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In 2011 all ECB publications feature a motif taken from the €100 banknote.

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CONTENTS

Abstract

In this paper we set up a New-Keynesian model that features an interbank market. The introduction of an interbank market is important to analyze liquidity problems among heterogenous agents within the financial sector. First, because this allows for a situation where increased liquidity supply by the central bank is only partially passed on to the interbank market. Second, this framework allows us to analyze one additional policy measure besides the common interest rate policy undertaken by central banks to alleviate the liquidity shortage on the interbank market. Namely haircuts on eligible assets in repurchase agreements ("Repos"). By varying haircuts applied to securities that serve as collateral in repurchase agreements the stress on the interbank market can be mitigated by bringing down the interest rate charged among banks. Furthermore an exogenous bubble process is modeled which enables us to examine the effects of a deviation of the market price of capital from its fundamental price. This leads to a discussion whether central banks should "lean against the wind", i.e. react to deviations of asset prices in the setting of their policy instrument. Finally, this paper tries to shed some light on the "exit strategy" that a central bank should follow after the asset price bubble bursted and the interbank market begins to work properly again.

JEL codes: E4, E5, E61, G21

KEYWORDS: DSGE, MONETARY POLICY, COLLATERAL, HAIRCUTS, EXIT STRATEGY

Non-technical Summary

The way central banks conduct monetary policy changed with the onset of the crisis. Central banks started not to rely exclusively on traditional interest rate policy but also prolonged the maturities for repurchase agreements and widened the set of collateral accepted in repurchase agreement transactions. To enable economists to analyze the macroeconomic consequences of a central bank resorting to a richer set of monetary policy tools requires to implement an interbank market in modern macroeconomic models. 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)).

We set up a New-Keynesian model that features a financial sector that consists of two different types of banks, commercial banks and "investment banks" that buy and sell liquidity on an interbank market. Commercial banks accept deposits from households and grant loans to entrepreneurs, i.e. the entrepreneur combines her net worth with a commercial bank loan to purchase her capital stock employed in production. We introduce a borrowing constraint in a borrower-lender relationship as in Iacoviello (2005) and more recently in Gerali *et al.* (2009). However, in our model the financial friction arises in the relationship between the commercial banks and the "investment banks" where the commercial bank's ability to obtain interbank liquidity is limited by the asset portfolio she can offer as collateral. Another unique feature of the setup is that the "investment banks" are the only banks which are able to enter into repurchase agreements with the central bank and hence are the only banks in direct contact with the central bank. Another feature incorporated in the model is the distinction between the fundamental price of capital, Q, equivalent to Tobin's Q and the market price of capital, S, which considered by the commercial bank sector to assess the collateral value. In terms of modeling these two variables we relied on the setup introduced by Bernanke and Gertler (1999). To enhance the monetary policy toolkit we introduce a haircut policy employed to securities that the central bank accepts as collateral in repurchase agreements with investment banks.

The results of Dib (2009) show that a financial sector helps to dampen monetary policy shocks to the real economy. This is also true for our model, however, in addition we can show that if bubbles exist in prices used to value collateral the financial sector amplifies shocks to the real economy. 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. However, both financial and macroeconomic volatility are lowest if asset price deviations are taken into consideration in the haircut rule. Finally after the burst of an asset price bubble which results in a recession a central bank thinking about an exit strategy should always communicate the exit date and credibly stick to it to ensure a smooth evolution of macroeconomic aggregates. Agents' expectations formation contributes then to a smoothing of key variables.

1 Introduction

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, (Volcker (April 8, 2008), Remarks by Paul Volcker at a Luncheon of the Economic Club of New York)

In the twenty years preceding the current financial crisis all major economies have witnessed low macroeconomic volatility. Hence, for central banks it seemed to be sufficient to concentrate on setting its policy instrument to stabilize the interbank rate around its desired level. However, 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 prolonged the maturities for Repos and widened the set of collateral accepted in Repo transactions. The latter is equivalent to a reduction in the haircut applied to specific types of assets not accepted before and aims at reviving the interbank market and stabilizing the economy.

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 *et al.* (1999) or Markovic (2006) banks are financial intermediaries who channel funds between borrowers and lenders and who 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 heterogenous financial sector that consists of two different types of banks whose behavior is the outcome of explicit optimization problems and who trade central bank reserves amongst each other on the interbank market. Although Dib (2009) contains an interbank market it is different from the definition of an interbank market we use. He 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 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. On the other hand studies that examine interbank liquidity flows are, for example Ewerhart and Tapking (2008), Allen *et al.* (2009) and Freixas and Jorge (2008), do not employ a DSGE framework. Our model also features a borrowing constraint in a borrower-lender relationship as in Iacoviello (2005) and more recently in Gerali *et al.* (2009). However, in our model the financial friction arises in the relationship between the commercial banks and the "investment banks" where the commercial bank's ability to obtain interbank liquidity is limited by the asset portfolio she can offer as collateral.

Another unique feature of the model setup employed in this paper is that the "investment banks" are the only banks which are in direct contact with the central bank to enter into repurchase agreements. This modeling strategy is based on the observation that usually central banks conduct their Repo transactions with only a limited number of participants. In the case of the Fed there are merely nineteen counterparts ("Primary Dealer"). The ECB in contrast lists about 2500 banks as eligible counterparties. However, actually only a limited number of eligible counterparties constantly take part in the main refinancing operations conducted by the ECB.

In most DSGE models (Smets and Wouters (2003), Christiano *et al.* (2005)) