take a step in the right direction by modeling an interbank sector that is motivated by individually optimal behavior of banks in the presence of an interbank market. By this modeling device unconventional monetary policy which includes not only a simple interest rate rule but with the haircut a collateral policy as well can be analyzed. Thereby not only central bank behavior in the crisis but also an exit strategy that all central banks in the world are looking for after a recession can be examined. Furthermore we are able to take up the debate of Bernanke and Gertler against primarily Cecchetti and argue whether it is advisable to include asset prices in the interest rate rule and contribute to it by analyzing a second monetary instrument.

We find that the interbank market matters for the economy as a whole as it decreases macroeconomic volatility if an interest rate shock hits the economy and amplifies it if a shock to asset prices occurs. Once this market is drying up or risks to be malfunctioning, central banks have to react and stimulate the liquidity situation on this market by other measures than traditional interest rate policy. The haircut as an additional instrument is even more important if the policy rate set by the central bank is already close to the zero lower bound and restricts the leeway of a central bank. Decreasing haircuts is the instrument we analyzed and it works fine to boost interbank lending and increase output in total. This comes at the risk of increased inflation in the first periods after a negative shock to haircuts. With respect to the ongoing debate in the literature we back the position of Bernanke and Gertler (1999) and claim that asset prices should not be incorporated in the interest rate rule. In this model framework both financial and macroeconomic volatility is lowest if the haircut responds to asset price deviations. After a negative shock to the market prices of financial assets, central banks could reduce the macroeconomic volatility further if they commit to exit at a pre-announced date. Agents' expectations formation contributes then to a smoothing of key variables.

An interesting way to extend the model would be first to implement default probabilities on the interbank market which certainly would increase the responses in a financial crisis setup. Secondly, having included several types of shocks both in the real as well as in the financial sector, one further possibility would be to estimate the model to match certain country characteristics more accurately.

Appendix Chapter 1

1.A Model Graph

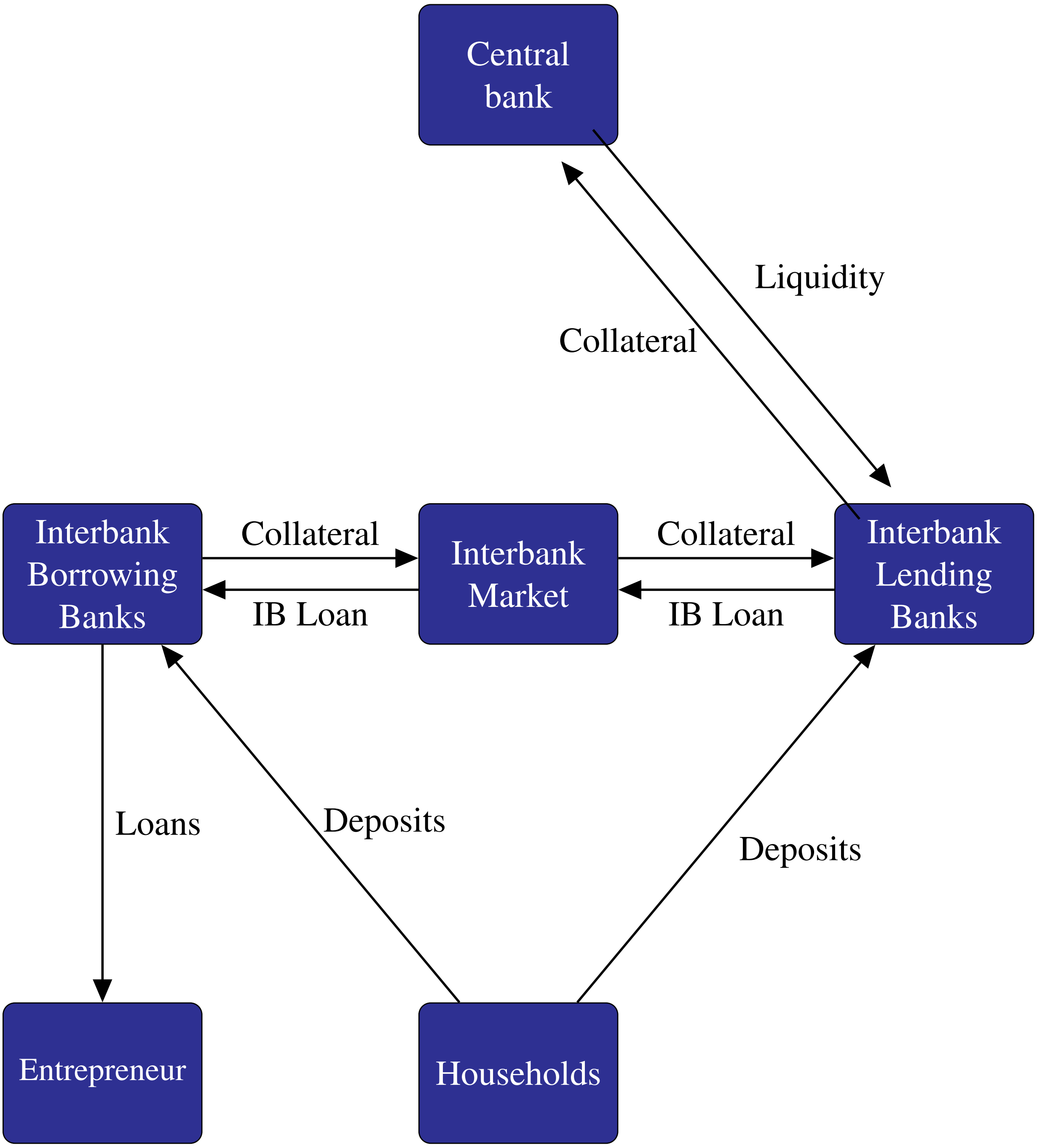


Figure 1.1: Model Economy: Graph

1.B Model Equations

1.B.1 First-order Conditions

Patient Households

$$
\begin{aligned}
\lambda_t &= (C_t(h))^{-\gamma} \\
\lambda_t &= \beta\lambda_{t+1}\frac{R_t^D}{\pi_{t+1}} \\
\lambda_t W_t &= \eta\frac{1}{(1-L_t(h))^{\gamma_l}}
\end{aligned}
$$

Entrepreneurs

$$
\begin{aligned}
R_t^k &= \alpha MC_t\frac{Y_t}{K_t} \\
W_t &= (1-\alpha)MC_t\frac{Y_t}{L_t}
\end{aligned}
$$

Capital Producers

$$
\begin{aligned}
& Q_t\left(1-\frac{\kappa_i}{2}\left(\frac{K_t}{K_{t-1}}-1\right)^2-\kappa_i\left(\frac{K_t}{K_{t-1}}-1\right)\frac{K_t}{K_{t-1}}\right) \\
+ \quad & \beta\kappa_i\left(\frac{\lambda_{t+1}}{\lambda_t}\right)Q_{t+1}\left(\frac{K_{t+1}}{K_t}-1\right)\left(\frac{K_{t+1}}{K_t}\right)^2=1
\end{aligned}
$$

Retailer

$$
\sum_{k=0}^{\infty}\theta^k E_{t-1}\left\{\Lambda_{t,k}\left(\frac{P_t^*}{P_{t+k}}\right)^{-\epsilon_y}Y_{t+k}^*(R)\left[\frac{P_t^*}{P_{t+k}}-\left(\frac{\epsilon_y}{\epsilon_y-1}\right)\frac{P_{t+k}^w}{P_{t+k}}\right]\right\}=0
$$

Interbank Borrowing Bank j

$$
\begin{aligned}
& -(1+\epsilon_d)D_t(j) + \left(1+\lambda_t^{CoB}\right)\epsilon_d \frac{R_t^{IB}}{R_t^D} D_t(j) - \kappa_d \left(\frac{R_t^D}{R_{t-1}^D} - 1\right)\frac{R_t^D}{R_{t-1}^D} D_t(j) \\
+ \quad & \beta^P \kappa_d \frac{\lambda_{t+1}^P}{\lambda_t^P}\left(\frac{R_{t+1}^D}{R_t^D} - 1\right)\left(\frac{R_{t+1}^D}{R_t^D}\right)^2 D_{t+1}(j) = 0 \\
& (1-\epsilon_h)B_t(j) + \left(1+\lambda_t^{CoB}\right)\epsilon_h \frac{R_t^{IB}}{R_t^H} B_t(j) - \kappa_h \left(\frac{R_t^H}{R_{t-1}^H} - 1\right)\frac{R_t^H}{R_{t-1}^H} B_t(j) \\
+ \quad & \beta^P \kappa_h \frac{\lambda_{t+1}^P}{\lambda_t^P}\left(\frac{R_{t+1}^H}{R_t^H} - 1\right)\left(\frac{R_{t+1}^H}{R_t^H}\right)^2 B_{t+1}(j) = 0
\end{aligned}
$$

Interbank Lending Bank k

$$
\begin{aligned}
X_t(k) &= \left(\frac{R_t^{Spread} - R_t^{IB}}{\lambda_t(1-\alpha)}\right)^{-\frac{1}{\alpha}} IB_t(k) \\
IB_t(k) &= X_t(k)\left(\frac{R_t^{Spread}\left(1+\frac{1-h_t}{m_t}R_t^{IB}\right) + R_t - \lambda_t \frac{1-h_t}{m_t} R_t^{IB}}{\lambda_t \alpha}\right)^{\frac{1}{\alpha-1}}
\end{aligned}
$$

1.B.2 Log-linearized Equations

Real Sector

$$
\begin{aligned}
Y_t &= \frac{C_{ss}}{Y_{ss}}C_t + \frac{G_{ss}}{Y_{ss}}G_t + \frac{I_{ss}}{Y_{ss}}I_t \\
\pi_t &= \frac{(1-\xi)(1-\xi\beta)}{\xi}MC_t + \beta\pi_{t+1} \\
K_t &= (1-\delta)K_{t-1} + \delta I_t \\
Y_t &= A_t + \alpha K_{t-1} + (1-\alpha)(1-\omega)LH_t \\
Q_t &= \varphi(I_t - K_{t-1}) \\
Y_t &= \frac{LH_{ss}}{1-LH_{ss}}LH_t + C_t + LH_t - MC_t \\
C_t &= \frac{h}{1+h}C_{t-1} + \frac{1}{1+h}C_{t+1} - \frac{1-h}{(1+h)\sigma}\left(R_t^D - \pi_{t+1}\right) + \\
&\quad + \frac{1-h}{(1+h)\sigma}\left(\epsilon_t^P - \epsilon_{t+1}^P\right) \\
R_t^Q &= (1-\vartheta)(MC_t + Y_t - K_{t-1}) + \vartheta Q_t - Q_{t-1} \\
R_{t+1}^Q &= R_t^B - \pi_{t+1} - \psi(N_t - (Q_t + U_t) - K_t) \\
N_t &= \nu\frac{R_{ss}^Q K_{ss}}{N_{ss}}\left\{R_t^Q - \left(1 - \frac{N_{ss}}{K_{ss}}\right)\left(R_{t-1}^B - \pi_t\right) - (1 - \frac{N_{ss}}{K_{ss}})\psi(K_{t-1} + Q_{t-1})\right. \\
&\quad \left. - \left[1 + \left(1 - \frac{N_{ss}}{K_{ss}}\right)[\psi - (1-b)]\right] + \vartheta U_t + \left[\left(1 - \frac{N_{ss}}{K_{ss}}\right)\psi + \frac{N_{ss}}{K_{ss}}\right]N_{t-1}\right\}
\end{aligned}
$$

Financial Sector

$$
\begin{aligned}
R_t^B &= \frac{\left(\kappa_b R_{t-1}^B + \beta\kappa_b R_{t+1}^B + (\epsilon_b - 1)R_t^{IB}\right)}{(\epsilon_b - 1 + \kappa_d(1+\beta))} \\
R_t^D &= \frac{\left(\kappa_d R_{t-1}^D + \beta\kappa_d R_{t+1}^D + (1 + \epsilon_d)R_t^{IB}\right)}{(1 + \epsilon_d + \kappa_d(1+\beta))} \\
B_t &= \frac{Q_{ss}K_{ss}}{B_{ss}}(Q_t + K_t) - \frac{N_{ss}}{B_{ss}}N_t \\
D_t &= \frac{B_{ss}}{D_{ss}}B_t - \frac{IB_{ss}}{D_{ss}}IB_t
\end{aligned}
$$

Financial Sector (cont.)

$$
\begin{aligned}
MBS_t^{CoB} &= (1-o)\frac{Q_{ss}K_{ss}}{MBS_{ss}^{CoB}}\left[(Q_{t+1}+U_{t+1})+K_t\right] - o\frac{N_{ss}}{MBS_{ss}^{CoB}}N_t \\
M &= \frac{G_{ss}}{M_{ss}}G_t - HC_{ss}\frac{MBS_{ss}^{CoB}}{M_{ss}}HC_t + (1-HC_{ss})\frac{MBS_{ss}^{CoB}}{M_{ss}}MBS_t^{CoB} \\
R_t^{spread} &= \frac{R_{ss}^{IB}}{R_{ss}^{spread}}R_t^{IB} - \frac{R_{ss}}{R_{ss}^{spread}}R_t \\
M_t &= \zeta IB_t + (1-\zeta)X_t \\
X_t &= \frac{1}{\zeta}\left(\frac{R_{ss}^{spread}}{R_{ss}^{spread}-R_{ss}^{IB}}R_t^{spread} - \frac{R_{ss}^{IB}}{R_{ss}^{spread}-R_{ss}^{IB}}R_t^{IB} - \lambda_t\right) + IB_t \\
IB_t &= \frac{1}{\zeta}\left[\left(R_{ss}^{spread}\left(1+\frac{(1-HC_{ss})}{m_{ss}}R_{ss}^{IB}\right) + R_{ss} - \left(R_{ss}^{IB}\right)^2\frac{1-HC_{ss}}{m_{ss}}\right.\right. \\
&\quad \left.\left. +\lambda_{ss}\frac{1-HC_{ss}}{m_{ss}}R_{ss}^{IB}\right) / \left(\lambda_{ss}\zeta X_{ss}^{(1-\zeta)}\right)\right]^{-1} \\
&\quad \left\{\frac{1+m_{ss}-HC_{ss}}{m_{ss}}R_{ss}^{IB}R_{ss}^{spread}R_t^{spread}\right. \\
&\quad + \left(R_{ss}^{spread}+\lambda_{ss}-2R_{ss}^{IB}\right)\frac{1-HC_{ss}}{m_{ss}}R_{ss}^{IB}R_t^{IB} \\
&\quad \left. + R_{ss}R_t + \left[\left(R_{ss}^{spread}+\lambda_{ss}-R_{ss}^{IB}\right)\frac{R_{ss}^{IB}}{m_{ss}}\right]HC_{ss}HC\right\} \\
&+ \frac{1-\zeta}{\zeta}X_{ss}X_t
\end{aligned}
$$

Shocks

$$
\begin{aligned}
A_t &= \rho_a A_{t-1} + \varepsilon_t^A \\
G_t &= \rho_g G_{t-1} + \varepsilon_t^G \\
U_t &= b\frac{R_{ss}^Q}{(1-\delta)}U_{t-1} + \varepsilon_t^U \\
R_t &= \phi_r R_{t-1} + \phi_\pi \pi_t + \phi_y Y_t(+dS_t) + \varepsilon_t^R \\
HC_t &= \rho_h HC_{t-1}(+cS_t) - \varepsilon_t^{HC} \\
m_t &= \rho_m m_{t-1} - 2*U_t + \varepsilon_t^m
\end{aligned}
$$

1.C Calibrated Parameters

Parameters	Values	Parameters	Values
β	0.997	ϵ_d	852
α	0.33	ϵ_b	759
δ	0.008	ϵ_y	6
κ_d	540	ψ	0.0506
κ_b	1125	ν	0.95
ξ_p	0.85	a	0.98
om	0.01	ϖ	0.5
ζ	0.9	ϑ	0.9792
γ^p	1	ρ_g	0.9
γ^i	1	ρ_m	0.9
γ^{CoB}	1	ρ_r	0.99
γ^{pd}	1	ρ_a	0.95
γ^l	1	ρ_h	0.98
γ^h	1	ρ_π	1.5
τ	0.15	ρ_y	0.5
$b = a \cdot (1 - \delta)$	0.9722	c	0
A^{ss}	1	d	0
π^{ss}	1	Ω	0.01
HC^{ss}	0.2	Lev	2
LH^{ss}	0.25	$\frac{G^{ss}}{Y^{ss}}$	0.2
$\frac{CE^{ss}}{Y^{ss}}$	0.04		

Table 1.9: Calibrated Model Parameters

1.D Dynamic Analysis

1.D.1 Impulse Response Analysis

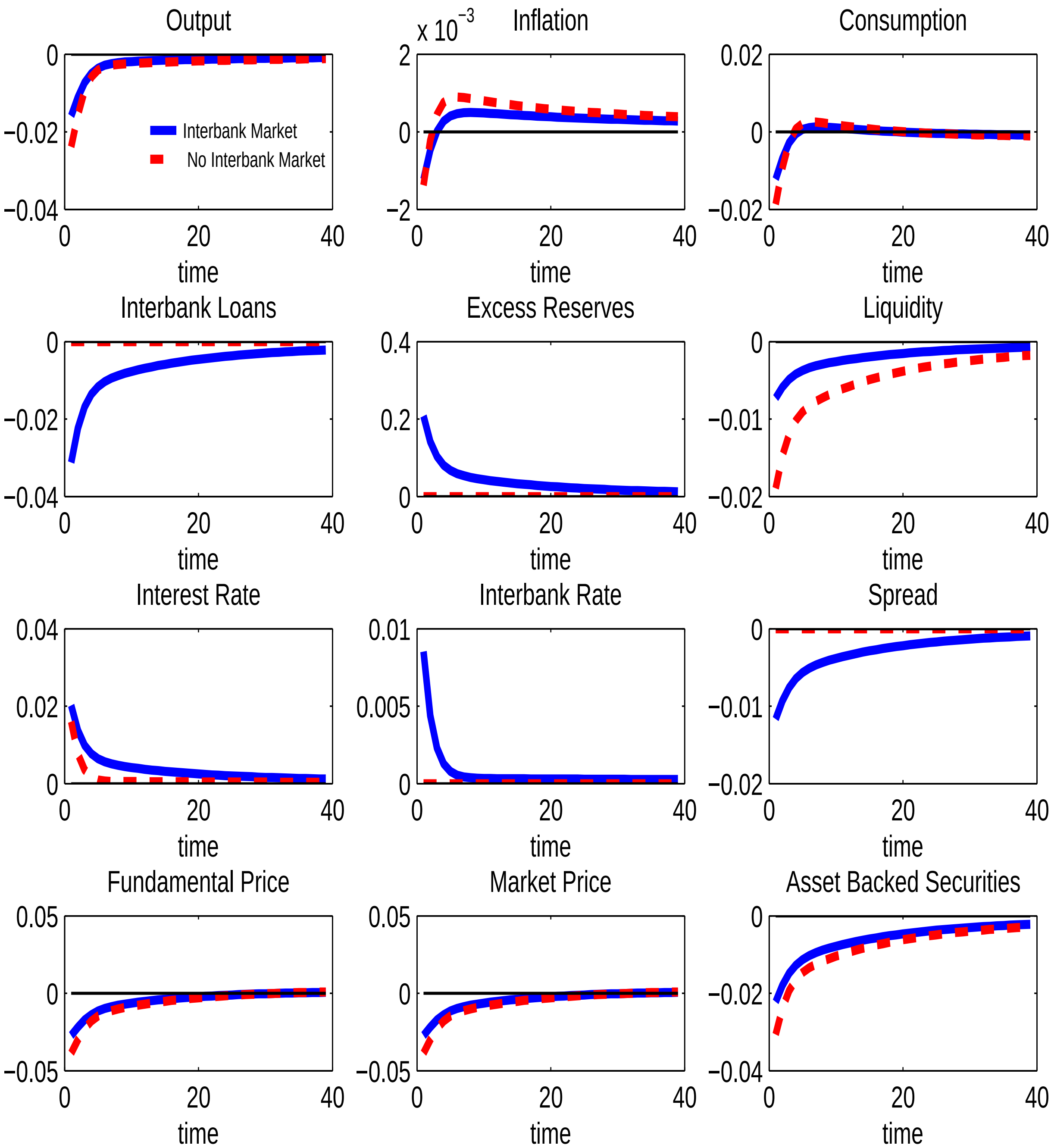


Figure 1.2: Interest Rate Shock

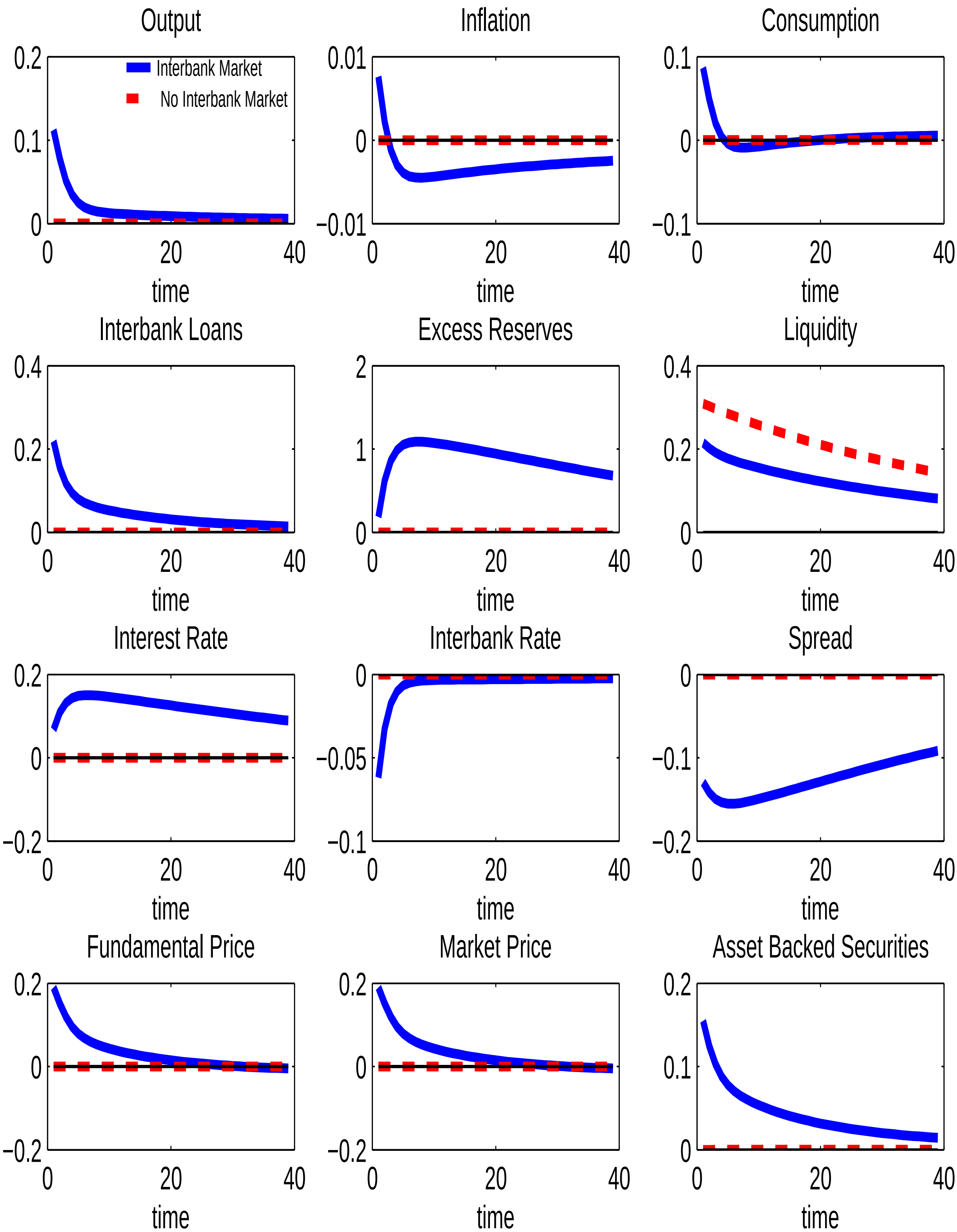


Figure 1.3: Haircut Shock

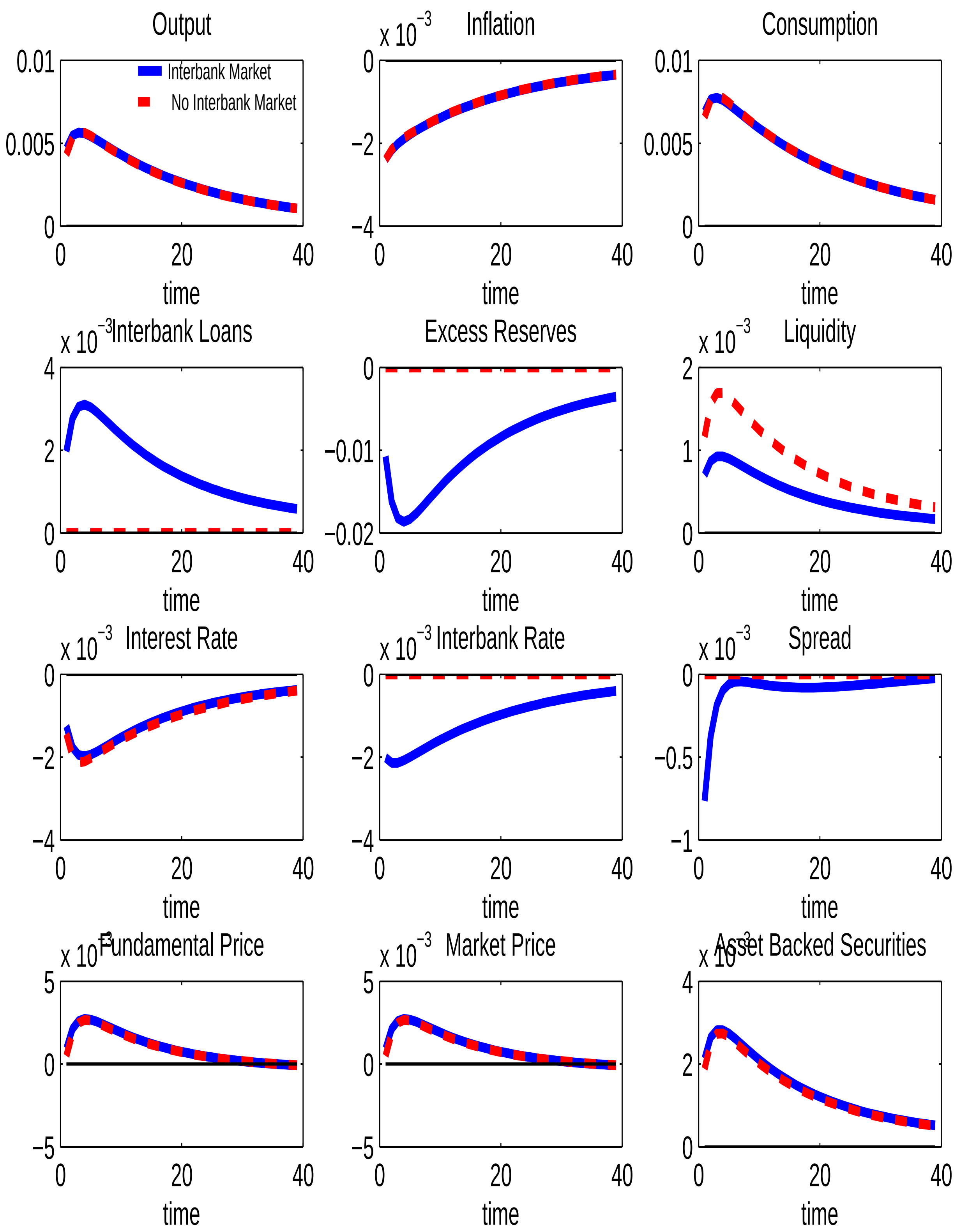


Figure 1.4: Technology Shock

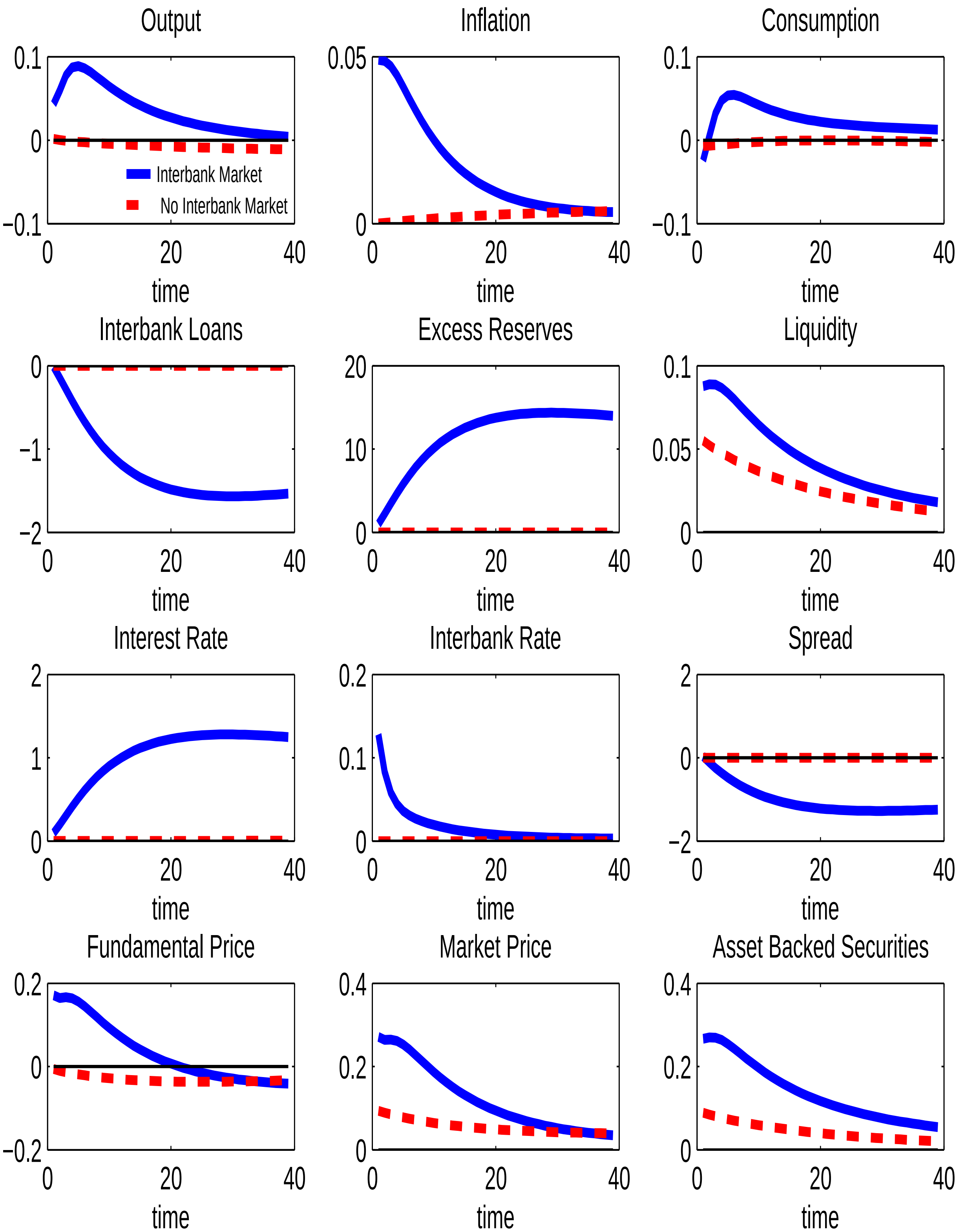


Figure 1.5: Market Price Shock

1.D.2 Boom-Bust Cycle

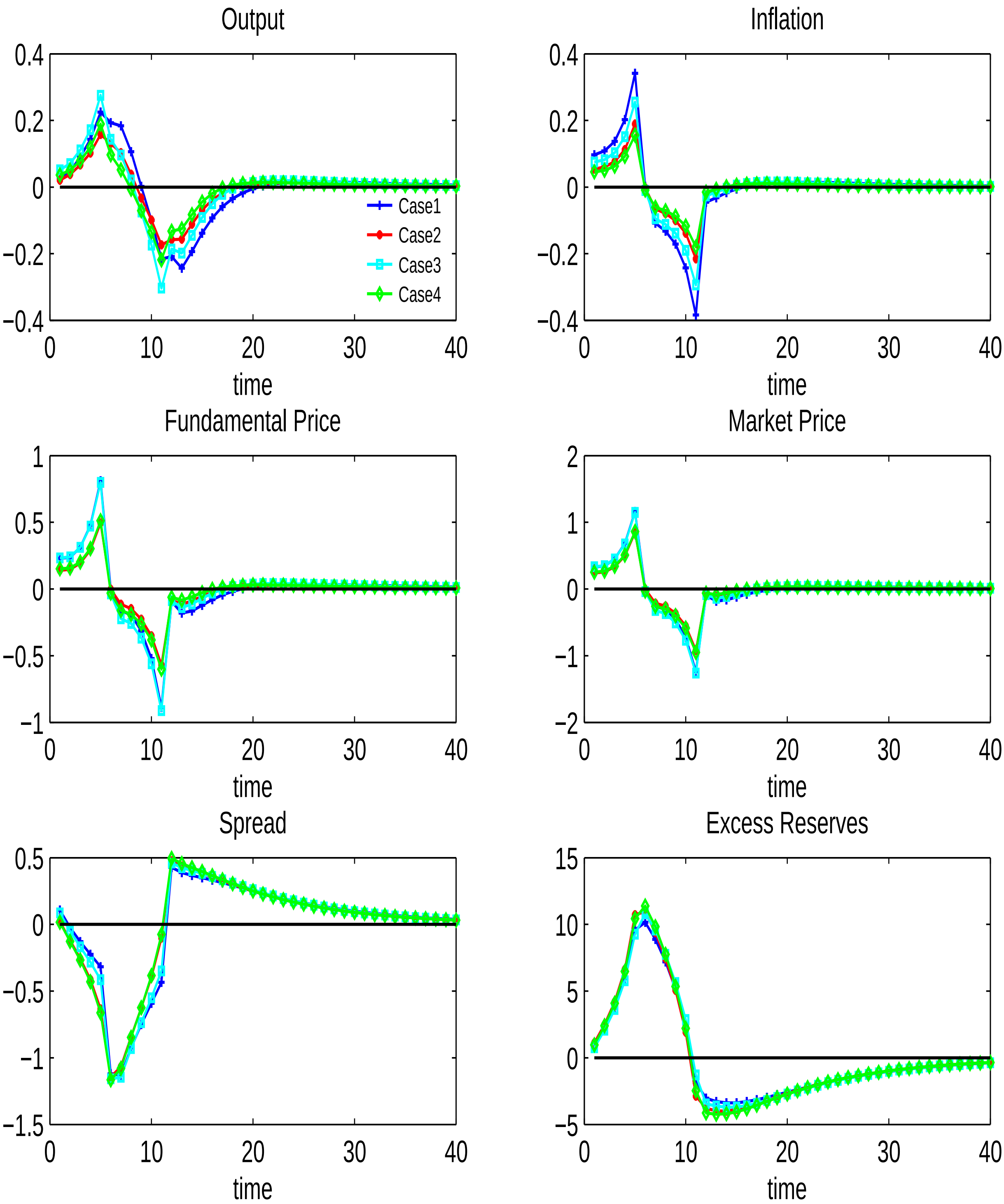


Figure 1.6: Boom-Bust Cycle I

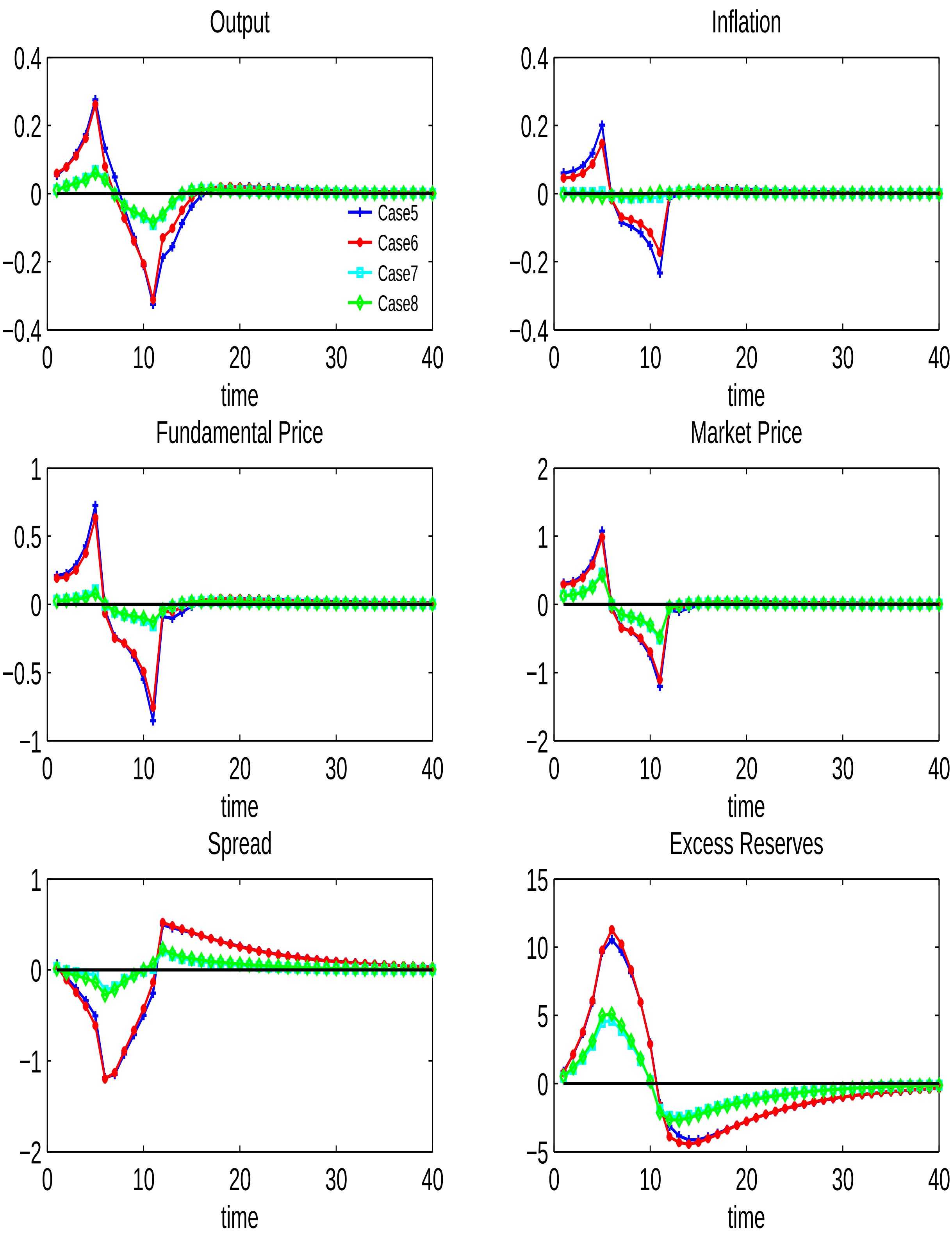


Figure 1.7: Boom-Bust Cycle II

1.D.3 Exit Strategy

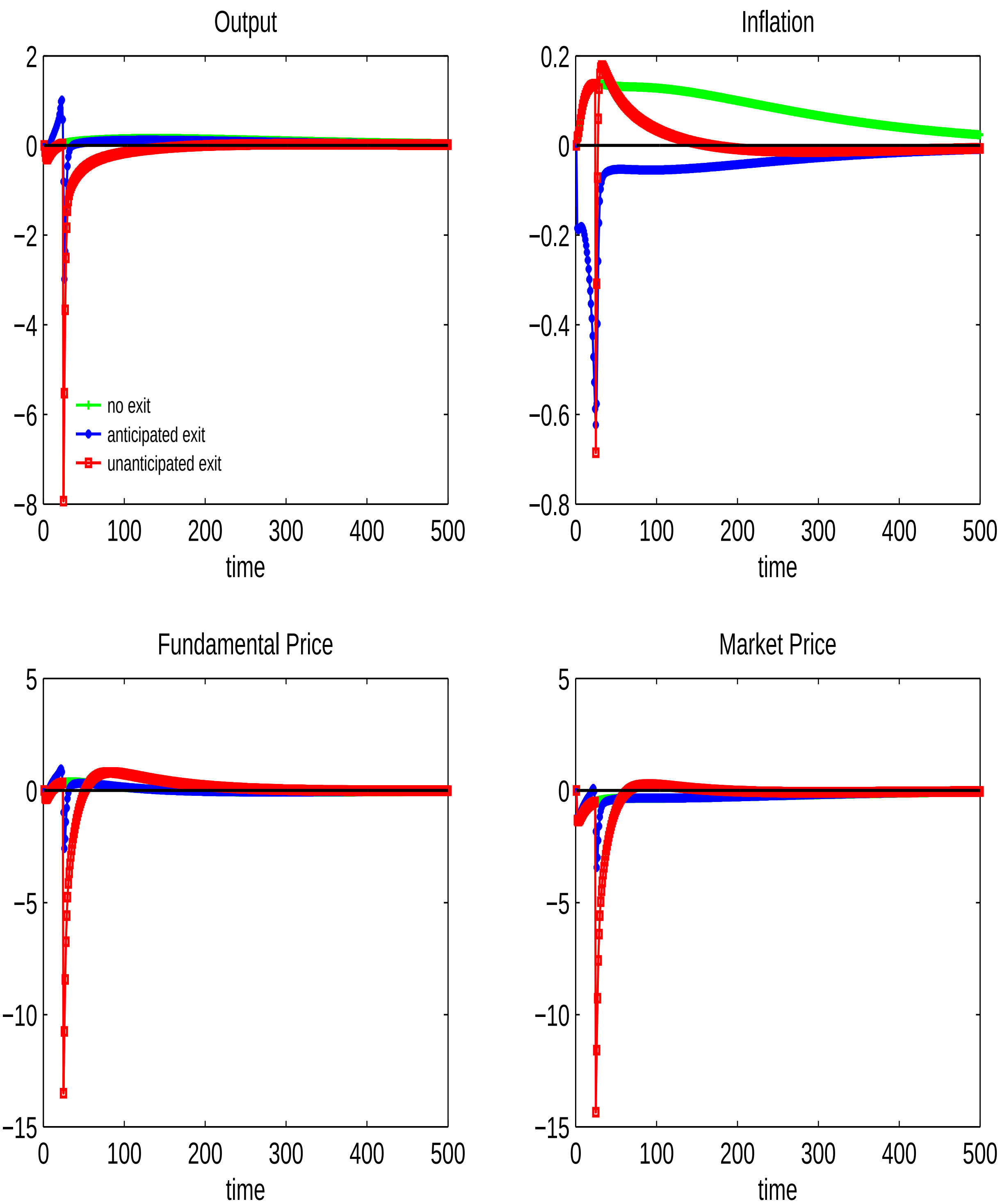


Figure 1.8: Exit Strategy: Haircut

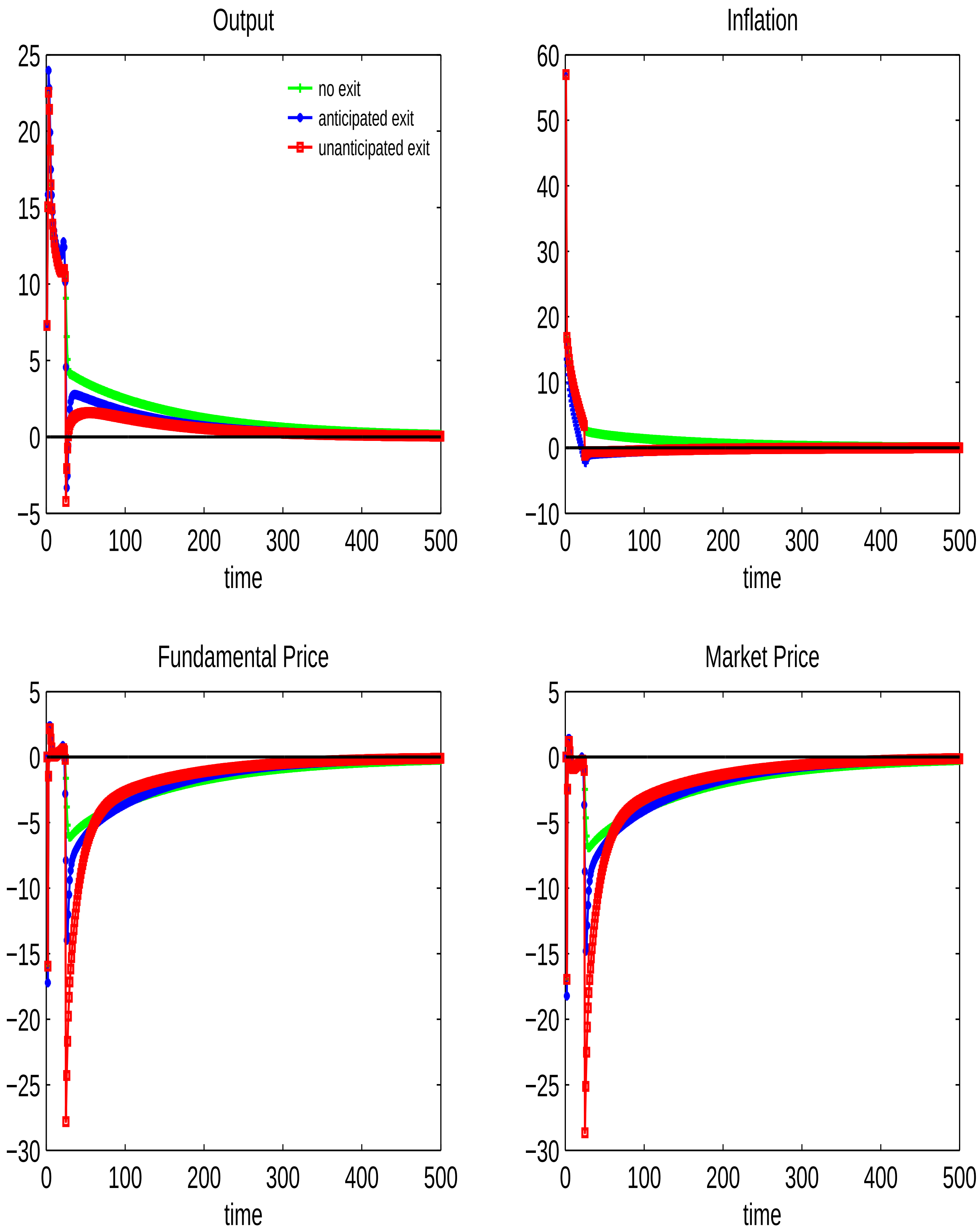


Figure 1.9: Exit Strategy: Haircut plus Taylor-Rule

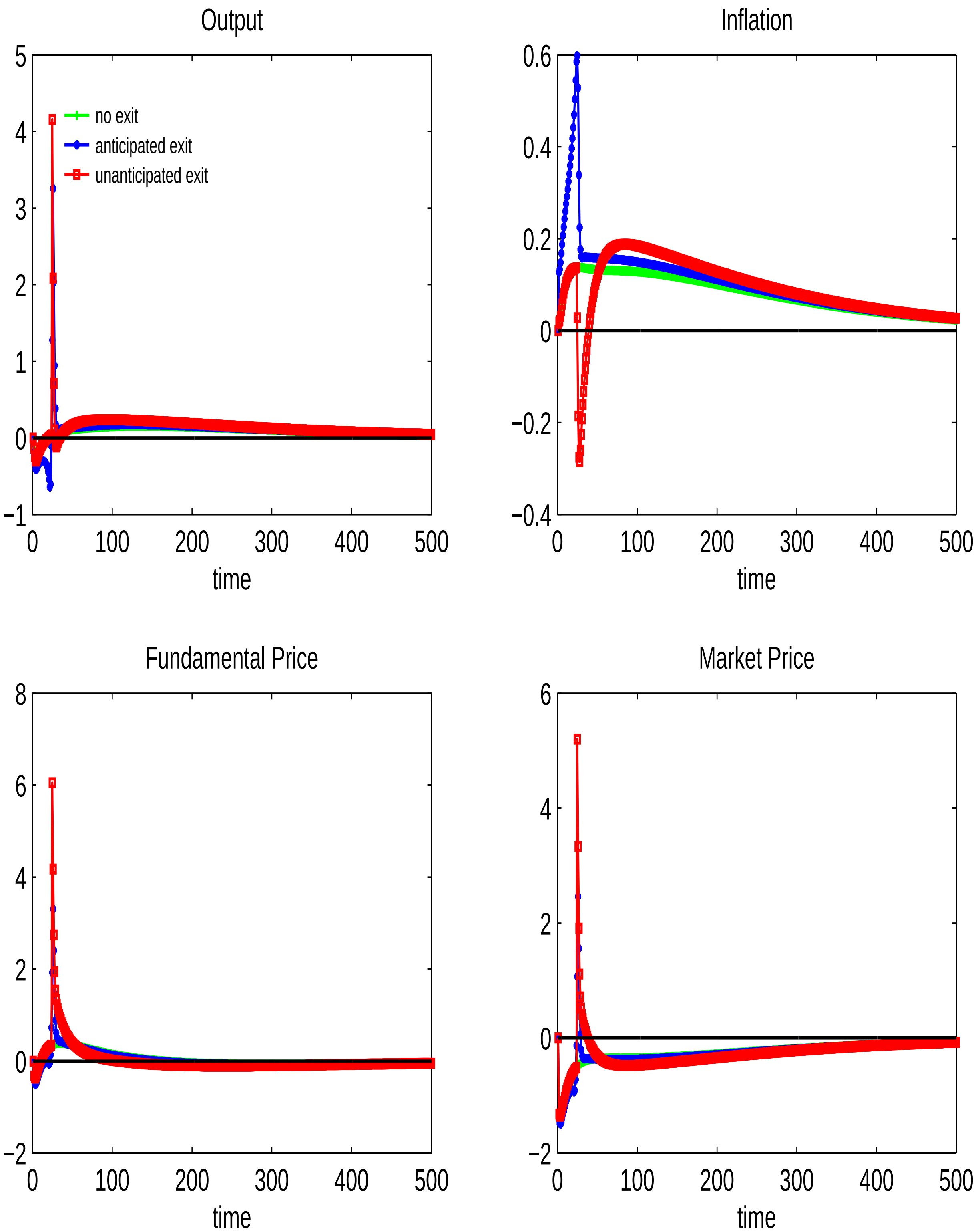


Figure 1.10: Exit Strategy: Loan-to-Value Ratio

Chapter 2

Interbank Refinancing Conditions and Bank Risk-taking

2.1 Introduction

It is commonly agreed that the seeds of the financial crisis have been sown by the subprime mortgage crisis sparked by the bursting of the housing price bubble in the United States. At the time the house prices in the United States plummeted financial institutions held large exposures of mortgage-related securities because they seemed to offer an attractive risk-return profile. As losses in those securities accumulated in the balance sheets of banks worldwide the trust in the stability of financial institutions began to vanish and refinancing started to become an issue for banks. Especially as liquidity on the important interbank market where banks with excess liquidity lend to banks with liquidity demand dried up. The persistent reluctance of banks to provide other banks with liquidity on the interbank market contributed to the amplification of the initial shock that originated in the US housing market.

Interbank markets in economics have been introduced by Bhattacharya and Gale (1987) who show that an interbank market where banks can borrow and lend liquidity is optimal to cope with idiosyncratic liquidity shocks. This emphasizes the importance of the interbank market for the liquidity management of banks. Since then the literature on interbank markets has grown considerably. There are models which incorporate an interbank market to examine its role for the propagation of financial shocks (Rochet and Tirole (1996), Allen and Gale (2000)), other models analyze the role of interbank markets for monetary transmission (Freixas and Jorge (2008b)) and still other models emphasize the role of central banks for emergency liquidity assistance of banks in the case of a failure of interbank markets (Rochet and Vives (2004), Repullo (2005), Acharya, Gromb, and Yorulmazer (2012)).

This paper focuses on a specific form of market failure which has been observed in the market for interbank liquidity since the beginning of the financial crisis, namely liquidity hoarding. This liquidity hoarding on part of banks has been confirmed empirically. For example, Acharya and Merrouche (2010) study the liquidity demand of banks in the Sterling money market and find that the banks' liquidity holdings increased by 30% during the subprime crisis in August 2007. For the Euro area Heider et al. (2009) provide similar evidence of liquidity hoarding in the unsecured Euro interbank market in September 2007. Using data on intraday account balances held by banks at the Federal Reserve and Fedwire interbank transactions Ashcraft et al. (2011) find evidence for precautionary hoarding of reserves in the Federal Funds market between September 2007 and August 2008. Afonso et al. (2011) examine the US federal funds market after the bankruptcy of Lehman Brothers. Their results suggest that banks became more concerned about counterparty risk. Similar results have been obtained by Taylor and Williams (2009). Hence, while liquidity hoarding by banks is confirmed by the data, if this behavior is caused by a precautionary motive or due to counterparty risk is not quite clear.

Like in the empirical literature, in the theoretical literature there exist two explanations why individual behavior of banks jointly led to disruptions on the interbank market. One strand of the literature argues that the observed liquidity hoarding by banks is the result of concerns about its own future liquidity needs. One example is the incomplete markets model by Allen et al. (2009b) who show that the price volatility due to the lack of hedging completely against aggregate and idiosyncratic shocks leads to the holding of excess reserves by banks. Hence, banks show precautionary behavior which can be explained by an internal motive for holding on to their liquidity and not providing liquidity on the interbank market. In contrast, Freixas and Jorge (2008b) or Heider et al. (2009) argue that it is rather an external motive, namely, that each bank is concerned about the balance-sheet conditions of other banks which leads to the tensions on the interbank market. Freixas and Jorge (2008b) show that interbank market imperfections results in an equilibrium with credit rationing. And the study of Heider et al. (2009) confirms that asymmetric information about the counterparty risk can lead to a breakdown of the interbank market.

In this paper a model with a heterogeneous banking sector is developed where some of the banks possess excess liquidity while others lack sufficient funds to finance a risky portfolio investment. The interbank market of the model allows for a transfer of liquidity from banks with a liquidity surplus to banks with a liquidity deficit. The level of counterparty risk in this model depends on the quality of the balance sheet and the portfolio choice made by a bank. It is assumed that the counterparty risk involved in interbank lending is not directly observable. But interbank lending banks possess a costless technology which allows them to imperfectly assess the quality

of a bank's balance sheet. The interbank market functions smoothly if interbank lending banks are sufficiently confident about their assessment of the counterparty risk involved in providing liquidity on the interbank market. Moreover, the model implies that if lending banks in the interbank market care about counterparty risk they are able to exert control on the risks taken by banks. However, it is shown that the liquidity on the interbank market can dry up if the reliability of the technology of the interbank lending banks falls below a certain threshold. As banks are then unable to differentiate between high and low counterparty risks they find it optimal not to lend on the interbank market even if their analysis signals that the true counterparty risk is low.
The model developed in this paper is based on Rajan (1994). However, in the model of Rajan (1994) it is assumed that a bank possesses sufficient own funds to implement the desired policy. This assumption no longer holds in this model where a bank is required to obtain liquidity on the interbank market to be able to implement the optimal portfolio decision. Only due to this extension the impact of the lending policy of banks in the interbank market on the riskiness of the balance sheet of banks with a liquidity demand cab be analyzed. The paper of Heider et al. (2009) is closely related to this paper as it examines the effect of counterparty risk on interbank lending activity. But in their model the counterparty risk is assumed to be totally random. In contrast, in this model the level of counterparty risk is partially determined endogenously by the strategic behavior of the interbank borrowing bank. Moreover, the results derived with this model can be applied to a broader set of economic situations as in contrast to Heider et al. (2009) it is unnecessary to assume that there is asymmetric information about the riskiness of the investment and the model framework developed in this chapter can be adapted to both collateralized and uncollateralized interbank lending. Like Heider et al. (2009) the result of a liquidity policy of the central bank is examined, however, the results derived in this paper is not confined to the effect on the level of liquidity supply. In addition, it is commented on the risk involved with such a liquidity policy, namely, that if a central bank supplies liquidity to a bank independent of the riskiness of the planned investment, the balance sheet quality can deteriorate further as the riskiness of the portfolio increases.
The paper is structured as follows. In Section 2.2 the model framework of the interbank market and the decision problems of both an interbank lending bank as well as an interbank borrowing bank is presented. Furthermore an agent referred to as "the analyst" who processes the earnings report of each interbank borrowing bank is introduced. Like an analyst in the banking industry, this agent has only access to public available information. Section 2.3 derives the equilibrium bank behavior on the interbank market. Section 2.4 discusses the model implications for the risk-taking of interbank borrowing banks and the role of the central bank in this model. Finally

section 2.5 concludes.

2.2 Model

To analyze the consequences of the risk-taking behavior of a bank on other banks' willingness to lend on the interbank market, a partial equilibrium model that builds on the framework of Rajan (1994) is set up. However, the framework derived in Rajan (1994) does not allow to study the behavior of banks on the interbank market because he assumes that at any time a bank possesses sufficient own funds to satisfy its liquidity needs. But the recent financial crisis showed that there are times where the funding liquidity risk of a bank can be substantial and hence the assumption made in Rajan (1994) is not fulfilled. Thus, this assumption is dropped and it is assumed instead that a bank which suffers a liquidity shortage has to resort to the interbank market to obtain liquidity. Moreover, the model of Rajan (1994) is generalized to a financial market setting where a bank invests its funds in a risky portfolio.
The timeline in Figure 2.1 provides an overview of the underlying model structure described in detail in this section. The description above the timeline belongs to banks with a demand for interbank liquidity, the description below the timeline to banks with a potential supply of interbank liquidity.

Bank i is randomly matched to a bank n ⇒ Investment in a risky portfolio	Balance sheet quality q of bank i realizes Portfolio outcome ω of bank i realizes Bank i decides on portfolio risk policy a^q	Earnings report by bank i Bank i faces costs of c if $a^q = a$ at $d = 1$
d=0	d=1	d=2
Bank n is matched to a bank i	Bank n decides about lending policy bs	Bank n privately learns balance sheet quality of bank i Payoff from interbank lending activity realizes

Figure 2.1: Model Timeline

It is assumed that at the beginning of $d = 0$ each bank is provided with an exogenously given liquidity endowment of size $E > 0$. To introduce heterogeneity among banks it is assumed that at $d = 0$ some banks are able to invest their endowment E in a risky portfolio X while others cannot.[1] The excess liquidity of a bank which does not have the chance to invest its funds in a

[1] The size of the portfolio investment is normalized to one. Hence, the value of the portfolio at any point in time is equal to its price.

portfolio at $d = 0$ is equal to its endowment E. In the following to differentiate between these two bank types, a bank with an investment opportunity is indexed by i, a bank with no investment opportunity by n. If an individual bank in the economy independent of its investment opportunity at $d = 0$ is referred to, the index m is used.

To motivate borrowing and lending on the interbank market it is assumed that bank i's endowment E_i is insufficient to finance the portfolio investment at $d = 0$, that is, $E_i < X$. Hence, bank i has to borrow an amount $X - E_i$ from a bank n on the interbank market. For simplicity it is assumed that at $d = 0$ one bank n is randomly matched to one bank i. The simultaneous interaction of many banks i that have a potential demand for liquidity and many banks n that have excess liquidity constitutes the interbank market in the model.[2] To account for the fact that the interbank lending market is an over-the-counter market, the lending decision of a bank n at $d = 0$ and $d = 1$ is neither observable by another lending bank $j \neq n$ nor by the analyst.

To abstract from investment decisions by banks i and lending decisions of banks n at $d = 0$, an homogenous balance sheet structure at $d = 0$ is assumed , that is, both banks i and banks n believe that the portfolio quality across interbank lending banks is identical. Based on the perceived homogenous quality of portfolios held by banks i, a bank i believes to report positive earnings at $d = 2$ with probability one and bank n is sure to earn a gross return of $1 + R$ on its interbank loan.[3] Due to this homogeneity assumption a bank i is always willing to make a portfolio investment and a bank n will always supply its liquidity on the interbank market at $d = 0$. This setup resembles the situation before the breakout of the financial crisis. Banks which invested in mortgage-related securities did not consider to make a loss on this investment. At the same time banks which lend on the interbank were sure that the profitability of a bank which is invested in these securities is high enough to be able to repay the interbank loan with probability one.

After having obtained liquidity $F_{0,IB}$ on the interbank market at $d = 0$, the homogenous balance sheet of a bank i is given by Table 2.1

2 For a given portfolio investment X there is a negative relationship between the initial endowment E_i and the liquidity demand $F_{0,IB} \equiv X - E_i$ on the interbank market at $d = 0$. Although $E_i < X$ is assumed to hold, it is possible that the interbank liquidity demand $F_{0,IB}$ is smaller than the excess liquidity E_n of bank n. In this case bank n invests the remaining excess liquidity $E_n - F_{0,IB}$ in a liquid, risk-free asset whose return is normalized to one. As the amount of excess liquidity is exogenous for a bank n, the proceeds from the investment in the risk-free asset do not affect the optimal decision of bank n at $d = 1$ and hence will not be considered in its optimization problem.

3 Let us assume that at $d = 0$ a bank i got assigned either the portfolio X_0^1 or the portfolio X_0^2. The assets contained in either portfolio are traded in an efficient asset market. If in addition the portfolios had the same price X_0 at $d = 0$, that is, $X_0 = X_0^1 = X_0^2$ and the projected path of the price of the two portfolios X^1 and X^2 is identical over the investment horizon, a rational investor will be indifferent between investing its funds in portfolio X^1 or X^2. Moreover, given that at $d = 0$ a bank i possesses only public information from that same asset market which demands the same price X_0 for the portfolios X^1 and X^2, a bank i itself is not informed about the quality of the portfolio X at the time of its initial investment.

Assets	Liabilities
X_0	E
	$F_{0,IB}$

Table 2.1: Homogenous Balance Sheet of Bank i at $d = 0$

At $d = 1$ new, public available information emerges that casts doubt on the quality of the assets held by some interbank borrowing banks.[4] Hence, as of $d = 1$ it is common knowledge that the portfolios held across banks i are not homogenous but form two subsets X^L and X^H. Let the low quality portfolio be denoted by X^L, the high quality portfolio by X^H. The heterogeneous balance sheet structure at $d = 1$ is depicted in Table 2.2.

Assets	Liabilities
X_1^L	E
	$F_{0,IB}$

(a) Low Quality

Assets	Liabilities
X_1^H	E
	$F_{0,IB}$

(b) High Quality

Table 2.2: Heterogenous Balance Sheet of Bank i at $d = 1$

These two portfolios differ in their probability to generate a profit for bank i at $d = 2$. Let θ^q denote the probability that a bank with a balance sheet quality q encounters a good portfolio outcome at $d = 1$. It is assumed that the probability of a good portfolio outcome is positively correlated to its quality. Hence,

$$0 < \theta^L < \theta^H \leq 1 \tag{2.1}$$

holds.

2.2.1 Portfolio Risk Decision of an Interbank Borrowing Bank i at $d = 1$

At $d = 1$ a bank i privately observes the portfolio outcome $\omega \in \Omega = \{G, B\}$.[5] Depending on the portfolio outcome ω a bank i decides on its portfolio risk $a^q \in \{0, a\}$.[6] While in the case of $a^q = 0$ the risk of the portfolio held by bank i is constant between $d = 1$ and $d = 2$, the portfolio

[4] After the portfolio investment at $d = 1$ by assumption the asset side of the balance sheet of bank i contains only the risky portfolio X. Hence, the expressions bank, balance sheet and portfolio is used interchangeably when referring to the quality of a bank i's asset side.

[5] For simplicity it is assumed that the portfolio outcome does not change between $d = 1$ and $d = 2$ if the composition of the portfolio X remains unaltered.

[6] The portfolio risk in this model is measured by the variance of the portfolio held by bank i.

risk increases if it sets $a^q = a$. The reason to set $a^q = a$ is to avoid a negative earnings report at $d = 2$ which decreases the reputation of bank i in the market. In the following reputation is defined as the probability that the balance sheet quality q of bank i is considered as high.[7]
If at $d = 1$ the outcome of the portfolio is good, that is $\omega = G$, it is assumed that the probability of a negative earnings report by bank i at $d = 2$ is equal to zero. Because a bank i is assumed to be risk neutral, the reputational concerns of bank i in connection with the assumption that the analyst only differentiates between positive and negative earnings but not between different levels of positive or negative earnings prevents bank i from increasing the risk of its portfolio by setting $a^q = a$. Hence, a bank i with a good portfolio outcome at $d = 1$ will set $a^q = 0$ with probability one. In contrast, in the case of a bad portfolio outcome $\omega = B$ the probability that bank i is able to report positive earnings at $d = 2$ is equal to zero if it sets $a^q = 0$. If a bank i decides to set $a^q = a$ instead, it invests in a portfolio Y whose properties will be derived below. If a bank i is able to report positive instead of negative earnings its expected payoff increases by an amount b and the gain in its reputation is given by $p^+ - p^-$. The expected costs for a bank i associated with the policy $a^q = a$ are denoted by c. It is assumed that the relationship $c > b$ holds.[8] Hence, a bank i which encounters a bad portfolio outcome $\omega = B$ at $d = 1$ prefers to set $a^q = a$ only if the following condition holds

$$\underbrace{b - c}_{\Delta\text{expected return}<0} + \overbrace{p^+ - p}^{\Delta\text{reputation}>0} > 0 \tag{2.2}$$

If a bank i sets $a^q = a$ it sells a fraction f of its portfolio X to invest those funds in a portfolio Y with expected return μ_Y and variance σ_Y^2.[9] If the portfolio outcome of Y is G, the profit PP^Y has to be sufficient to offset the loss of the portfolio X at $d = 1$ to enable bank i to report positive earnings at $d = 2$.[10]

$$fPP^Y \geq LL^X \tag{2.3}$$

[7] As will be shown in Section 2.2.3 the reputation of a bank i is strictly larger if it reports positive earnings.
[8] Because of the assumption $c > b$ the policy $a^q = a$ will be never optimal if bank i does not care about its reputation p in the market. Hence, in the following it is assumed that $\gamma > 0$ holds.
[9] To abstract from optimal portfolio considerations about the fraction of portfolio X to be sold at $d = 1$ by bank i the fraction f is exogenously given.
[10] Note that to buy the portfolio Y a bank i is required to sell a fraction f of its portfolio X at $d = 1$. As a result a bank i realized a loss of fLL_X already at $d = 1$

In the model the probability of a good portfolio outcome of portfolio Y is denoted by a. The following assumption on the size of a is made in this model

$$0 < a < \theta^L \tag{2.4}$$

The lower bound for a is zero which implies that there is at least a small probability that conditional on obtaining an interbank loan the investment in the risky portfolio Y succeeds. The upper bound is given by the probability θ^L which denotes the probability that a low quality portfolio encounters a good outcome.
In contrast, if the outcome of the risky portfolio Y at $d = 2$ is bad, which happens with a probability of $1 - a$, the loss of the portfolio investment in Y, LL^Y, adds to the loss encountered from holding the portfolio X

$$(1 - f)LL^X + f(LL^X + LL^Y) > LL^X \quad \Leftrightarrow \quad f\ LL^Y > 0 \tag{2.5}$$

The relationship $c > b$ is satisfied if the expected loss of an investment in portfolio Y, $c \equiv (1 - a)f\ LL^Y$, is larger than the expected profits $b \equiv afPP^Y$.
The effect of the portfolio decision $a^q = a$ on the balance sheet of bank i is illustrated in figure 2.2.

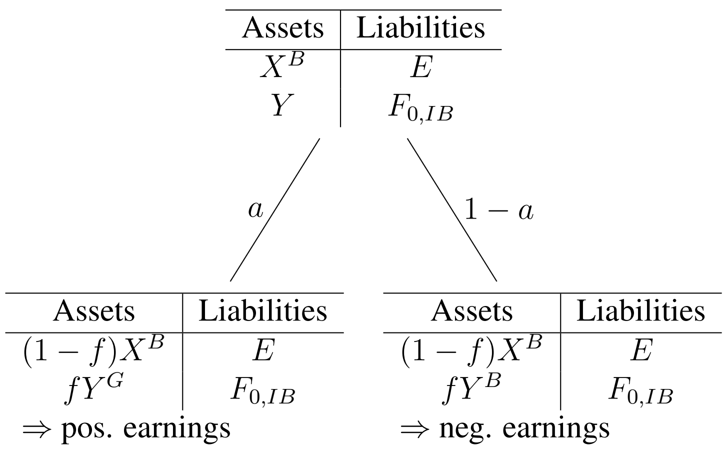


Figure 2.2: High Risk Balance Sheet

Thus, because the portfolio decision of a bank i with a good portfolio outcome G is invariant and equal to $a^q = 0$ it is only a bank i with a bad portfolio outcome at $d = 1$ which decides about the portfolio risk $a^q \in \{0, a\}$ at $d = 1$.
The objective function maximized by a bank with a bad portfolio outcome $\omega = B$ at $d = 1$ is

given by

$$U = (1-\gamma)\left\{-\left(1 - a^q \mathbb{I}_{[bs=1]}\right)\min\left[E_i, LL_X\right] - c\mathbb{I}_{[a^q=a\,\cap\, bs=1]}\right\} + \gamma \mathbb{E}_1 p \tag{2.6}$$

The structure of the objective function (2.6) of bank i is taken from Rajan (1994) and consists of two parts. The first term is the expected discounted payoff of the portfolio X conditional on a bad portfolio outcome $\omega = B$ at $d = 1$.[11] The second term represents the contribution of the reputation of bank i to the expected value of its objective function. The size of γ determines the importance of such reputational concerns for bank i relative to the expected payoff of the portfolio X.

To take the limited liability on part of bank i into account the term $\min\left[E_i, LL^X\right]$ is introduced where LL^X denotes the loss of bank i suffered from the portfolio investment at $d = 0$. Independent of the portfolio quality q the downside risk of a portfolio measured by LL^X is assumed to be large relative to its upside potential measured by PP^X minus the interest rate charged on the interbank loan $F_{0,IB}$. Hence, the contribution of $PP^X - (1+R)F_{0,IB}$ to the expected payoff of the portfolio X is negligible compared to the loss LL^X suffered on the portfolio X and hence is omitted in the formulation of the objective function (2.6).

The objective function of bank i is allowed to be conditional on the provision of interbank liquidity at $d = 1$ as indicated by the indicator function $\mathbb{I}_{[bs=1]}$ to account for the effect of bank n's lending decision $bs \in \{0, 1\}$ on bank i's risk policy choice $a^q \in \{0, a\}$. This is different from Rajan (1994) where bank i is assumed to be fully self-financed and it does not have to consider the optimizing behavior of a bank n in its policy choice at $d = 1$. In contrast to Rajan (1994) in this model it is possible that a bank n does not provide liquidity to bank i at $d = 1$. In this case bank i has to sell its portfolio at a fire-sale price $\underline{\lambda}$ to obtain the required liquidity and reports negative earnings with probability one at $d = 2$.

Although in Rajan (1994) the parameters c and b have an interpretation, their size is not determined by the assumptions made therein.[12] In contrast, the advantage of relating the risk policy $a^q = a$ to the decision of a bank i to invest in a risky portfolio Y is that the expected costs and benefits of such a policy can be expressed in terms of changes in the portfolio return and the portfolio variance. In the following the assumptions on the expected return and the variance of a portfolio Y to satisfy the assumptions made in connection with the risk policy $a^q = a$ are derived. As the relationship $c > b$ holds by assumption, the overall expected return of the two portfolios X and Y at $d = 2$, μ_{XY}, is required to be lower than the expected return on the portfolio X

[11] For simplicity a discount rate of zero is assumed.

[12] In Rajan (1994) the relationship b=a holds as the loss has been normalized to one.

alone. This is satisfied only if the expected return of the portfolio Y is lower than the expected return on the portfolio X, that is,

$$\mu_{XY} \equiv (1-f)\mu_X + f\mu_Y < \mu_X \quad \Leftrightarrow \quad \mu_Y < \mu_X \tag{2.7}$$

At the same time the portfolio variance of the combined portfolio denoted by σ^2_{XY} is required to be larger than the variance of the portfolio X because there is a non-zero probability that the positive return on the portfolio Y is sufficiently high to offset the negative return of the portfolio X. As a consequence the following relationship holds[13]

$$\sigma^2_{XY} \equiv (1-f)\sigma^2_X + f\sigma^2_Y > \sigma^2_X \quad \Leftrightarrow \quad \sigma^2_Y > \sigma^2_X \tag{2.8}$$

2.2.2 Lending Decision of an Interbank Lending Bank n at $d = 1$

The payoff from interbank lending which realizes at $d = 2$ depends on the true balance sheet quality $q \in Q = \{L, H\}$ and the risk policy $a^q \in \{0, a\}$ of bank i. However, neither the quality of bank i nor its risk policy is observable at $d = 1$ when bank n has to make its interbank lending decision.[14] Although a bank n cannot observe the balance sheet quality of bank i, it has prior information on the distribution of the balance sheet quality q among the population. Let the common prior that the balance sheet quality of bank i is high be denoted by $p = P(q = H)$. It is assumed that a bank n and the analyst hold the belief that both good and bad balance sheet qualities exist in the economy. This implies the following restrictions on the common prior p

$$0 < p < 1 \tag{2.9}$$

Unlike the analyst, a bank n cannot use the earnings announcement of bank i itself to update its prior belief p as it has to decide on its lending policy before bank i's earnings report takes place. However, for a given conjecture about bank i's behavior at $d = 1$, a bank n is able to form expectations about the posterior of p. In addition, based on the idea forwarded by Broecker (1990) a bank n is assumed to perform a financial analysis to assess a bank's ability to repay a loan. The financial analysis relies only on public information about the fundamentals of a potential borrower available at the time when bank n has to make its lending decision. A source of public available information are the past quarterly and annual reports published by bank i.

[13] For simplicity it is assumed that the correlation between the two portfolios is zero.

[14] The unobservability of the balance sheet quality q is allowed to be permanent because the quality of the balance sheet remains private knowledge of bank i.

The resulting signal $s \in S = \{l, h\}$ of such a financial analysis is positively but imperfectly correlated with the true type of bank i. The probability of correctly identifying a bank i of type H as type H is defined by $r = P(h|H) < 1$ where uppercase letters denote the true borrower type and lowercase letters identify the type assigned to a bank i by the test. The probability that the test identifies a low ability bank i to be of type H is denoted by $w := P(h|L) > 0$. Given the signal h from its creditworthiness test and forming expectations about the posterior distribution of the reputation p of bank i, $\mathbb{E}_1 p$, a bank n is able to update the probability that bank i is of type H using Bayes' formula

$$P(H|h) \equiv \varphi^h(a^H, a^L, bs) = \frac{r\mathbb{E}_1 p(a^H, a^L, bs)}{r\mathbb{E}_1 p(a^H, a^H, bs) + w(1 - \mathbb{E}_1 p(a^H, a^L, bs))} \tag{2.10}$$

As of $d = 1$ the expected payoff from lending on the interbank market is computed from the posterior probability φ^q and the expected payoff of a portfolio with quality q owned by a bank i whose conjectured risk policy is a^q. To be able to differentiate between the interbank lending rate R and the return from lending to a bank i whose risk policy is a^q and whose true balance sheet quality is q, the latter return will be denoted by $RR(a^q)$.

$$\begin{aligned}
V^{1,h} &\equiv V(a^L, a^H, s = h, bs = 1) \\
&= \varphi\, RR(a^H, H) + (1 - \varphi) RR(a^L, L) \\
&= \varphi \left[\theta^H (1 + R) F_{0,IB} + (1 - \theta^H)\lambda(a^H = 0)\right] \mathbb{I}_{[a^H = 0]} \\
&+ \varphi \left\{\theta^H (1 + R) F_{0,IB} + (1 - \theta^H) \left[a(1 + R) F_{0,IB} + (1 - a)\lambda(a^H = a)\right]\right\} \mathbb{I}_{[a^H = a]} \\
&+ (1 - \varphi) \left[\theta^L (1 + R) F_{0,IB} + (1 - \theta^L)\lambda(a^L = 0)\right] \mathbb{I}_{[a^L = 0]} \\
&+ (1 - \varphi) \left\{\theta^L (1 + R) F_{0,IB} + (1 - \theta^L) \left[a(1 + R) F_{0,IB} + (1 - a)\lambda(a^L = a)\right]\right\} \mathbb{I}_{[a^L = a]}
\end{aligned} \tag{2.11}$$

The parameter $\lambda(a^q)$ denotes the long run recovery value of the portfolio of bank i which sets a^q at $d = 1$.[15] Irrespective of the risk policy $a^q \in \{0, a\}$ set at $d = 1$ a portfolio of quality $q = H$ is expected to have a higher long run recovery value than a portfolio of quality $q = L$. Moreover, the recovery value will be strictly higher if bank i sets $a^q = 0$. Equation (2.12) depicts

[15] Due to the assumption that a bank n will sell the portfolio as soon as its price is high enough to ensure full repayment of the interbank loan $F_{0,IB}$ it is inconsequential if a bank n continues to rollover the interbank loan to bank i beyond $d = 2$ or if it takes over the assets of bank i at $d = 2$ in the case of collateralized borrowing on the interbank market.

the relationship

$$\lambda(a^H = 0) = F_{0,IB} > \lambda(a^L = 0) > \lambda(a^H = a) > \lambda(a^L = a) \tag{2.12}$$

Moreover, it is assumed that the payoff of bank n is strictly smaller if bank i sets $a^q = a$ instead of $a^q = 0$.

$$V(0, 0, s = h, bs = 1) > V(a, a, s = h, bs = 1) \tag{2.13}$$

For that condition to hold it is assumed that the following assumptions on $\lambda(a^H = 0)$ and $\lambda(a^L = 0)$ are satisfied

$$\lambda(a^H = 0) > \big[a(1 + R)F_{0,IB} + (1 - a)\lambda(a^H = a)\big] \tag{2.14}$$

$$\lambda(a^L = 0) > \big[a(1 + R)F_{0,IB} + (1 - a)\lambda(a^L = a)\big] \tag{2.15}$$

It is assumed that the financial analysis of a bank n is as reliable in identifying a high quality balance sheet $q = H$ as it is in identifying a low quality balance sheet $q = L$, that is,

$$r = P(h|H) = P(l|L) \qquad w = P(h|L) = P(l|H) \tag{2.16}$$

Hence, having observed the signal $s = l$, the posterior probability that a bank i is of type L is given by

$$P(L|l) \equiv \varphi^l(a^H, a^L, bs) = \frac{r\left(1 - \mathbb{E}_1 p(a^H, a^L)\right)}{r\left(1 - \mathbb{E}_1 p(a^H, a^L)\right) + w\mathbb{E}_1 p(a^H, a^L, bs)} \tag{2.17}$$

and the expected payoff from lending on the interbank market is given by

$$\begin{aligned}
V^{1,l} &\equiv V(a^L, a^H, s = l, bs = 1) \\
&= \varphi\, RR(a^L, L) + (1 - \varphi)RR(a^L, L) \\
&= \varphi\left[\theta^L(1 + R)F_{0,IB} + (1 - \theta^L)\lambda(a^L = 0)\right]\mathbb{I}_{[a^L=0]} \\
&+ \varphi\left\{\theta^L(1 + R)F_{0,IB} + (1 - \theta^L)\left[a(1 + R)F_{0,IB} + (1 - a)\lambda(a^L = a)\right]\right\}\mathbb{I}_{[a^L=a]} \\
&+ (1 - \varphi)\left[\theta^H(1 + R)F_{0,IB} + (1 - \theta^H)\lambda(a^H = 0)\right]\mathbb{I}_{[a^H=0]} \\
&+ (1 - \varphi)\left\{\theta^H(1 + R)F_{0,IB} + (1 - \theta^H)\left[a(1 + R)F_{0,IB} + (1 - a)\lambda(a^H = a)\right]\right\}\mathbb{I}_{[a^H=a]}
\end{aligned} \tag{2.18}$$

Due to the assumptions on the probability of a good portfolio outcome $\theta^H > \theta^H$, the parameter restrictions on $\lambda(a^q)$ shown in equation (2.12), and the assumptions on the precision of the financial analysis of bank n made in equation (2.16), the payoff of a bank n whose signal at $d = 1$ identifies the balance sheet quality of bank i as high, that is $s = h$, is strictly larger than the payoff from lending to a bank i for which the financial analysis obtained a signal $s = l$. Hence, the relationship

$$V^{1,h} > V^{1,l} \tag{2.19}$$

holds, which implies that a bank n will always prefer to lend to a bank i for which the financial analysis of bank n generated the signal $s = h$.

The outside option of a bank n is not to rollover the interbank loan at $d = 1$ and refrain from the interbank market in the future. Independent of the true portfolio quality q the proceeds from a fire sale at $d = 1$ are $\underline{\lambda}$. The upper bound for the loss encountered from lending on the interbank market at $d = 0$ is denoted by κ. The value of κ is determined by the hedging strategy of bank n which in turn depends on its risk appetite. Hence, the payoff from not lending on the interbank market at $d = 1$ is given by

$$V^0 \equiv V(bs = 0) = \kappa \geq \underline{\lambda} \tag{2.20}$$

The following properties of the objective function of bank n are derived only for the case of $s = h$. The signs of the partial derivatives of the objective function are true if the assumption made in (2.1),(2.4), and (2.12) hold.[16]

If φ increases because either the signal-to-noise ratio of bank n's financial analysis improves or the expectations about the posterior distribution of p, $\mathbb{E}_1 p$, increases, the expected payoff from interbank lending increases if irrespective of the risk policy a^q the expected payoff from lending to a bank i with balance sheet quality $q = H$ is larger then that from lending to a bank i with balance sheet quality $q = L$.

$$\begin{aligned}
\frac{\partial V^{1,h}}{\partial \varphi} &= \left[(\theta^H - \theta^L)(1+R)F_{0,IB} + (1-\theta^H)\lambda(a^H = 0) - (1-\theta^H)\lambda(a^L = 0)\right] \mathbb{I}_{[a^H = a^L = 0]} \\
&+ (1-a)\left[(\theta^H - \theta^L)(1+R)F_{0,IB} + (1-\theta^H)\lambda(a^H = a)\right] \mathbb{I}_{[a^H = a^L = a]} \\
&- (1-a)\left[(1-\theta^L)\lambda(a^L = a)\right] \mathbb{I}_{[a^H = a^L = a]} \\
&> 0
\end{aligned} \tag{2.21}$$

[16] To obtain the results for $s = l$ just exchange H by L and change the sign of the derivative.

The value of the payoff function strictly increases with the interbank lending rate R.

$$
\begin{aligned}
\frac{\partial V^{1,h}}{\partial R} &= \varphi \left\{ \theta^H F_{0,IB} \mathbb{I}_{[a^H=0]} + \left[\theta^H F_{0,IB} + (1-\theta^H) a F_{0,IB} \right] \mathbb{I}_{[a^H=a]} \right\} \\
&+ (1-\varphi) \left\{ \theta^L F_{0,IB} \mathbb{I}_{[a^L=0]} + \left[\theta^L F_{0,IB} + (1-\theta^L) a F_{0,IB} \right] \mathbb{I}_{[a^L=a]} \right\} \\
&> 0 \qquad (2.22)
\end{aligned}
$$

The partial derivative of $V^{1,h}$ with respect to θ^q is positive because the payoff from supplying liquidity on the interbank market increases with the probability that a bank i with a portfolio of quality $q \in \{L, H\}$ encounters a good portfolio outcome.

$$
\begin{aligned}
\frac{\partial V^{1,h}}{\partial \theta^H} &= \varphi \left[(1+R) F_{0,IB} - \lambda(a^H = 0) \right] \mathbb{I}_{[a^H=0]} \\
&+ \varphi \left\{ (1+R) F_{0,IB} - \left[a(1+R) + (1-a)\lambda(a^H = a) \right] \right\} \mathbb{I}_{[a^H=a]} \qquad (2.23) \\
\frac{\partial V^{1,h}}{\partial \theta^L} &= (1-\varphi) \left[(1+R) F_{0,IB} - \lambda(a^L = 0) \right] \mathbb{I}_{[a^L=0]} \\
&+ (1-\varphi) \left\{ (1+R) F_{0,IB} - \left[a(1+R) + (1-a)\lambda(a^L = a) \right] \right\} \mathbb{I}_{[a^L=a]} \\
&> 0 \qquad (2.24)
\end{aligned}
$$

The partial derivative of $V^{1,h}$ with respect to a is positive as an increase in the probability of a good portfolio outcome of portfolio Y increases the probability that a bank i with a bad portfolio outcome that sets $a^q = a$ at $d = 1$ is able to report positive earnings and hence repays the interbank loan $F_{0,IB}$

$$
\begin{aligned}
\frac{\partial V^{1,h}}{\partial a} &= \varphi(1-\theta^H) \left[(1+R) F_{0,IB} - \lambda(a^H = a) \right] \mathbb{I}_{[a^H=a]} \\
&+ (1-\varphi)(1-\theta^L) \left[(1+R) F_{0,IB} - \lambda(a^L = a) \right] \mathbb{I}_{[a^L=a]} \\
&> 0 \qquad (2.25)
\end{aligned}
$$

Finally, the expected payoff increases if $\lambda(a^H = a)$, $\lambda(a^L = 0)$ or $\lambda(a^H = a)$ increases without violating condition (2.12)

$$
\begin{aligned}
\frac{\partial V^{1,h}}{\partial \lambda(a^H = a)} &= \varphi(1-\theta^H)(1-a)\mathbb{I}_{[a^H=a]} > 0 \qquad (2.26) \\
\frac{\partial V^{1,h}}{\partial \lambda(a^L = 0)} &= (1-\varphi)(1-\theta^L)(1-a)\mathbb{I}_{[a^L=0]} > 0 \qquad (2.27) \\
\frac{\partial V^{1,h}}{\partial \lambda(a^L = a)} &= (1-\varphi)(1-\theta^L)(1-a)\mathbb{I}_{[a^L=a]} > 0 \qquad (2.28)
\end{aligned}
$$

2.2.3 The Analyst

The agent referred to as the analyst processes the earnings information provided by each bank i at $d = 2$.[17] Like a bank n the analyst can neither observe the quality $q \in \{L, H\}$ of bank i nor its risk policy $a^q \in \{0, a\}$ of bank i. In addition, to account for the fact that the interbank lending market is an over-the-counter market it is assumed that the lending decision of a bank n is unobserved by the analyst. However, for a given conjecture about the portfolio decision a^q of bank i and about the lending decision bs of bank n at $d = 1$ in connection with the earnings report of bank i at $d = 2$ the analyst is nevertheless able to compute the posterior $p^{\text{post}} \in \{p^+, p^-\}$ using Bayesian updating.[18]

If at $d = 2$ the earnings report e of bank i is positive, the analyst is able to infer that bank n lent to bank i at $d = 1$. However, it still has to conjecture the risk policy $a^{q,c} \in \{0, a\}$ of bank i because a positive earnings report can be the result of a good portfolio outcome G at $d = 1$, that is, bank i set $a^q = 0$ or the result of a bad portfolio outcome B in connection with the portfolio decision $a^q = a$. Hence, conditional on the conjecture $a^{q,c} \in \{0, a\}$ and $bs = 1$, the reputation of a bank i after a positive earnings report at $d = 2$ is given by

$$
\begin{aligned}
& p^+(a^H, a^L, bs) = P(H|e > 0, a^H, a^L, bs = 1) \\
= & \frac{P(e > 0|H, a^H, a^L, bs = 1)P(H)}{P(e > 0|H, a^H, a^L, bs = 1)P(H) + P(e > 0|L, a^H, a^L, bs = 1)P(L)} \\
= & \frac{\left[\theta^H + (1 - \theta^H)a^H\right] p}{\left[\theta^H + (1 - \theta^H)a^H\right] p + \left[\theta^L + (1 - \theta^L)a^L\right](1 - p)}
\end{aligned} \tag{2.29}
$$

If a bank i reports negative earnings at $d = 2$, the analyst has to have conjectures on both the portfolio decision of bank i as well as the lending policy of bank n because there are three reasons why bank i has to report negative earnings at $d = 2$. First, bank i encountered a bad portfolio outcome and bank n supplied liquidity on the interbank market but bank i set $a^q = 0$. Second, bank i encountered a bad portfolio outcome and set $a^q = a$ but bank n refused to supply liquidity on the interbank market. Third, bank i set $a^q = a$ and bank n supplied liquidity on the interbank market but the outcome of the portfolio Y at $d = 2$ is bad. Hence, if at $d = 2$ the earnings

[17] At this point it is abstracted from strategic interactions in the investment decision of banks i by assuming that the earnings information provided by a bank i at $d = 2$ does not contain any valuable information to update the prior on the balance sheet quality of bank $j \neq i$.

[18] As the balance sheet quality q is not directly observable but the analyst updates its belief about the balance sheet quality q after learning about the earnings of a bank i at $d = 2$, the definition of reputation in this model follows Kreps and Wilson (1982) and Milgrom and Roberts (1982).

report e of bank i is negative and the analyst conjectures that bank i's portfolio policy is given by $a^q \in \{0, a\}$ and a bank n is following lending policy $bs \in \{0, 1\}$, the reputation of a bank i is

$$\begin{aligned} & p^-(a^H, a^L, bs) = P(H|e < 0, a^H, a^L, bs) \\ = & \frac{P(e<0|H, a^H, a^L bs)P(H)}{P(e<0|H, a^H, a^L bs)P(H) + P(e<0|L, a^H, a^L, bs)P(L)} \\ = & \frac{(1-\theta^H)(1-a^H)p\mathbb{I}_{[bs=1]} + p\mathbb{I}_{[bs=0]}}{(1-\theta^H)(1-a^H)p\mathbb{I}_{[bs=1]} + p\mathbb{I}_{[bs=0]} + (1-\theta^L)(1-a^L)(1-p)\mathbb{I}_{[bs=1]} + (1-p)\,\mathbb{I}_{[bs=0]}} \end{aligned} \tag{2.30}$$

If a bank n refuses to lend to a bank i, that is $bs = 0$, a bank i reports negative earnings with probability one independent of the true portfolio quality at $d = 1$ and (2.30) shows that the posterior probability $p^-(a^H, a^L, 0)$ is equal to its prior p. Hence a reduction of the interbank lending activity by bank n at $d = 1$ has an adverse effect on the information conveyed in the earnings signal of a bank i at $d = 2$.

$$p^-(a^H, a^L, 0) = p \tag{2.31}$$

The equivalence of the prior and the posterior belief about the balance sheet quality of a bank i in the case of no interbank lending at $d = 1$ is especially fatal if due to an external shock the prior p about the fraction of banks with a good portfolio quality declines.

In the following derivations it is made use of the invariance property of the policy decision of a bank i given in (2.32).

$$a^H = a^L \tag{2.32}$$

This relationship states that conditional on a bad portfolio outcome at $d = 1$, the policy decision a^q of a bank i is independent of the balance sheet quality q. The reason for this is that the objective function of bank i (2.6) is independent of the portfolio quality q and thus the incentive compatibility constraints used to determine the equilibrium behavior of bank i as well.

The following results confirm the findings in Rajan (1994), however, in the present model the reputation is sensitive to the willingness of bank n to provide liquidity on the interbank market at $d = 1$.

Given that bank n provides liquidity to bank i at $d = 1$ and (2.1), (2.4), and (2.9) hold, the reputation of bank i after a positive earnings report is larger if the conjecture is $a^{q,c} = 0$

$$\begin{aligned}
& p^+(0,0,1) > p^+(a,a,1) \\
\Rightarrow \quad & \frac{\theta^H p}{\theta^H p + \theta^L(1-p)} > \frac{\left[\theta^H + (1-\theta^H)a\right] p}{\left[\theta^H + (1-\theta^H)a\right] p + \left[\theta^L + (1-\theta^L)a\right](1-p)} \\
\Leftrightarrow \quad & \theta^H p(1-p)\left[\theta^L + (1-\theta^L)a\right] > 0
\end{aligned} \tag{2.33}$$

In contrast, after a negative earnings report the conjecture $a^{q,c}$ does not influence the reputation of a bank i which received liquidity on the interbank market at $d = 1$

$$\begin{aligned}
p^-(0,0,1) &= p^-(a,a,1) \\
\Rightarrow \quad \frac{(1-\theta^H)p}{(1-\theta^H)p + (1-\theta^L)(1-p)} &= \frac{(1-\theta^H)(1-a)p}{(1-\theta^H)(1-a)p + (1-\theta^L)(1-a)(1-p)} \\
\Leftrightarrow \quad \frac{(1-\theta^H)p}{(1-\theta^H)p + (1-\theta^L)(1-p)} &= \frac{1-a}{1-a}\frac{(1-\theta^H)p}{(1-\theta^H)p + (1-\theta^L)(1-p)}
\end{aligned} \tag{2.34}$$

Due to the assumptions made in (2.1) and (2.9) and using the result in (2.34), one can show that the reputation of a bank i which reports negative earnings if a bank n does not supply liquidity on the interbank market is higher compared to a negative earnings report if bank n rolls over the interbank loan at $d = 1$. The reason for this result is that even a bank i with a good portfolio outcome G at $d = 1$ has to report negative earnings if a bank n sets $bs = 0$ at $d = 1$.

$$\begin{aligned}
& p^-(0,0,0) > p^-(a,a,1) \\
\Rightarrow \quad & p > \frac{(1-\theta^H)p}{(1-\theta^H)p + (1-\theta^L)(1-p)} \\
\Leftrightarrow \quad & p(1-p)(\theta^H - \theta^L) > 0
\end{aligned} \tag{2.35}$$

Given the relationships (2.33) and (2.34) one can show that the reputation of a bank i after a positive earnings report is strictly larger than the reputation after a negative earnings report if (2.1) holds

$$\begin{aligned}
& p^+(a,a,1) > p^-(0,0,1) \\
\Rightarrow \quad & \frac{\left[\theta^H + (1-\theta^H)a\right] p}{\left[\theta^H + (1-\theta^H)a\right] p + \left[\theta^L + (1-\theta^L)a\right](1-p)} > \frac{(1-\theta^H)p}{(1-\theta^H)p + (1-\theta^L)(1-p)} \\
\Leftrightarrow \quad & \frac{\theta^H}{1-\theta^H} > \frac{\theta^L}{1-\theta^L}
\end{aligned} \tag{2.36}$$

2.3 Equilibrium Bank Behavior

Table 2.3 summarizes each of the agents possible actions, which information each of them has and which actions each one has to guess when deciding about its own actions.

	Bank i	Bank n	Analyst
Information	Portfolio Quality $q \in \{L, H\}$ Portfolio Outcome $\omega \in \{G, B\}$	- -	- -
Guess	Lending Policy bs	Portfolio Risk Decision a^q	Portfolio Risk Decision a^q Lending Policy bs
Actions	Portfolio Risk Decision $a^q \in \{0, a\}$	Lending Policy $bs \in \{0, 1\}$	-

Table 2.3: Agents' Information Sets and Actions

At $d = 1$ a bank i is the only agent in the model that has perfect information about its own portfolio quality $q \in Q = \{L, H\}$ and the portfolio outcome $\omega \in \Omega = \{G, B\}$ when making its portfolio decision $a^q \in \{0, a\}$. Both a bank n and the analyst have only information about the distributions of q and ω and hence need to guess the equilibrium risk policy of a bank i. In addition, the analyst cannot observe the lending policy decision of a bank n as the interbank market is an over-the-counter market and thus it has to guess the equilibrium lending policy of bank n as well. To illustrate the interaction among the agents in the process of guessing an equilibrium strategy, the graph below shows the considerations that each of those agents has to incorporate in that process. A bank i decides on its risk policy a^q conditional on the conjecture about the lending policy of a bank n at $d = 1$ denoted by bs^{ci}. Bank n at $d = 1$ needs to guess an equilibrium strategy for the risk policy of bank i denoted by $a^{q,cn}$ conditional on its own lending policy $bs \in \{0, 1\}$ at $d = 1$. Likewise does the analyst conjecture the equilibrium behavior of a bank i denoted by $a^{q,cp}$ conditional on the conjecture bs^{cp}. An equilibrium of the model exists if

1. conditional on the lending policy of bank n at $d = 1$, the conjectures of bank n and the analyst about the risk policy of bank i coincide, that is, $a^{q,cn}|bs = a^{q,cp}|bs = a^{q,c}|bs$
2. conditional on the lending policy of bank n at $d = 1$, the conjecture $a^{q,c}|bs$ is in line with the actual risk policy of bank i, that is, $a^q|bs = a^{q,c}|bs$
3. conditional on the risk policy of bank i at $d = 1$, the conjectures of bank i and the analyst about the lending policy of bank n coincide, that is, $bs^{ci}|a^q = bs^{cp}|a^q = bs^c|a^q$
4. conditional on the risk policy of bank i at $d = 1$, the conjecture $bs^c|a^q$ is in line with the actual lending policy of bank n, that is, $bs|a^q = bs^c|a^q$

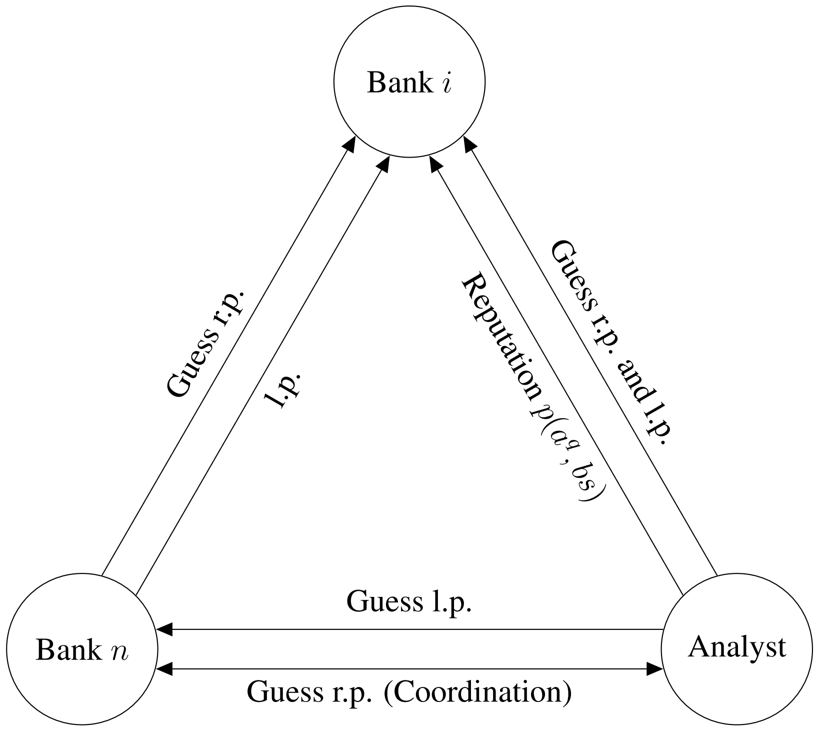


Figure 2.3: Equilibrium Interrelationships

To find the model equilibrium in the following the optimal risk policy a^q of bank i conditional on a conjectured lending policy of bank n is derived. In a second step the conditions under which the conjectured lending policy of bank n satisfies the incentive compatibility constraint of bank n are checked. Because the objective function of bank i given in (2.6) is independent of the quality of the portfolio held by bank i, the incentive compatibility constraints used to derive the optimal portfolio decision of bank i are independent of the portfolio quality q as well. Hence, the derivation of the equilibrium risk policy of bank i will be confined to pooling equilibria and it is not differentiated between a^H and a^L but will use only the term a^q to refer to the risk policy of a bank i. Moreover, as noted in section 2.2.3 the earnings information provided by a bank i at $d = 2$ does not contain any valuable information to update the prior on the balance sheet quality of bank $j \neq i$. In the following the analyst and bank n are referred to as financial market participants. In addition, to simplify notation the size of the interbank loan is set to one, that is, $F_{0,IB} = 1$.

To derive the equilibrium risk policy of bank i and the equilibrium lending policy of bank n one has to set up the incentive compatibility constraints obtained from equation (2.6), (2.11) and (2.18), respectively.

2.3.1 Interbank Lending Equilibrium I

If bank i conditional on observing a negative portfolio outcome B and conditional on its guess $bs^c = 1$ about bank n's lending policy at $d = 1$ decides to set $a^q = a$ the following incentive compatibility constraint has to hold

$$(1-\gamma)\left[-(1-a)\min\left[E_i, LL_X\right] - c\right] + \gamma\left[ap^+(a,a,1) + (1-a)p^-(a,a,\pi)\right] \geq (1-\gamma)(-1) + \gamma p^-(a,a,1) \quad (2.37)$$

where the reputational terms $p^+(a,a,1)$ and $p^-(a,a,1)$ are given by

$$p^+(a,a,1) = \frac{\left[\theta^H + (1-\theta^H)a\right]p}{\left[\theta^H + (1-\theta^H)a\right]p + \left[\theta^L + (1-\theta^L)a\right](1-p)} \quad (2.38)$$

$$p^-(a,a,1) = \frac{(1-\theta^H)(1-a)p}{(1-\theta^H)(1-a)p + (1-\theta^L)(1-a)(1-p)} \quad (2.39)$$

The left hand side and the right hand side of (2.37) represents the expected payoff of setting $a^q = a$ and $a^q = 0$, respectively, conditional on the financial market participants' conjecture $a^{q,c} = a$ and conditional on the conjecture $bs^c = 1$ on the lending policy of bank n. To constitute an equilibrium for bank i the left hand side of (2.37) has to be larger than the right hand side. If this would not be the case bank i would deviate from the equilibrium strategy conjectured by the financial market participants. Hence, bank i will implement a liberal risk policy $a^q = a$ if

$$c \leq a\left[\min\left[E_i, LL_X\right] + \frac{\gamma}{1-\gamma}\left(p^+(a,a,1) - p^-(a,a,1)\right)\right] \quad (2.40)$$

To support such an equilibrium conditional on bank n's guess that bank i will set $a^q = a$, the following incentive constraint of bank n has to be satisfied

$$\begin{aligned} V(a,a,h,1) &= \varphi(a,a,1)\left\{\theta^H(1+R) + (1-\theta^H)\left[a(1+R) + (1-a)\lambda(a^H = a)\right]\right\} \\ &+ (1-\varphi(a,a,1))\left\{\theta^L(1+R) + (1-\theta^L)\left[a(1+R) + (1-a)\lambda(a^L = a)\right]\right\} \\ &\geq \kappa = V(0) \end{aligned} \quad (2.41)$$

where $\varphi(a,a,1,\pi)$ is defined as

$$\varphi(a,a,1) = \frac{r\mathbb{E}_1 p(a,a,1)}{r\mathbb{E}_1 p(a,a,1) + w(1-\mathbb{E}_1 p(a,a,1))} \quad (2.42)$$

with

$$\begin{aligned}\mathbb{E}_1 p(a,a,1) &= \left[p\theta^H + p(1-\theta^H)a + (1-p)\theta^L + (1-p)(1-\theta^L)a\right] p^+(a,a,1) \\ &+ \left[p(1-\theta^H)(1-a) + (1-p)(1-\theta^L)(1-a)\right] p^-(a,a,1) \end{aligned} \tag{2.43}$$

The incentive compatibility constraint (2.41) can be rearranged to give a reliability condition as proposed by Heiner (1983) which links the ability of the individual bank n with the parameters that define the economic environment $v \equiv \{\theta^H,\, \theta^L,\, p,\, a,\, \lambda(a^q)\}$.
Assume that the following relationship holds

$$R_1(H,v) \equiv \theta^H(1+R) + (1-\theta^H)\left[a(1+R) + (1-a)\lambda(a^H = a)\right] > \kappa \tag{2.44}$$

$$R_1(L,v) \equiv \theta^L(1+R) + (1-\theta^L)\left[a(1+R) + (1-a)\lambda(a^L = a)\right] < \kappa \tag{2.45}$$

Given a signal that identifies a balance sheet of bank i as quality $q = H$, the payoff denoted by $R(H,v)$ is the expected return from lending to a bank i whose true balance sheet quality is H, while $R(L,v)$ denotes the expected return from lending to a bank i with balance sheet quality $q = L$ on the interbank market. The corresponding reliability condition is given by

$$\begin{aligned} \frac{r}{w} &> \frac{\overbrace{\kappa - R_1(L,v)}^{\equiv l_1(v)}}{\underbrace{R_1(H,v) - \kappa}_{\equiv g_1(v)}} \frac{1 - \mathbb{E}_1 p(a,a,1)}{\mathbb{E}_1 p(a,a,1)} \\ \Leftrightarrow \quad \frac{r}{w} &> \underbrace{\frac{l_1(v)}{g_1(v)} \frac{1 - \mathbb{E}_1 p(a,a,1,\pi)}{\mathbb{E}_1 p(a,a,1,\pi)}}_{\equiv \mathbb{E}\, T_1(v)} \end{aligned} \tag{2.46}$$

Equation (2.46) shows that a bank n will lend on the interbank market if the actual reliability r/w of bank n's creditworthiness test is larger than the minimum required reliability $T_1(v)$. The former can depend on both the ability of a bank n and the economic environment v. However, due to the assumption that potential interbank lending banks are identical, the actual reliability r/w is constant. The actual reliability r/w has to increase if the loss from lending to a bank with a low balance sheet quality increases or the probability of encountering a bank with a low quality balance sheet in the economy increases. Similarly, the actual reliability r/w is allowed to decrease if the minimum required reliability $T_1(v)$ decreases as either the gain from lending to a bank of quality $q = H$ increases or the posterior probability that a bank i has a high quality balance sheet increases.

2.3.2 Interbank Lending Equilibrium II

If bank i conditional on observing a negative portfolio outcome B and conditional on its guess $bs^c = 1$ about bank n's lending policy at $d = 1$ decides to set $a^q = 0$ the following incentive compatibility constraint has to hold

$$\begin{aligned}(1-\gamma)(-1) + \gamma p^-(0,0,1) \geq \\ (1-\gamma)\left[-(1-a)\min\left[E_i, LL_X\right] - c\right] + \gamma\left[ap^+(0,0,1) + (1-a)p^-(0,0,1)\right] \quad (2.47)\end{aligned}$$

where the reputational terms $p^+(0,0,1)$ and $p^-(0,0,1)$ are given by

$$p^+(0,0,1) = \frac{\theta^H p}{\theta^H p + \theta^L(1-p)} \quad (2.48)$$

$$p^-(0,0,1) = \frac{(1-\theta^H)p}{(1-\theta^H)p + (1-\theta^L)(1-p)} \quad (2.49)$$

Hence, bank i will implement a liberal risk policy $a^q = 0$ if

$$c \geq a\left[\min\left[E_i, LL_X\right] + \frac{\gamma}{1-\gamma}\left(p^+(0,0,1,\pi) - p^-(0,0,1,\pi)\right)\right] \quad (2.50)$$

To support such an equilibrium conditional on bank n's guess that bank i will set $a^q = a$, the following incentive constraint of bank n has to be satisfied

$$\begin{aligned}V(0,0,1) &= \varphi\left[\theta^H(1+R) + (1-\theta^H)\lambda(a^H = 0)\right] \\ &+ (1-\varphi)\left[\theta^L(1+R) + (1-\theta^L)\lambda(a^L = 0)\right] \\ &\geq \kappa = V(0) \quad (2.51)\end{aligned}$$

where $\varphi(0,0,1)$ is defined as

$$\varphi(0,0,1,\pi) = \frac{r\mathbb{E}_1 p(0,0,1)}{r\mathbb{E}_1 p(0,0,1) + w(1-\mathbb{E}_1 p(0,0,1))} \quad (2.52)$$

with

$$\begin{aligned}\mathbb{E}_1 p(0,0,1,\pi) &= \left[p\theta^H + (1-p)\theta^L\right] p^+(0,0,1,\pi) \\ &+ \left[p(1-\theta^H) + (1-p)(1-\theta^L)\right] p^-(0,0,1,\pi) \quad (2.53)\end{aligned}$$

The incentive compatibility constraint (2.51) can be rearranged to obtain a reliability condition. Assume that the relationships

$$R_2(H,v) \equiv \theta^H(1+R) + (1-\theta^H)\lambda(a^H=0) > \kappa \tag{2.54}$$

and

$$R_2(L,v) \equiv \theta^L(1+R) + (1-\theta^L)\lambda(a^L=0) < \kappa \tag{2.55}$$

hold.
Solving (2.51) for r/w results in the following reliability condition

$$\begin{aligned} \frac{r}{w} &> \frac{\overbrace{\kappa - R_2(L,v)}^{\equiv l_2(v)}}{\underbrace{R_2(H,v) - \kappa}_{\equiv g_2(v)}} \frac{1-\mathbb{E}_1 p(0,0,1)}{\mathbb{E}_1 p(0,0,1)} \\ \Leftrightarrow \quad \frac{r}{w} &> \underbrace{\frac{l_2(v)}{g_2(v)} \frac{1-\mathbb{E}_1 p(0,0,1)}{\mathbb{E}_1 p(0,0,1)}}_{\equiv \mathbb{E}\, T_2(v)} \end{aligned} \tag{2.56}$$

2.3.3 No Interbank Lending Equilibrium

Conditional on observing a negative portfolio outcome B and conditional on its guess $bs^c = 0$ about bank n's lending policy at $d = 1$ a bank i has to sell its portfolio irrespective of its portfolio decision $a^q \in \{0, a\}$ at $d = 1$ and reports negative earnings at $d = 2$ with probability one. The value of its objective function is then determined by the following relationship

$$U = (1-\gamma)(-1) + \gamma p^-(0,0,0) \tag{2.57}$$

To support an equilibrium where a bank n irrespective of the portfolio decision $a^q \in \{0, a\}$ does not supply liquidity on the interbank market at $d = 1$ the following incentive constraint has to be satisfied

$$V(0) = \kappa > V(a^q, a^q, s, 1) \tag{2.58}$$

Due to the assumption made in (2.14) and (2.15), $V(0,0,h,1) > V(a,a,h,1)$ holds. Moreover, due to (2.19), $V(0,0,h,1) > V(0,0,l,1)$. Hence, equation (2.58) becomes

$$V(0) = \kappa > V(0,0,h,1) \tag{2.59}$$

where $V(0,0,h,1)$ is defined in (2.51). If $V(0,0,h,1) < \kappa$ holds and bank n engaged in uncollateralized lending at $d = 0$ it strictly prefers not to rollover the loan and executes its option to sell the debt claim at the strike price κ at $d = 1$. In the case of collateralized lending, bank i executes the option to sell the debt claim only if the condition $\underline{\lambda} < \kappa$ holds.
Solving (2.59) for r/w results in the following reliability condition

$$\begin{aligned} \frac{r}{w} &\leq \underbrace{\frac{\overbrace{\kappa - R_2(L,v)}^{\equiv l_2(v)}}{R_2(H,v) - \kappa}}_{\equiv g_2(v)} \frac{1 - \mathbb{E}_1 p(0,0,1)}{\mathbb{E}_1 p(0,0,1)} \\ \Leftrightarrow \quad \frac{r}{w} &\leq \underbrace{\frac{l_2(v)}{g_2(v)} \frac{1 - \mathbb{E}_1 p(0,0,1,\pi)}{\mathbb{E}_1 p(0,0,1,\pi)}}_{\equiv \mathbb{E}\, T_2(v)} \end{aligned} \tag{2.60}$$

2.3.4 Derivation of Equilibrium Regions

After having examined the different equilibria of this model, in the following the thresholds for the costs c encountered by bank i when setting $a^q = a$ as well as the thresholds for the signal-to-noise-ratio r/w which play an essential role in the lending decision of bank n are defined. These thresholds will then be used in the identification of the equilibrium regions. In Rajan (1994) a similar exercise is conducted to determine the thresholds for the cost parameter c. However, due to the lack of an interbank market in Rajan (1994) no thresholds for the signal-to-noise-ratio can be derived.
Based on the incentive constraints of bank i, (2.40) and (2.50), define

$$c' = a\left\{\min\left[E_i, LL_X\right] + \frac{\gamma}{1-\gamma}\left[p^+(a,a,1) - p^-(a,a,1)\right]\right\} \tag{2.61}$$

$$c'' = a\left\{\min\left[E_i, LL_X\right] + \frac{\gamma}{1-\gamma}\left[p^+(0,0,1) - p^-(0,0,1)\right]\right\} \tag{2.62}$$

To determine the relationship between c' and c'', it suffices to evaluate the expressions $p^+(a,a,1) - p^-(a,a,1)$ and $p^+(0,0,1) - p^-(0,0,1)$. From equation (2.34) it is already known that the condition $p^-(a,a,1) = p^-(0,0,1)$ holds. Moreover, in (2.33) it is shown that conditional on bank n providing interbank liquidity, the reputation of a bank i will be strictly larger in the case of a low risk policy, that is, $p^+(0,0,1,\pi) - p^+(a,a,1,\pi) > 0$ holds. Hence, the following condition holds

$$c'' > c' \tag{2.63}$$

Thus, conditional on a bank n supplying liquidity on the interbank market, it will be optimal for bank i to set $a^q = a$ if $c < c'$ holds and $a^q = 0$ if $c > c''$ holds.[19] Similarly, the reliability conditions (2.46) and (2.56) of bank n are used to define thresholds for the actual reliability r/w

$$\left(\frac{r}{w}\right)' = \frac{l_1(v)}{g_1(v)} \frac{1 - \mathbb{E}_1 p(a,a,1)}{\mathbb{E}_1 p(a,a,1)} \tag{2.64}$$

$$\left(\frac{r}{w}\right)'' = \frac{l_2(v)}{g_2(v)} \frac{1 - \mathbb{E}_1 p(0,0,1)}{\mathbb{E}_1 p(0,0,1)} \tag{2.65}$$

To determine the relationship between $(r/w)'$ and $(r/w)''$, each of the components in (2.64) and (2.65) are compared across equations. Given (2.15) a comparison of the losses from falsely lending to a bank with a low balance sheet quality $q = L$ on the interbank market, namely $l_1(v)$ and $l_2(v)$, shows that $l_1(v) > l_2(v)$ holds.

$$l_1(v) \equiv \kappa - R_1(L,v) = \kappa - \theta^L(1+R) + (1-\theta^L)\left[a(1+R) + (1-a)\lambda(a^L = a)\right] \tag{2.66}$$

$$l_2(v) \equiv \kappa - R_2(L,v) = \kappa - \theta^L(1+R) + (1-\theta^L)\lambda(a^L = 0) \tag{2.67}$$

At the same time, due to (2.14) the gain from lending to a bank i of type H increases if a bank i sets $a^q = 0$ instead of $a^q = a$, that is, $g_2(v) > g_1(v)$

$$g_1(v) \equiv R_1(H,v) - \kappa = \theta^H(1+R) + (1-\theta^H)\left[a(1+R) + (1-a)\lambda(a^H = a)\right] - \kappa \tag{2.68}$$

$$g_2(v) \equiv R_2(H,v) - \kappa = \theta^H(1+R) + (1-\theta^H)\lambda(a^H = 0) - \kappa \tag{2.69}$$

As a result of equations (2.66)-(2.69) the following relationship holds

$$\frac{l_1(v)}{g_1(v)} > \frac{l_2(v)}{g_2(v)} \tag{2.70}$$

[19] Given the relationship $c'' > c'$ one can prove that the costs of setting $a^q = a$ outweighs its benefits, that is, $c' > b$ is true. From (2.33) it is known that $p^+(a,a,1) - p^-(a,a,1) > 0$ holds. Hence,

$$c' = b + a\frac{\gamma}{1-\gamma}\underbrace{\left[p^+(a,a,1,\pi) - p^-(a,a,1,\pi)\right]}_{>0}$$

$$\Rightarrow c' > b$$

To pin down the relationship between $(r/w)'$ and $(r/w)''$ one needs to consider the expressions for the expected reputation of bank i as well. Hence, equations (2.43) and (2.53) are analyzed next

$$\begin{aligned}\mathbb{E}_1 p(a,a,1) &= \left[p\theta^H + p(1-\theta^H)a + (1-p)\theta^L + (1-p)(1-\theta^L)a\right] p^+(a,a,1) \\ &+ \left[p(1-\theta^H)(1-a) + (1-p)(1-\theta^L)(1-a)\right] p^-(a,a,1) \qquad (2.71)\\ \mathbb{E}_1 p(0,0,1) &= \left[p\theta^H + (1-p)\theta^L\right] p^+(0,0,1,\pi) \\ &+ \left[p(1-\theta^H) + (1-p)(1-\theta^L)\right] p^-(0,0,1,\pi) \qquad (2.72)\end{aligned}$$

Evaluating the expressions (2.29) and (2.30) one obtains the following results for $\mathbb{E}_1 p(a,a,1)$ and $\mathbb{E}_1 p(0,0,1)$

$$\mathbb{E}_1 p(a,a,1) = \mathbb{E}_1 p(0,0,1) = p \qquad (2.73)$$

Taking together the results derived in (2.70) and (2.73) it holds true that

$$\left(\frac{r}{w}\right)' > \left(\frac{r}{w}\right)'' \qquad (2.74)$$

Given the relationships derived in (2.63) and (2.74) and conditional on obtaining a signal $s = h$ the equilibrium regions of the model are defined as follows

$$\begin{aligned}\left[\frac{r}{w}\right]_h > \left(\frac{r}{w}\right)' \quad &\text{and} \quad c \leq c' \;\Rightarrow\; (a^H = a, a^L = a, bs = 1) \qquad \text{(I)}\\ \left[\frac{r}{w}\right]_h > \left(\frac{r}{w}\right)' \quad &\text{and} \quad c \geq c'' \;\Rightarrow\; (a^H = 0, a^L = 0, bs = 1) \qquad \text{(II)}\\ \left(\frac{r}{w}\right)' \geq \left[\frac{r}{w}\right]_h > \left(\frac{r}{w}\right)'' \quad &\text{and} \quad c \leq c' \;\Rightarrow\; (a^H = 0, a^H = 0, bs = 1) \qquad \text{(III)}\\ \left(\frac{r}{w}\right)' \geq \left[\frac{r}{w}\right]_h > \left(\frac{r}{w}\right)'' \quad &\text{and} \quad c \geq c'' \;\Rightarrow\; (a^H = 0, a^H = 0, bs = 1) \qquad \text{(IV)}\\ \left[\frac{r}{w}\right]_h \leq \left(\frac{r}{w}\right)'' \quad &\;\Rightarrow\; (a^H = 0, a^L = 0, bs = 0) \qquad \text{(V)}\end{aligned}$$

The results in (I)-(V) relate the actual signal-to-noise-ratio of a bank n denoted by $\left[\frac{r}{w}\right]_h$ to the required signal-to-noise-ratio $(r/w)'$ and $(r/w)''$. Case (I) describes the situation where a bank n lends on the interbank market at $d = 1$ conditional on bank i implementing the risk policy $a^q = a$. Conditional on bank i setting $a^q = 0$ a bank n supplies interbank liquidity in case (II). These are the cases included in Rajan (1994). In case (III) the only way for a bank i to obtain liquidity on the interbank market at $d = 1$ is to set $a^q = 0$. While in case (IV) the actual reliability $[r/w]$ of bank n and the costs c of bank i are such that an interbank lending equilibrium where bank i sets $a^q = 0$ is optimal for both counterparties, However, this choice is not optimal from the point of view of bank i, because from the perspective of a bank i the level of c is low enough to set $a^q = a$. Finally in case (V) the probability of bank n supplying interbank liquidity at $d = 1$ is zero because the actual signal-to-noise-ratio of the financial analysis of bank n is so unreliable that independent of the portfolio decision $a^q \in \{0, a\}$ of bank i it prefers not to engage in interbank lending at all. Hence, even if a bank i intends to follow a low risk policy it is denied an interbank loan at $d = 1$.

Conditional on the financial analysis of bank n generating a signal $s = l$ the expression for φ^l using the result (2.73) is defined as

$$\varphi^l = \frac{r(1-p)}{r(1-p) + wp} \tag{2.75}$$

Analogously to the incentive compatibility condition of a bank n after a signal $s = h$, the incentive constraint after observing $s = l$ is given by the following expression

$$V^{1,l} = \varphi^l R_k(L, v) + (1 - \varphi^l) R_k(H, v) > \kappa \tag{2.76}$$

where the payoff of lending to a bank with balance sheet quality $q = L$ and $q = H$ are defined by $R_k(L, v)$ and $R_k(H, v) - \kappa$ respectively for $k \in \{1, 2\}$. Hence, defining $l_k(v) = \kappa - R_k(L, v)$ and $g_k(v) = R_k(H, v) - \kappa$ one obtains the following expression for the reliability condition of a bank n which received a signal $s = l$

$$\left[\frac{r}{w}\right]_l < \frac{g_k(v)}{l_k(v)} \frac{p}{1-p} \tag{2.77}$$

Comparing the expression in (2.77) with (2.46) and (2.56), the relationship between the required reliability across signals s is given by

$$\left[\frac{r}{w}\right]_l = 1/\left[\frac{r}{w}\right]_h \tag{2.78}$$

Hence, if it is assumed that the signal $s = h$ generated by the financial analysis of bank n at $d = 1$ is informative, that is, $[r/w]_h > 1$, a bank n will only lend to a bank i after receiving a signal $s = l$ if the signal $s = l$ is uninformative with respect to the balance sheet quality of a bank i. Thus, by assuming that the signal s is informative irrespective of its value $s \in S = \{l, h\}$ the possibility that a bank n rolls over the interbank loan if the signal $s = l$ is received is excluded and it is not differentiated between $[r/w]_h$ and $[r/w]_l$.

2.4 Discussion

2.4.1 Bank Risk-taking and Interbank Lending Activity

The equilibrium regions (I)-(V) derived in the previous section prove that there exists a relationship between the unobservable balance sheet risk of a bank i and the uncertainty involved in the financial analysis result of bank n. The lower the signal-to-noise-ratio, the lower is the willingness of a bank n to bear the risk involved in the lending activity to a bank i with an unobservable balance sheet quality and hence unobservable level of counterparty risk. The signal-to-noise-ratio increases if for example past financial information is no longer a reliable source due to a structural break in the relationship between variables of interest. If the informativeness of the financial analysis is lower than $(r/w)''$, a bank n refuses to supply interbank liquidity at all at $d = 1$. Hence, the non-provision of interbank liquidity at $d = 1$ is an optimal response to the uncertainty of assessing the counterparty risk involved in interbank lending. The model implications on the relationship between the uncertainty involved in lending and the lending activity are in line with Flannery (1996) who argues that that a lender loses confidence in its own ability to assess the creditworthiness of a potential borrower in times where potential lenders expect that the fundamentals of a counterparty deteriorated.

A potential solution would be to increase the transparency on the risks contained in the bank balance sheets. In terms of the model an increase in transparency corresponds either to a higher actual reliability ratio, that is, transparency influences the left-hand side of the reliability condition derived from the incentive compatibility constraint of bank n. Or transparency lets interbank lending banks revise their prior beliefs about the distribution of balance sheet qualities in the interbank market upward which then in turn decreases the required reliability threshold $T(v)$ which constitutes the right hand side of the reliability condition.

The stress tests conducted by the European Banking Authority (EBA) is an example of a temporary increase in transparency. For these stress tests the major European banks were required to disclose certain positions of their balance sheets. Moreover they provided numbers about their capital adequacy ratio. This information was then used to test the resilience of an individual bank to several shock scenarios. As Figure 2.4 shows did the EONIA trading volumes increase every time the EBA published the results of the stress test. The publication dates are marked by the black vertical lines.[20] However, the effect was only temporary. A possible explanation could be that news which cast doubt on the quality of other asset classes arrived which were not covered in

[20] The red vertical line in April 2009 marks the date of a second G-20 summit where political leaders planned to discuss about the implementation of specific measures which aim at stabilizing the financial system.

the latest stress test. The results for the equilibrium region (III) and (V) present a second impor-

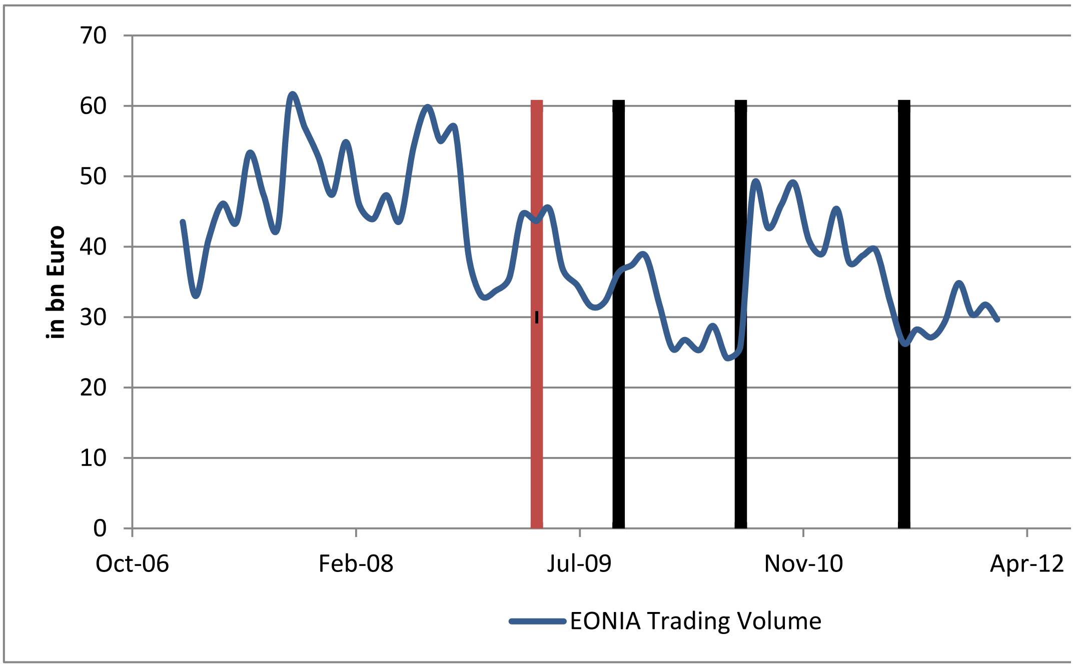


Figure 2.4: EONIA Trading Volumes, Source: Bloomberg

tant implication of this model, namely, that a bank n is able to influence the risk-taking of bank i, even though the interbank market in this model is characterized by asymmetric information about the balance sheet quality of interbank borrowing banks. In the equilibrium region (III) it is optimal for a bank i to set $a^q = a$ as the level of the costs related to this portfolio decision is lower than the threshold c'. However, due to the uncertainty about its own ability to differentiate between a bank with a low quality balance sheet and a bank with a high quality balance sheet, bank n is only willing to supply liquidity on the interbank market if in equilibrium a bank i sets $a^q = 0$. However, in case of $r/w < (r/w)''$ the uncertainty of bank n about the signal s is so low that it prefers not to lend to a bank i at all. At the same time if $r/w > (r/w)'$ a bank n even supports the high risk policy of a bank i. Hence, the market discipline exercised by interbank lending banks in the interbank market can only complement the efforts of the supervisory authorities.

2.4.2 Liquidity Policy

To preserve the stability of the financial system a central bank has an interest that the banks are not forced to sell large parts of their asset portfolio at $d = 1$. Even if the central bank is not

better informed than any other private bank n in the economy, it has the advantage to be able to provide sufficient liquidity to all banks i in the economy at the same time. Compared to a single interbank lending bank n with its restricted amount of liquidity, this is a function that an individual bank n is unable to fulfill. At the same time a central bank can take advantage of the law of large numbers. Hence, for the same level of risk in the economy, liquidity provision by the central bank involves significantly less risk than for a private bank n.
To analyze the effect of a central bank initiative that is intended to provide those banks with liquidity which are otherwise unable to obtain liquidity via the interbank market an additional agent is introduced. The only task of this agent is to inelastically supply liquidity on the interbank market. In the following this agent is called “central bank”. The central bank assumes an active role in the model if it is of the opinion that a bank i is unable to obtain the desired liquidity at $d = 1$. In this case the central bank decides to increase the liquidity supply via its main refinancing operations which enables a bank i to obtain liquidity. As a result of this policy a bank n is no longer involved in the lending process. As a lender of last resort the central bank by assumption does not engage in a financial analysis of individual counterparties. Moreover, the central bank does not conjecture the equilibrium strategy $a^q \in \{0, a\}$. Thus, the portfolio decision a^q of bank i is only restricted by the level of c, that is, the costs related to the risky portfolio decision $a^q = a$. If $c \leq c'$ holds, bank i will set $a^q = a$ and $a^q = 0$ if the costs are too high, that is, if $c \geq c''$ holds.

$$c \leq c' \quad \Rightarrow \quad (a^H = a, a^L = a) \tag{VI}$$

$$c \geq c'' \quad \Rightarrow \quad (a^H = 0, a^L = 0) \tag{VII}$$

The positive effect of the direct liquidity assistance by the central bank in this model is that a bank i in need of liquidity is not forced to liquidate its asset portfolio to obtain the required liquidity. But at the same time the liquidity policy of the central bank impedes the adjustment process which would lead to a new equilibrium which is characterized by a new level of balance sheet risk. As a result the central bank is able to reduce the liquidity risk but the level of counterparty risk remains unaltered as banks are reluctant to actively reduce their exposures. In the model this corresponds to a situation where the earnings reports of a bank i contains no useful information to update the prior belief about the portfolio quality distribution in the interbank market. Hence, the posterior belief is identical to the prior belief. This view is also confirmed by Figure 2.5 which calculates the risk premium for the Euro area as the difference between the three-month EURIBOR and the overnight index swap rate (EONIA). Using CDS prices this risk premium is divided between a credit risk premium and a liquidity risk premium. According to this graph the risk premium in the Euro area interbank market is the result of the counterparty risk prevailing in the market. Another drawback of the liquidity policy is that a central bank

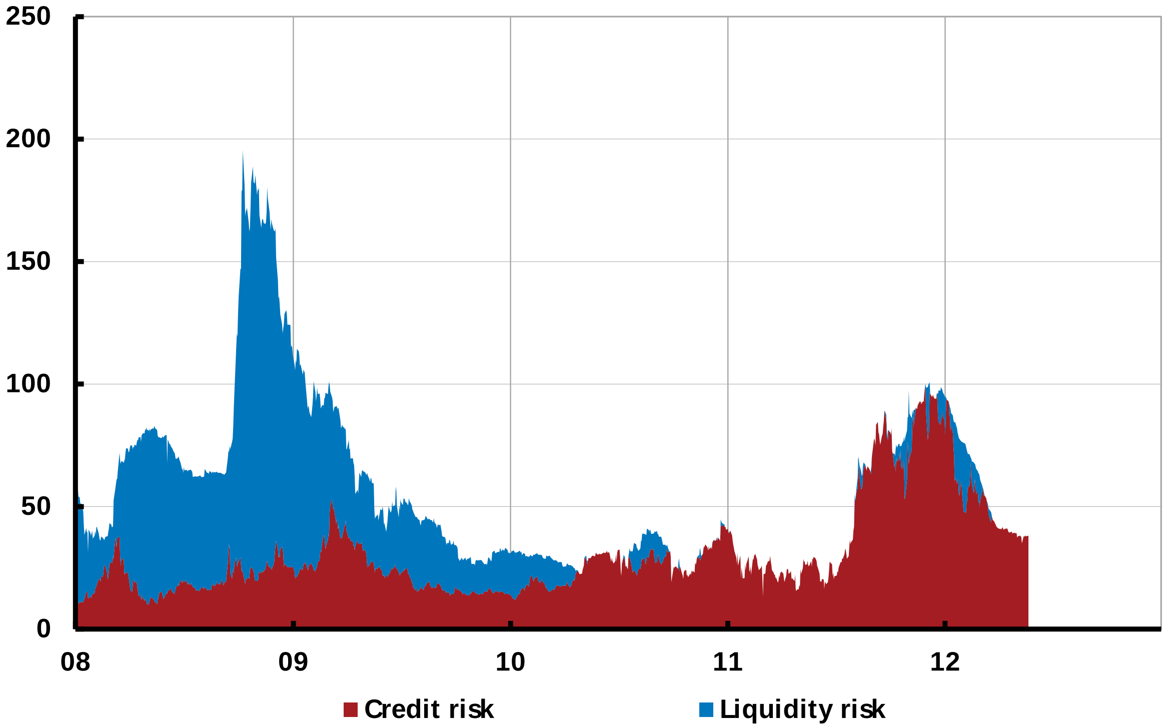


Figure 2.5: Breakdown of the 3-month Risk Premium in the Euro area Interbank Market
Source: Sveriges Riksbank (2012)

cannot control the risk-taking behavior of banks as it supplies liquidity to a bank i inelastically, that is, it does not differentiate between a bank i which demands liquidity to set $a^q = 0$ and a bank i which sets $a^q = a$ and invests the liquidity in a risky portfolio Y with a lower expected return and a higher variance compared to portfolio X. Hence, the liquidity policy of the central bank can lead to a higher overall level of balance sheet risk compared to the market equilibrium where interbank liquidity is provided by interbank lending banks n.

2.5 Conclusion

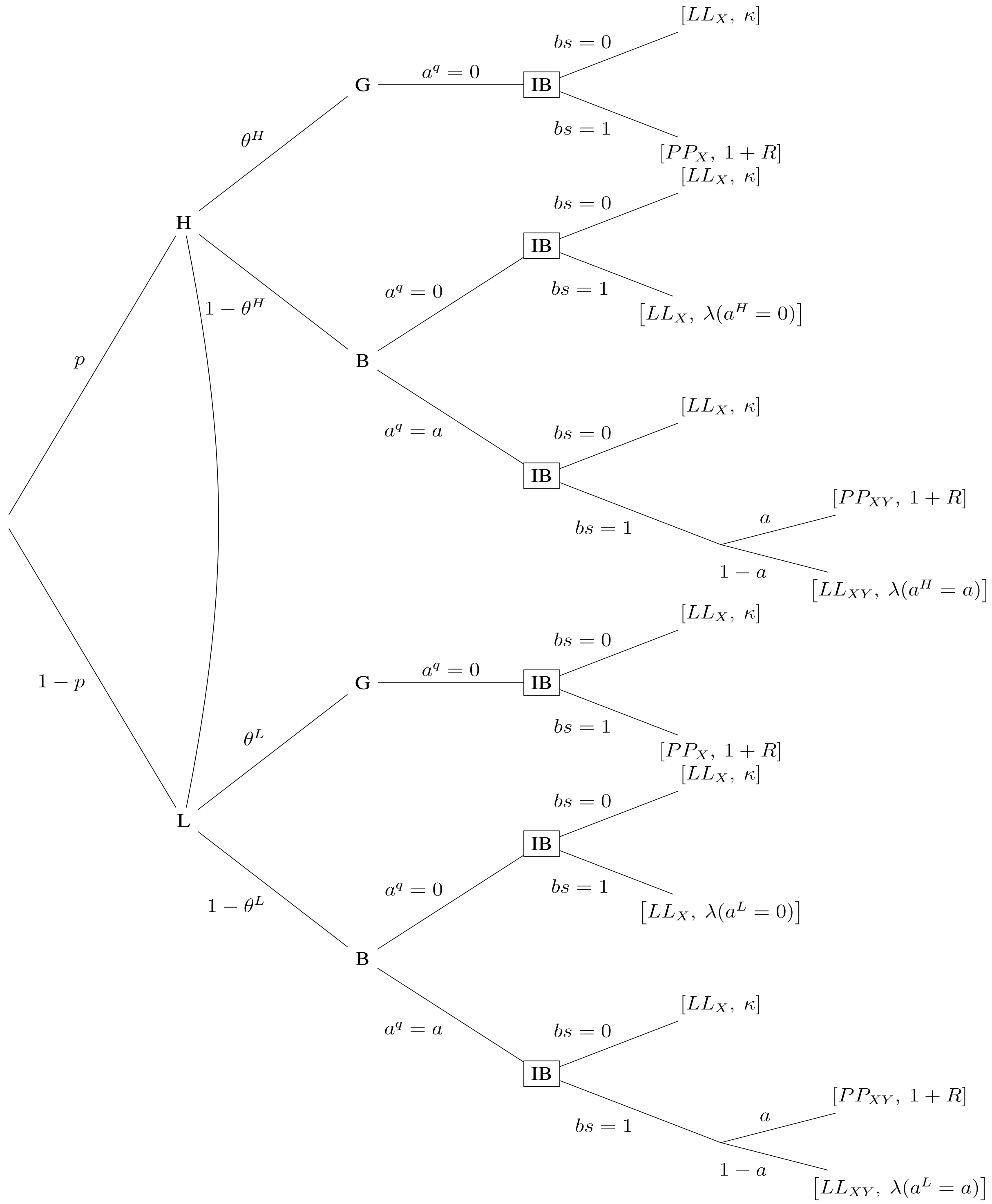
The framework developed in this paper contributes to the literature which tries to explain the behavior of banks on the interbank market and especially the lending behavior of banks in this market. The model consists of interbank borrowing banks which exhibit strategic behavior in their portfolio risk decision and interbank lending banks which have imperfect information about the balance sheet risk of interbank borrowing banks. The model results indicate that the higher the uncertainty about the borrower quality and hence the higher the uncertainty about the counterparty risk involved in interbank lending, the less willing an interbank lending bank is to lend on the interbank market. Moreover, the model implies that under certain conditions interbank lending constitutes a market disciplining device whereby a lending bank is able to influence the risk-taking of the borrowing bank.

According to this model the interbank market can be revived if the supervisory authority imposes higher transparency standards for the reporting of balance sheet risks by banks. Moreover, the model predicts that the level of counterparty risk in the interbank market remains unaltered as the liquidity policy of the central bank inhibits the adjustment process in the balance sheet of an interbank lending bank. Another disadvantage of a central bank's liquidity policy revealed by the present model is that because the central bank supplies liquidity to a bank i inelastically it is unable to control the risk-taking behavior of banks.

A possible avenue for further research would be to allow for multiple refinancing sources by each lending bank. As a result there will be a coordination problem among all interbank lending banks lending to the same bank as the lending decision of one bank will depend on the conjecture about the lending decision of all the other banks. Another possibility to enrich the current analysis is to consider a dynamic setting where each period a new cohort of banks demands liquidity on the interbank market and the lending decision in the current period depends on the posterior probability that a lending bank has a high quality balance sheet. This would allow to make a statement about the persistence of interbank liquidity dry-ups and the effect of the liquidity policy of a central bank on the interbank lending behavior over time. A further extension would be to incorporate explicitly the liquidity policy of the central bank into the strategic decision making process of both an interbank borrowing bank i and an interbank lending bank n. In this case the portfolio decision of a bank i as well as the lending policy of a bank n would become a function of the probability that a bank n obtains liquidity from the central bank at $d = 1$. Finally, at this point no welfare analysis is provided to assess the liquidity policy of a central bank from a normative point of view. Hence a welfare analysis could give a better guideline for the way central banks design their liquidity policies.

Appendix Chapter 2

2.A Decision Tree



Chapter 3

Market Discipline in the German Bank Bond Market: An Empirical Analysis

3.1 Introduction

The third pillar introduced by the Basel Committee on Banking Supervision in the second Basel accords ('Basel II') was intended to strengthen the market discipline by imposing specific disclosure requirements on banks to help market participants in their assessment of a bank's capital adequacy and other risk parameters of an individual bank. The rationale for the introduction of a third pillar was to reduce the asymmetric information between the bank and potential investors and to ensure a continuous monitoring by the market in addition to a less frequent evaluation of a bank by the national supervisory authority. Given the information about a bank's capital adequacy and its exposure to several kinds of risk it is expected that investors' required return is higher the higher the reported risks and the lower the levle of capital which is able to absorb losses stemming from those risks. But do market participants assume the role meant for them by the supervisory authority? Do bank debt holders execute their power to contain bank risk by asking for higher spreads if banks increase their risk-taking?

The agency theory of the firm developed in Jensen and Meckling (1976) and Fama (1980) predicts that in the presence of asymmetric information and costly monitoring, the interests of the decision maker in the firm and the investors in the firm's capital are not aligned and hence the risk taken by the firm might be too high. This provides the rationale for the supervision of banks. The idea that the supervision by market participants complements the efforts by the supervisory authority has been empirically assessed first by Flannery and Sorescu (1996) and Berger et al. (2000). Bliss and Flannery (2001) emphasize that market discipline is a combination of "monitoring" and "influence". The aspect of monitoring by the market participants requires that investors are perfectly informed about a bank's risk level and use this information to determine the fair market price. The second component of market discipline requires that a bank adjusts its level of bank risk given that it is monitored by market participants to avoid an increase in its future funding costs.

Most empirical studies examine market discipline with a focus on monitoring, that is, the first component of market discipline and have a focus on the banking industry in the United States. For example, Flannery and Sorescu (1996), Jagtiani et al. (2002), and Covitz et al. (2004) examine how market discipline was affected by a change to the setup of the Federal Deposit Insurance Corporation introduced by the Federal Deposit Insurance Corporation Improvement Act ("FDICIA"). As a result of this change in the legal framework in 1991 where the US government basically committed itself to a "no bail-out"-strategy, studies which examine US data of the post-FDICIA period find that bondholders are effectively monitoring bank risk. An assessment of the degree of market discipline in the European banking industry has been done by Sironi (2003).

In this paper, we will focus on the monitoring aspect of market discipline and collect evidence on the existence of efficient monitoring of German banks in the bank bond market by testing whether bond holders are sensitive to changes in the riskiness of a bank. The result of this analysis gives regulators a better insight to which extent supervisory authorities can rely on market discipline to keep in check banks' risk-taking. We contribute to the existing literature by constructing a rich data set which contains bond specific and bank specific information to analyze market discipline in the German bank bond market. To our knowledge there is only one other study by Pfingsten, Straeter, and Wissing (2008) which uses German bank data but they focus on deposits of German savings banks. We in contrast use data on commercial banks, savings banks, and credit unions and concentrate on uncovered bank bonds. In addition, we examine if the degree of market discipline varies over time. This is especially interesting in the light of the recent financial crisis which began in August 2007 and peaked in the bankruptcy of Lehman Brothers in September 2008. To tackle this hypothesis, we test for multiple unknown breaks in the relation between bank risk variables and bond spreads. A recent study by Palvia and Patro (2011) uses a panel of large commercial and investment banks in the United States to examine the ability of market participants to monitor the risk-taking behavior of banks. However, while we employ a structural break analysis to endogenously determine the point at which the relationship between bond spreads and certain bank specific variables changes they define the crisis period exogenously.

The paper is organized as follows. In section two, we describe the data and variables used in our analysis. In section three, we test for the existence of market discipline in the German bank bond market and use a structural break analysis to examine if the financial crisis significantly changed the relationship between bank risk and the yield spread. Finally section four concludes.

3.2 Data Description

For our empirical analysis we use data collected at three different levels which are assumed to have an impact on the interest rate a bank has to offer on its bond issue to attract investors. The first subset of variables used in the regression are those related to the level of a single bond issue. Those variables are complemented by variables which convey information on the level of the issuing bank. Finally by incorporating data at the macroeconomic level we account for the general economic environment in which all banks included in the sample operate.

Because we are interested in the effect of bank-specific characteristics on the yield of a bank bond, the bond-specific information as well as the data collected at the macroeconomic level act as control variables to identify the effect of bank-specific variables on the bond yield of an individual bank.

3.2.1 Data Sources

As part of the banking statistics each bank reports several characteristics about their active bond issues to the German Bundesbank on a monthly basis. The data of each bond issue comprises information on the yield of the bond at issuance, the price at which the bond has been sold on the primary market at a specific point in time, the original maturity, the number of months remaining until maturity at the time of the sale, the coupon rate, and the total volume of bonds outstanding for each issue.

In our analysis, we concentrate on the subset of bonds which are listed on the stock exchange to ensure market adequate pricing. We focus our attention on the primary market for bank bonds in order to avoid irregularities, for example, with respect to quoted prices at which no trade has occurred. Usually, banks do not place the entire bond issue at once but rather stretch it over several months or even years. For a large fraction of bonds we therefore have more than one observation over time. On average, we have 14 observations per bond.

The bond specific information covers bank bond issues of fourteen years between January 1998 and January 2011. We deliberately choose to exclude bonds backed by mortgages as well as those secured by loans to the public sector as their yield will by a large extent not depend on the individual characteristics of the issuing institution. Moreover, due to the explicit guarantees on the level of federal states and local governments we exclude bank bond issues by savings banks before August 2005. Furthermore, our sample includes only fixed-coupon bonds and zero-coupon bonds. We explicitly exclude floating rate bonds and non-Euro denominated bonds. Finally, as our focus is on the capital market we exclude all bonds which do not have a maturity or time to maturity of at least 12 months. The evolution of the bond volume comprised of those bonds which satisfy the above criteria are depicted in figure 3.1. From the beginning of the sample until the end of the year 2005 the bond volume issued by the banks included in the sample was more or less constant. In the period from 2006 until 2009 the issued bond volume increases. Especially at the beginning of the year 2008 the bond volume jumped up and remained on a high level until the end of the year 2009. This is explainable by the increased capital demand of banks on the one hand and tensions on the interbank market which led to a shift in the financing sources. The sharp decline in the volume of uncovered bonds since 2009 is caused by a shift to covered bank bond issues which are backed by high quality collateral. Data on bank specific

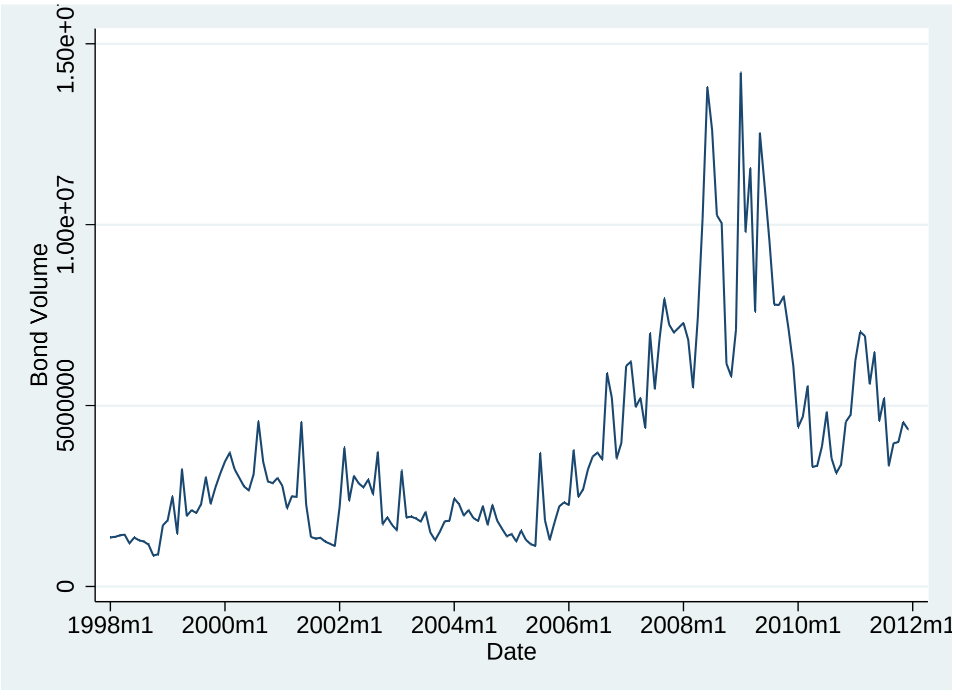


Figure 3.1: Bond Volume

characteristics includes both balance sheet data from the balance sheet statistics reported to the German Bundesbank as well as supplementary data found in various annexes to the balance sheet statistics which allow to obtain more detailed information about specific balance sheet positions. Another source of issuer-specific data is regulatory information which are reported to the German Bundesbank to prove compliance with banking supervision requirements. The frequency of this

data ranges from monthly to yearly. In cases where data is not available on a monthly basis we keep the value fixed until new information is available. Due to different frequencies at which bank specific information is provided, the data on bank specific characteristics is distorted if mergers of banks occurred. In the higher frequency data, the information is based on the merged institution, while the lower frequency data is still based on the pre-merger institution. Therefore, we only take into account those bonds which are issued until the day of the merger and after the end of the year where the merger took place.
Finally, the data on macroeconomic and financial time series are either obtained from the public available macroeconomic time series database provided by the German Bundesbank or from Datastream.

3.2.2 Variables

The dependent variable employed in the regression is the spread between the yield to maturity on a bank bond and the current yield of a German government bond listed on the stock exchange with an equivalent time to maturity. The bond issuing institution reports the yield on a bank bond to the Bundesbank. We also calculate the yield based on the information about the price at the time of the sale, the size of the coupon, and the time to maturity in order to check the correctness of the reported bond yields. The time series for the yield on a German government bond with a given time to maturity is estimated by the Svensson (1994) method which is based on the method developed by Nelson and Siegel (1987) and is available from the macroeconomic time series database of the German Bundesbank. The resulting spread gives an indication about the risk premium required by investors who rather invest in a risky bank bond than in a low risk German government bond. Figure 3.2 depicts the evolution of the median of the spread calculated from the bank bonds contained in the sample together with the spread between the current yield on bank bonds and German government bonds as calculated by the German Bundesbank. Although quantitatively different the median of the spread calculated from the bonds in our sample is a good representation of the spread calculated by the German Bundesbank. We divide the set of independent variables into two subsets: variables of interest and control variables. Bond-specific as well as aggregate macroeconomic and financial time series belong to the latter class, bank-specific variables to the former. In line with the CAMEL approach developed at the U.S. Federal Reserve Bank, we use **C**apital adequacy, **A**sset quality, **M**anagement quality, **E**arnings, and **L**iquidity to assess the quality of a bank. Furthermore, we add balance sheet **s**ize to the analysis. The lower the quality of a bank, the higher is its default risk and ultimately the bank bond's risk premium demanded by investors. Hence, if market discipline is present in the German bank

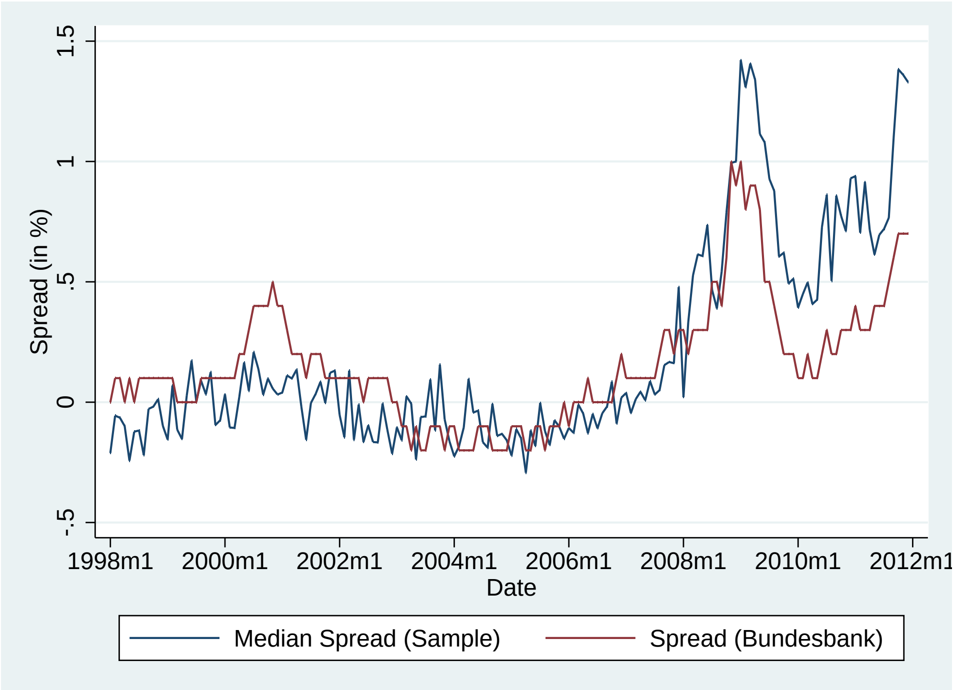


Figure 3.2: Bond Spread

bond market, there should be a negative relationship between the spread and the riskiness of a bank.

Capital adequacy is measured as the ratio of Tier 1 capital to risk weighted assets. If this ratio increases the banks ability to absorb losses increases and the probability of default decreases. Hence, the regression coefficient on the capital adequacy should be negative as it reduces the risk premium of a bank bond. Asset quality will be measured by the ratio of the non-performing loans relative to the size of the overall loan portfolio. Because assets which are held in the trading book need to be marked-to-market it is hard to measure the asset quality of these assets. Nevertheless, as the loan portfolio of banks makes up a large fraction of a bank's balance sheet the non-performing loans ratio is a good proxy to the overall balance sheet quality of a bank. Because those write-offs reduce the capital of a bank and hence reduces the bank's ability to pay interest on the bank bond, we expect that the effect on the spread is positive. Management quality is captured by bank-specific fixed effects as management qualities are not easily observable and are likely to be time-invariant. The earnings situation of a bank will be proxied by the return earned on its assets. Higher profitability generally informs the investor about the success of the investment and business strategy followed by the bank. If the return on assets ("RoA") increases, the bank's profit will increase and hence the probability to fulfill its debt obligations will increase. As a result we hypothesize that there is a negative relationship between the RoA and the spread. The liquidity of a bank is measured as the sum of liquid assets which are defined as those assets which can be quickly turned into cash without being too dependent on the current market environment. These assets comprise the most liquid asset, namely cash, central bank deposits, short-term debt securities issued by the government, and money market funds. We do not include positions from the fixed income and stock portfolio as although they can be regarded as highly liquid they can be sometimes sold only at high discounts. Finally, we include the balance sheet size of a bank in the regression to proxy for the systemic importance of a bank. If a bank maintains a large balance sheet it is expected that it is well-connected to other banks in the financial system. The sign of the coefficient on balance sheet size in the regression depends on the net effect of two counteracting forces. If a bank is highly interconnected with other banks, the probability increases that this bank is affected by shocks emanating from another bank. This effect can be offset by the expectation that such a highly connected bank is deemed as systemically important and hence enjoys the benefit of being rescued by the government. Table 3.1 shows the summary statistics for the bank specific variables in our regression. Except for the earnings variable, we will use the log of the bank specific variables in the regressions.

Variable	Mean	Median	Std.Dev.	Min	Max
Spread (in bps)	26.86	12.20	55.64	-186.30	322.80
Earnings (in %)	0.13	0.14	0.30	-2.30	2.18
Asset Quality (in %)	4.80	3.58	4.19	0.11	29.4764
Capital Adequacy (in %)	9.55	8.55	3.52	4.03	29.06
Liquidity (in %)	1.77	1.40	1.44	0.02	12.76
Size (in bn Euro)	133	3.59	184	~ 0	1910

Table 3.1: Summary Statistics

We now turn to the bond specific control variables. The ease with which the bond can be turned into cash is likely to affect the bond spread. If the bond cannot be turned into cash easily an investor demands an illiquidity premium. Hence, the higher the liquidity of a bond, the lower will be the illiquidity premium and the lower will be the spread. A common liquidity measure first proposed by Fisher (1959) is the volume of bonds outstanding. The hypothesis is that the larger the bond issue, the higher is the trading volume and the higher are the chances that a bond can be easily sold. Because we do not have numbers on the trading volumes of individual bank bonds, we include the volume of a bond issue as a proxy for its trading volume and hypothesize that the coefficient has a negative sign.

Besides bond liquidity we incorporate information on the time to maturity into our regression.

By substracting the yield of a German government bond with an equivalent time to maturity, the effect of the term premium required by an investor as compensation for the longer investment horizon is already partialled out. Therefore, we do not include the time to maturity itself but the distance in months between the time to maturity of the bank bond and the time to maturity of an equivalent German government bond. This is necessary as the smallest difference in the maturities for government bonds is one year. Given the way we define this variable it is expected that the coefficient on this control variable is positive.
Finally, we consider macroeconomic and financial variables which affect all banks alike. To control for the general level of liquidity in the market for bank bonds, we incorporate the volume of outstanding bank bonds across all maturities at each point in time as a measure of aggregate bond liquidity in the regression. We expect to obtain a negative coefficient on this variable, as a higher level of liquidity in the aggregate bank bond market should decrease the illiquidity premium on each individual bond. Because the stock market performance of a company depends on the investor's assessment about the company's future profitability and a stock index reflects the development of the individual stocks contained in that index we include the stock performance subindex "DAX Banks" which contains all listed German banks as a proxy for the general level of profitability among German banks. If the index rises the profitability in the banking sector is expected to increase which decreases the default risk and leads to an increase in bond prices. Thus, the spread should vary negatively with the stock market. As a proxy for the volatility on the German bond market we include the volatility of the German stock index DAX measured by the VDAX. Because a higher volatility in the stock market indicates a higher level of uncertainty and is expected to translate into higher volatility in the bond market as well, our hypothesis is that the effect on the VDAX on the spread variable should be positive.

3.3 Empirical Analysis

In the first part of our empirical analysis, we test whether banks in the bank bond market are subject to market discipline exerted by potential investors. We regress the spread of uncovered bank bonds at the day of their issuance on bank specific characteristics while controlling for bond specific and macroeconomic variables. In the second part, we test whether the enforcement of market discipline changes over time. In order to test for a structural break at unknown time, we use the sequential testing procedure proposed by Bai and Perron (1998) and use the critical values derived therein.

3.3.1 Existence of Market Discipline

In this section, we collect evidence for the existence of market discipline in the German bond market. In doing so, we differentiate between weak and strong form of market discipline. In line with the focus of Basel II on risk-weighted assets and Tier 1 capital, we consider the negative relation between capital adequacy the bond spread as a minimum requirement for market discipline. In short, at least the coefficient of capital adequacy should be significantly different from zero and negative. Basel III emphasizes the so far underestimated importance of liquidity. In line with this, strong market discipline exists if not only the level of a bank's capital adequacy but also liquidity risk is reflected in the price of a bond. The coefficient on liquidity should hence be significant and negative. If only the former and not the latter requirement is fulfilled, we will refer to it as the weak form of market discipline.

In our empirical analysis on the existence of market discipline, we consider the following fixed effects regression:

$$\text{Spread}_{it} = \alpha_i + \alpha_t + \beta_1 c_{it} + \beta_2 a_{it} + \beta_3 e_{it} + \beta_4 l_{it} + \beta_5 s_{it} + \gamma B_{it} + \delta F_t + \varepsilon_{it} \quad (3.1)$$

where α_i denotes the bank specific fixed effects which control for unobservable, time-invariant factors: amongst others but in particular the banks' management quality. The Hausman test confirms that accounting for fixed-effects is necessary: With a p-value of 0.00, we reject the hypothesis that the coefficients of a random effects model and a fixed effects model are equal. Further, we include quarterly time-dummies, α_t, to account for time variation which is not captured by our macroeconomic and financial variables contained in the variable matrix F_t.

In addition to these time variables, we account for the possibility that the overall level of the spread changes in the observed period. In particular, we thought of the recent financial crisis. Therefore, we endogenously determine the structural break-point using the max-F-statistic developed by Andrews (1993). With a test statistic equal to 194, we concluded that the structural break found in December 2007 is significant at the 1%-significance level and incorporated the resulting crisis dummy as another macroeconomic variable in the matrix F_t. The most important variables in our empirical analysis are the variables **c**apital adequacy, **a**sset quality, **e**arnings, **l**iquidity and **s**ize which are included in the regressions to capture bank risk. The bond-specific variables, bond liquidity and maturity are subsumed in matrix B_{it}. Finally, ε_{it} denotes the residual of the fixed effects regression.

Estimation results are reported in the first column of Table 3.2. We do not find evidence for market discipline as neither capital adequacy nor bank liquidity are significant at the 10%-level.

The only variables of interest which are significant are asset quality and size. The positive coefficient of asset quality is significant at the 10% significance level and indicates that investors do price in the risk stemming from non-performing loans. The positive sign for balance sheet size indicates that larger banks have to pay more on their debt. One possible explanation for this result is, that larger banks are expected to be more vulnerable to shocks from the national and international financial system as they are deemed to exhibit a higher degree of connectedness with other financial institutions. This finding can be interpreted as modest evidence against the lack of market discipline as the opposite sign would be in line with the "too-big-to-fail"-hypothesis that large banks are expected to enjoy an implicit state-guarantee. Almost all control variables are significant at least at the 5% significance level and have the correct sign. Exceptions are the market size, which is insignificant, and bond liquidity which has the wrong sign. A reason for the latter might be that the volume of outstanding bonds is a poor proxy for liquidity. However, the sign of the latter is robust across several proxies for bond liquidity such as the bond liquidity relative to the total bond volume in that period, the Amihud ratio proposed in Amihud (2002) or the bond age. To include bond age is motivated by the observation of Sarig and Warga (1989) that the liquidity of a bond decreases with its age. Based on our previous definition we conclude that there is no evidence for market discipline although we find some weak evidence for risk-adequate pricing.

In order to ensure that our results are not driven by outliers, we conduct an outlier analysis. To that aim, we compute the standard deviation of the residual ε_{it} from the fixed effects regression (3.1). An observation is then defined to be an outlier if the corresponding residual is larger (smaller) than (minus) two standard deviations. In that way, we identify and eliminate 454 observations as they have the potential to distort the regression results. The spreads removed from the sample range from -402 bps to +4625 bps. The estimation results of the outlier adjusted sample can be found in the second column of Table 3.2.

While the fit of the model, in terms of R-squared, has increased notably from 0.19 to 0.54, the adjustment changes the estimation results only quantitatively. Neither capital adequacy nor liquidity are significant at the 10% level. In contrast to the estimation on the whole sample, asset quality becomes insignificant and earnings become significantly positive at the 10% significance level. Unexpectedly, investors seem to associate a high return on assets with more risk since they demand a higher risk premium. Coefficients and significance of the control variables do not change notably, with the expectation of the market size which becomes significant and has the expected sign. To conclude, despite of a better fit, the estimation results do not convey evidence on the existence of market discipline.

Independent Variables	whole sample coefficient	std.dev.	outlier adjusted coefficient	std.dev.
Earnings	0.979	[2.193]	1.524*	[0.899]
Log(Asset Quality)	0.021*	[0.012]	-0.005	[0.005]
Log(Capital Adequacy)	0.035	[0.038]	0.017	[0.016]
Log(Liquidity)	0.008	[0.009]	-0.004	[0.004]
Log(Size)	0.086**	[0.040]	0.081***	[0.016]
Log(Bond Market Size)	-0.641	[0.458]	-1.205***	[0.187]
Log(Stock Market)	-0.487***	[0.077]	-0.383***	[0.032]
Stock Market Volatility	0.004**	[0.002]	0.005***	[0.001]
Crisis Dummy	0.316***	[0.057]	0.334***	[0.023]
Bond Liquidity	0.022***	[0.003]	0.022***	[0.001]
Time to maturity (residual)	0.219***	[0.017]	0.172***	[0.007]
Observations		26483		26029
Number of Banks		148		148
R-squared		0.192		0.540

Note: We include bank-fixed effects and time dummies for all quarters except for 1998Q1. Standard errors in brackets. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3.2: Fixed Effects Regression before and after Outlier Adjustments

The sample exhibits a large amount of heterogeneity as it contains both small regional institutes as well as large, global players. Although we include both bank fixed effects in order to account for differences in the management quality and the business model as well as a bank's balance sheet size to account for the size and importance of an individual bank, we decide to split up the sample into three groups according to a bank's size. In line with Penas and Unal (2004) we define a bank as small if its share in the total assets of the German banking system is lower than 0.35%.[1] Moreover, a bank is referred to as large if the fraction of its total assets relative to the total assets of the German banking system is larger than 2%. The estimation result of the three subsamples can be found in Table 3.3.[2] Again, we do not find evidence for market discipline in the German bank bond market: While capital adequacy is not significant at the 10% level for small and large banks, it is significant at the 1% level for medium size banks. However, the sign differs from the sign we expected. Investors seem to deem banks with less capital to be more profitable ignoring the potential risk this bears. Earnings remain significant for medium and large banks. Asset

[1] The total assets of the German banking system is provided by Deutsche Bundesbank in its macroeconomic time-series database

[2] As the outlier analysis is performed independently for the full sample and the subsamples by bank size the number of banks and the observations across the three subsamples do not add up to the numbers from the full sample.

Independent Variables	All Banks spread	Small spread	Medium spread	Large spread
Earnings	1.524*	2.302	4.763**	5.631***
	[0.899]	[1.777]	[2.044]	[1.558]
Log(Asset Quality)	-0.005	0.068***	-0.011	-0.038***
	[0.005]	[0.008]	[0.011]	[0.010]
Log(Capital Adequacy)	0.017	0.036	0.176***	0.040
	[0.016]	[0.029]	[0.032]	[0.034]
Log(Liquidity)	-0.004	-0.007	-0.070***	0.061***
	[0.004]	[0.005]	[0.005]	[0.010]
Log(Size)	0.081***	0.158***	0.263***	-0.112***
	[0.016]	[0.017]	[0.067]	[0.043]
Log(Bond Market Size)	-1.205***	-0.341	-0.472*	-2.677***
	[0.187]	[0.235]	[0.256]	[0.384]
Log(Stock Market)	-0.383***	-0.166***	-0.381***	-0.701***
	[0.032]	[0.045]	[0.044]	[0.061]
Stock Market Volatility	0.005***	0.007***	0.004***	0.005***
	[0.001]	[0.001]	[0.001]	[0.002]
Crisis Dummy	0.334***	0.260***	0.310***	0.367***
	[0.023]	[0.036]	[0.033]	[0.041]
Bond Liquidity	0.022***	0.022***	0.033***	-0.004
	[0.001]	[0.002]	[0.002]	[0.003]
Time to maturity (residual)	0.172***	0.178***	0.170***	0.141***
	[0.007]	[0.008]	[0.010]	[0.014]
Observations	26029	8770	8008	9139
Number of Banks	148	122	24	12
R-squared	0.540	0.476	0.593	0.604

Note: We include bank-fixed effects and time dummies for all quarters except for 1998Q1
Standard errors in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3.3: Fixed Effects Regression Results II

quality exhibits a significantly positive sign in line with risk-adequate pricing for small banks but the opposite and significant sign for large banks. Liquidity is significantly negative indicating market discipline for medium sized banks but is significantly positive for large banks. Size is significantly positive for small and medium-sized banks. Interestingly, in contrast to the estimation results for the full sample which did not support the "too-big-to-fail"-hypothesis after splitting up the sample the coefficient on size becomes significant and negative for large banks which is actually in line with the "too-big-to-fail"-hypothesis that banks can refinance themselves cheaper due to an implicit state guarantee.

3.3.2 Time Variance of Market Discipline

To examine if at least for specific periods we are able to identify market discipline in the German bank bond market we allow for two structural breaks at unknown time in our bank-specific variables (not including bank fixed effects). For the determination of the breaks we resort to the sequential testing procedure proposed by Bai and Perron (1998) and for inference purposes to the critical values derived therein. The equation used for the sequential testing procedure is given below:

$$Spread_{it} = \alpha_i + \alpha_t + \beta_0 X_{it} + \sum_{j=1}^{m} \beta X_{it}\, D_t(\lambda_j) + \gamma B_{it} + \delta F_t + \epsilon_{it} \tag{3.2}$$

The matrix X_{it} contains the bank specific variables capital adequacy, asset quality, earnings, liquidity and size. For those variables, we endogenously determine two break dates and test for their significance. The variable $D_t(\lambda_j)$ is a step dummy variable defined as follows:

$$D_t(\lambda_j) = \begin{cases} 1\,, & t = [\lambda_j T] + 1, \ldots, [\lambda_{j+1} T] \\ 0\,, & \text{else} \end{cases} \tag{3.3}$$

where m takes the values 1 or 2 depending on the number of breaks tested. In the former case, $j = 1$, in the latter case $j = 1, 2$. The parameter λ_j varies in the interval $[\varepsilon, 1 - \varepsilon]$ where the restriction $\frac{T_j - T_{j-1}}{T} \geq \varepsilon = 0.05$ ensures that there are at least 9 months (=5% of all month) between two breaks. The first endogenous break point is the one for which the joint F-tests on $X_{it}\, D_t(\lambda_1)$ is largest. In order to determine whether this break is significant, we compare the test statistic with the critical values tabulated by Bai and Perron (1998) for $m = 1$. The analysis is repeated for the subsample before and after the first break. The second break date, λ_2 is the one for which the F-test statistics computed for both subsamples is largest. Again, significance is determined using the tabulated critical values for $m = 2$. The tables with the regression results are found in

Appendix 3.A

We test for a structural break in the full sample and detect two structural breaks: The first in April 2008 and the second in September 2009. In Table 3.4, coefficients and standard deviations of our variables of interest in the three different time periods are presented. Based on our definition of market discipline, we do not find evidence for market discipline before September 2009. However, in the period September 2009 until the end of the sample period in January 2012, the coefficients of capital adequacy and of liquidity have the correct sign and are significant at the 1% level. Hence, we conclude that the German bank bond market exhibits strong market discipline since September 2009. In addition, the coefficient of asset quality related to the amount of non-performing loans is positive and significant at the 1% level. In addition, earnings are positively related to the spread which is in line with our expectations in case market discipline does exist. It is interesting to observe that the coefficient of capital adequacy is positive before April 2008, is insignificant for the period between the first and second break point, and becomes negative for the time period after September 2009. Qualitatively the same development can be observed for liquidity as well. The coefficient of liquidity is insignificant before April 2008 but becomes highly significant and has the correct sign thereafter. This can be interpreted as a sign of an increase in the awareness of investors that banks are subject to liquidity risk after April 2008. To conclude, the structural break analysis reveals that for the time after September 2009 the German bank bond market is characterized by strong market discipline.

We refine the structural break analysis and examine if the change in the market discipline in the full sample can be attributed to a subset of banks. For that reason we assign, as before, each bank to one of three subsets according to their balance sheet size relative to the sum of total assets of the German banking system. Based on the structural break analysis for each subset of banks we find that neither small nor large banks are responsible for the compliance with the strong definition of market discipline observed in the full sample.

For the subset of small banks we find only one significant break in March 2008. From the estimation results depicted in Table 3.5 in Appendix 3.A we conclude that there is evidence for strong market discipline before March 2008 but no evidence for market discipline afterwards. A tentative explanation for this result is, that investors usually expect that small banks are allowed to fail and therefore price their risk adequately. However, in the crisis, investors might have seen the credit supply-oriented business model especially of small savings banks and unions as "save haven" compared to larger banks. In line with that, asset quality measured by the fraction of non-performing loans became more important since the crisis.

Estimation results for the subsample of large banks are shown in Table 3.7 in Appendix 3.A. We find weak market discipline as the sign capital adequacy is negative and significant at the 1% level after the first break detected in January 2005 and continues to be significant and negative after the second break in October 2009. However, liquidity is not adequately priced throughout the sample period. This might be the case because investors expect that large institutions will receive emergency liquidity assistance if their liquidity is seriously constrained. Interestingly, the coefficient of size is positive before 2005, as is the case for the smaller banks. However, after 2005, size reduces the bond spread providing evidence for the "too-big-to-fail"-hypothesis. This refinancing advantage comes to an end after the end of 2009, when the coefficient of size becomes insignificant. An explanation for this result might be the increased international effort to ensure that large institutions can fail without causing unbearable costs to the real economy. Examples of such efforts are discussions in the context of Basel III on living wills as well as the adoption of a EU law on bank resolution.

From the estimation results presented in Table 3.6 in Appendix 3.A we conclude that the subsample of medium size banks drives the results of the overall sample. The coefficient of capital adequacy indicates that only after the second break point in November 2009, a higher Tier 1 capital ratio decreases the spread between the bank bond and an equivalent German government bond. The coefficient of liquidity is negative and highly significant for the whole sample period. This indicates, that investors increase their risk premium in case of an increase in liquidity risk and do not expect medium sized banks to receive emergency liquidity assistance. From our findings, we conclude that medium size banks are subject to the strong form of market discipline after November 2009.

Based on the empirical analysis conducted we conclude that it is important to distinguish between small, medium and large banks and at the same time to allow for structural breaks to be able to confirm the existence of market discipline in the German bank bond market. Due to this approach, we detected that small banks have been subject to the strong form of market discipline only until roughly the outburst of the recent financial crisis. In contrast, large banks are subject to the weak form of market discipline since 2005 and the degree of market discipline did not change in response to the recent crisis. In addition, it is worthwhile mentioning that the "too-big-to-fail-subsidy" came to an end in late-2009. For medium sized banks we find evidence that they are subject to strong market discipline since November 2009. Overall, the results can be interpreted as positive. Since 2009, market discipline is in place for medium and large banks. However, policy makers must stick to their proposed reform agenda as it is important to conserve the existing level of market discipline.

3.4 Conclusion

In this paper, we construct a dataset which contains both bank specific and bond specific information to analyze whether bank bond spreads in the primary market respond to the riskiness of banks if one controls for bond specific and macroeconomic effects. In line with the CAMEL approach developed at the U.S. Federal Reserve Bank, we focus our attention on the bank specific variables capital adequacy, asset quality, earnings and liquidity and additionally size. In our analysis, we differentiate between weak and strong form of market discipline. In line with the focus of Basel II on risk-weighted assets and Tier 1 capital, we consider the negative relation between capital adequacy and the bond spread as a minimum requirement for market discipline to exist. Basel III emphasizes the so far underestimated importance of liquidity. In line with this, strong market discipline exists if not only capital adequacy but also liquidity risk is considered in the market price of a bank bond in the primary market. If only the former and not the latter requirement is fulfilled we will refer to it as the weak form of market discipline.

The results of our paper suggest that it is important to distinguish between small, medium and large banks and at the same time to allow for structural breaks in order to uncover market discipline in the German bank bond market. In a first step we analyze if the German bank bond market as a whole shows signs of weak or strong market discipline by means of a fixed effects regression. The regression results indicate that bond spreads in the German bank bond market do not show signs of market discipline. Neither of the strong nor of the weak form. In a second step we split up the sample into three groups according to a bank's size and examine if market discipline is more important for a subsample of banks. The results vary across subsamples but for neither of the subsamples the existence of market discipline can be confirmed for the whole sample period. In the last step of our empirical analysis we allow for two structural breaks to examine if the market discipline within each of the subsamples has been subject to variations over time given that market discipline could not be confirmed for the whole sample period in the previous step. In this step we found out that small banks have been subject to strong market discipline only until roughly the outburst of the recent financial crisis. Large banks are considered as being weakly disciplined by the bond market since 2005. In addition the degree of market discipline exerted on large banks did not change as a reaction to the recent financial crisis. However, it is worthwhile mentioning that since late-2009 banks no longer enjoy a refinancing advantage because of their sheer size. Another interesting result found in this last step of our empirical analysis is that medium sized banks are strongly disciplined by markets since November 2009.

Overall we come to the conclusion that since the beginning of the financial crisis the German bank bond market exhibits at least a weak form of market discipline for bonds issued by medium size and large banks. However, policy makers must stick to their proposed reform agenda as market discipline has to be conserved. To foster market discipline, policy makers must ensure that investors obtain sufficient information to evaluate the risk of an individual bank. Furthermore, in order to give investors an incentive to exercise market discipline, policy makers must take measures which ensure that each bank can fail without causing unbearable damage to the financial system. Things are going in the right direction. On a G20-level, regulators are working on closing data-gaps for regulatory but also external use. In Germany, the “Restrukturierungsgesetz” was a first step in order to make an orderly bank resolution more credible. However, more actions have to be taken especially in the direction of keeping liquidity risk under control. Current developments in connection with Basel III regarding a net stable funding ratio and a liquidity coverage ratio aim at a regulatory solution to this problem. However, the regulatory control exerted by debt markets should not be left aside. In order to give debtholders an incentive to price liquidity risk correctly, for example, emergency liquidity assistance must be kept at a minimum.

The current analysis can be extended to the secondary market for bank bonds as well if it can be ensured that the secondary market prices reported are based on trades and not on quotes on which no bond turnover has been generated. Another interesting extension would be to complement the data on losses in the loan portfolio by data on losses made in the bank’s trading book or at least obtain data on write-offs to the banking book. Such data would be interesting as in Germany banks were more affected by losses on their security portfolio than by losses on their loan portfolio. At the moment the size of a bank enters only linearly. Hence, the effect of increasing its size is independent of the level from which a bank starts. However, if there exists a frontier above which a bank is considered as too-big-to-fail, then the effect of size on the bond spread is expected to be a step function. After a bank crossed this threshold the effect on the bond yield is expected to be constant.

Appendix Chapter 3

3.A Structural Break Analysis

		All Banks	
Independent Variables	01/1998-03/2008	04/2008-08/2009	09/2009-01/2012
Earnings	2.303*	-0.558	4.463**
	[1.247]	[1.462]	[1.795]
Log(Asset Quality)	0.018***	-0.070***	0.030***
	[0.006]	[0.009]	[0.010]
Log(Capital Adequacy)	0.107***	0.030	-0.158***
	[0.018]	[0.022]	[0.020]
Log(Liquidity)	0.003	-0.074***	-0.049***
	[0.004]	[0.007]	[0.006]
Log(Size)	0.049***	0.140***	0.133***
	[0.016]	[0.016]	[0.017]
Test Statistic		181.70***	63.03***
	Observations	Number of Banks	R-squared
	26029	148	0.561

Note: We include bank-fixed effects and time dummies for all quarters except for 1998Q1
Standard errors in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3.4: Structural Break Analysis: All Banks

		Small Banks	
Independent Variables	01/1998-02/2008	03/2008-01/2012	
Return on Assets	12.988**	2.002	
	[5.624]	[1.782]	
Log(Asset Quality)	-0.027*	0.059***	
	[0.015]	[0.008]	
Log(Capital Adequacy)	-0.150***	0.123***	
	[0.034]	[0.030]	
Log(Liquidity)	-0.051***	-0.007	
	[0.012]	[0.005]	
Log(Size)	0.119***	0.177***	
	[0.017]	[0.017]	
Test Statistic		48.13***	
	Observations	Number of Banks	R-squared
	8770	122	0.490

Note: We include bank-fixed effects and time dummies for all quarters except for 1998Q1
Standard errors in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3.5: Structural Break Analysis: Small Banks

		Medium Sized Banks	
Independent Variables	01/1998-11/2007	12/2007-10/2009	11/2009-01/2012
Return on Assets	7.993***	63.102***	-36.990***
	[2.571]	[4.106]	[3.954]
Log(Asset Quality)	0.088***	-0.074***	-0.016
	[0.016]	[0.016]	[0.019]
Log(Capital Adequacy)	0.245***	0.136***	-0.148***
	[0.035]	[0.045]	[0.038]
Log(Liquidity)	-0.029***	-0.142***	-0.074***
	[0.007]	[0.009]	[0.009]
Log(Size)	0.269***	0.345***	0.334***
	[0.070]	[0.069]	[0.070]
Test Statistic		108.34***	101.46***
	Observations	Number of Banks	R-squared
	8008	24	0.642

Note: We include bank-fixed effects and time dummies for all quarters except for 1998Q1
Standard errors in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3.6: Structural Break Analysis: Medium Size Banks

		Large Banks	
Independent Variables	01/1998-12/2004	01/2005-09/2009	10/2009-01/2012
Return on Assets	-14.820**	-0.646	21.824***
	[6.299]	[1.808]	[3.197]
Log(Asset Quality)	-0.126***	-0.116***	-0.101***
	[0.048]	[0.014]	[0.025]
Log(Capital Adequacy)	0.313**	-0.262***	-0.234***
	[0.135]	[0.039]	[0.062]
Log(Bank Liquidity)	0.059*	0.037***	0.038**
	[0.031]	[0.011]	[0.017]
Log(Assets)	0.346***	-0.348***	0.074
	[0.104]	[0.064]	[0.048]
Test Statistic		51.48***	46.29***
	Observations	Number of Banks	R-squared
	9139	12	0.625

Note: We include bank-fixed effects and time dummies for all quarters except for 1998Q1
Standard errors in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3.7: Structural Break Analysis: Large Banks

Bibliography

V. V. Acharya and O. Merrouche. Precautionary hoarding of liquidity and inter-bank markets: Evidence from the sub-prime crisis. NBER Working Papers 16395, National Bureau of Economic Research, Inc, Sept. 2010.

V. V. Acharya, D. Gromb, and T. Yorulmazer. Imperfect competition in the interbank market for liquidity as a rationale for central banking. *American Economic Journal: Macroeconomics*, 4 (2):184–217, April 2012.

T. Adrian and H. S. Shin. Money, liquidity, and monetary policy. *American Economic Review:Paper&Proceedings*, 99:2:600–605, 2009.

G. Afonso, A. Kovner, and A. Schoar. Stressed, not frozen: The federal funds market in the financial crisis. *Journal of Finance*, 66(4):1109–1139, 08 2011.

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

F. Allen, E. Carletti, and D. Gale. Interbank liquidity and central bank intervention. *Working Paper*, 2009a.

F. Allen, E. Carletti, and D. Gale. Interbank market liquidity and central bank intervention. *Journal of Monetary Economics*, 56(5):639–652, July 2009b.

Y. Amihud. Illiquidity and stock returns: cross-section and time-series effects. *Journal of Financial Markets*, 5(1):31–56, January 2002.

D. W. K. Andrews. Tests for parameter instability and structural change with unknown change point. *Econometrica*, 61:821–56, 1993.

I. Angeloni, E. Faia, and R. Winkler. Exit strategy. *Working Paper*, 2010.

A. Ashcraft, N. Garleanu, and L. H. Pedersen. Two monetary tools: Interest-rates and haircuts. *Working Paper*, 2010.

A. Ashcraft, J. Mcandrews, and D. Skeie. Precautionary reserves and the interbank market. *Journal of Money, Credit and Banking*, 43:311–348, October 2011.

J. Bai and P. Perron. Estimating and testing linear models with multiple structural changes. *Econometrica*, 66:47–78, 1998.

A. N. Berger, S. M. Davies, and M. J. Flannery. Comparing market and supervisory assessments of bank performance: Who knows what when? *Journal of Money, Credit and Banking*, 32(3): 641–67, August 2000.

B. Bernanke and M. Gertler. Monetary policy and asset price volatility. *Economic Review*, pages 17–51, 1999.

B. Bernanke and M. Gertler. Should central banks respond to movements in asset prices. *American Economic Review Papers and Proceedings*, 91(2):253–257, 2001.

B. Bernanke, M. Gertler, and S. Gilchrist. *The financial accelerator in a quantitative business cycle framework*, volume 1, chapter 21, pages 1341–1393. Handbook of Macroeconomics, 1999.

S. Bhattacharya and D. Gale. Preference shocks, liquidity and central bank policy. In W. A. Barnett and K. J. Singleton, editors, *New Approaches to Monetary Economics*, chapter 4, pages 69–88. Cambridge University Press, 1987.

O. J. Blanchard and M. Watson. *Bubbles, Rational Expectations and Financial Markets*. Wachtel, Crises in the Economic and Financial Structure, 1982.

R. R. Bliss and M. J. Flannery. Market discipline in the governance of u.s. bank holding companies: Monitoring versus influencing. In *Prudential Supervision: What Works and What Doesn't*, NBER Chapters, pages 107–146. National Bureau of Economic Research, Inc, 2001.

V. Borgy, J.-S. Mesonnier, T. Laubach, and J.-P. Renne. Fiscal policy, default risk and euro area sovereign bond spreads. *Working Paper*, 2011.

T. Broecker. Credit-worthiness tests and interbank competition. *Econometrica*, 58(2):429–52, March 1990.

G. Calvo. Staggered prices in a utility maximizing framework. *Journal of Monetary Economics*, 12:383–398, 1983.

S. G. Cecchetti, H. Genberg, and S. Wadhwani. Asset price in a flexible inflation targeting framework. *NBER Working Paper Series*, (8970), 2002.

I. Christensen and A. Dib. The financial accelerator in an estimated new keynesian model. *Review of Economic Dynamics*, 11:155–178, 2008.

D. M. Covitz, D. Hancock, and M. L. Kwast. A reconsideration of the risk sensitivity of u.s. banking organization subordinated debt spreads: a sample selection approach. *Economic Policy Review*, (Sep):73–92, 2004.

V. Curdia and M. Woodford. The central-bank balance sheet as an instrument of monetary policy. *Working Paper*, 2010.

G. DeWalque, O. Pierrard, and A. Rouabah. Financial(in)stability, supervision and liquidity injections: a dynamic general equilibrium approach. *Working paper*, 2009.

A. Dib. Banks, credit market frictions and business cycles. *Working paper*, 2009.

C. Ewerhart and J. Tapking. Interbank lending, collateral, and the 2007 liquidity crisis. *Working paper*, 2008.

E. F. Fama. Agency problems and the theory of the firm. *Journal of Political Economy*, 88(2): 288–307, April 1980.

L. Fisher. Determinants of risk premiums on corporate bonds. *Journal of Political Economy*, 67: 217, 1959.

M. J. Flannery. Financial crises, payment system problems, and discount window lending. *Journal of Money, Credit, and Banking*, 28(4):804–824, 1996.

M. J. Flannery and S. M. Sorescu. Evidence of bank market discipline in subordinated debenture yields: 1983-1991. *Journal of Finance*, 51(4):1347–77, September 1996.

X. Freixas and J. Jorge. The role of interbank markets in monetary policy: A model with rationing. *Journal of Money, Credit and Banking*, 40(6):1151–1176, 2008a.

X. Freixas and J. Jorge. The role of interbank markets in monetary policy: A model with rationing. *Journal of Money, Credit and Banking*, 40(6):1151–1176, 09 2008b.

A. Gerali, S. Neri, L. Sessa, and F. Signoretti. Credit and banking in a dsge model. *mimeo; Bank of Italy*, 2009.

M. Gertler and P. Karadi. A model of unconventional monetary policy. *Working Paper*, 2009.

M. Gertler and N. Kiyotaki. Financial intermediation and credit policy in business cycle analysis. *forthcoming in: Hankbook of Monetary Economics*, 2010.

G. Gorton and A. Metrick. Haircuts. *Yale ICF Working Paper No. 09-15*, 2009.

F. Heider, M. Hoerova, and C. Holthausen. Liquidity hoarding and interbank market spreads: The role of counterparty risk. Working Paper Series 1126, European Central Bank, Dec. 2009.

R. A. Heiner. The origin of predictable behavior. *American Economic Review*, 73:560–595, 1983.

M. Iacoviello. House prices, borrowing constraints, and monetary policy in the business cycle. *American Economic Review*, 95(3):739–764, June 2005.

J. Jagtiani, G. Kaufman, and C. Lemieux. The effect of credit risk on bank and bank holding company bond yields: Evidence from the post-fdicia period. *Journal of Financial Research*, 25(4):559–575, 2002.

M. C. Jensen and W. H. Meckling. Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4):305–360, October 1976.

A. Justiniano, G. E. Primiceri, and A. Tambalotti. Investment shocks and business cycles. *Journal of Monetary Economics*, 57(2):132–145, March 2010.

N. Kiyotaki and J. Moore. Credit cycles. *Journal of Political Economy*, 105(2):211–48, April 1997.

D. M. Kreps and R. Wilson. Reputation and imperfect information. *Journal of Economic Theory*, 27(2):253–279, August 1982.

B. Markovic. Bank capital channels in the monetary transmission mechanism. *Bank of England, Working Paper No.313*, 2006.

P. Milgrom and J. Roberts. Predation, reputation, and entry deterrence. *Journal of Economic Theory*, 27(2):280–312, August 1982.

C. R. Nelson and A. F. Siegel. Parsimonious modeling of yield curves. *The Journal of Business*, 60(4):473–89, October 1987.

A. A. Palvia and D. K. Patro. Re-examining the role of market discipline for bank supervision: Evidence from the subprime crisis. January 2011, 2011.

M. F. Penas and H. Unal. Gains in bank mergers: Evidence from the bond markets. *Journal of Financial Economics*, 74(1):149–179, October 2004.

A. Pfingsten, N. Straeter, and D. Wissing. Market discipline at german savings banks. September 2008.

G. E. Primiceri. Time varying structural vector autoregressions and monetary policy. *Review of Economic Studies*, 72:821–852, 2005.

R. G. Rajan. Why bank credit policies fluctuate: A theory and some evidence. *Quarterly Journal of Economics*, 109(2):399–441, 1994.

R. Repullo. Liquidity, risk taking, and the lender of last resort. *International Journal of Central Banking*, 1(2):47–80, September 2005.

J.-C. Rochet and J. Tirole. Interbank lending and systemic risk. *Journal of Money, Credit and Banking*, 28(4):733–62, November 1996.

J.-C. Rochet and X. Vives. Coordination failures and the lender of last resort: Was bagehot right after all? *Journal of the European Economic Association*, 2(6):1116–1147, December 2004.

O. Sarig and A. Warga. Bond price data and bond market liquidity. *Journal of Financial and Quantitative Analysis*, 24(03):367–378, September 1989.

A. Schabert. Optimal central bank lending. *Working Paper*, 2010.

A. Sironi. Testing for market discipline in the european banking industry: Evidence from subordinated debt issues. *Journal of Money, Credit and Banking*, 35(3):443–72, June 2003.

J. H. Stock and M. W. Watson. Has the business cycle changed and why? In *NBER Macroeconomics Annual 2002, Volume 17*, NBER Chapters, pages 159–230. National Bureau of Economic Research, Inc, 2003.

L. E. O. Svensson. Estimating and interpreting forward interest rates: Sweden 1992-1994. IMF Working Papers 94/114, International Monetary Fund, Sept. 1994.

Sveriges Riksbank. Financial stability report 2012:1. Technical report, Sveriges Riksbank, 2012.

J. Taylor. Discretion versus policy rules in practice. *Carnegie-Rochester Series on Public Policy*, 39:195–214, 1993.

J. B. Taylor and J. C. Williams. A black swan in the money market. *American Economic Journal: Macroeconomics*, 1(1):58–83, January 2009.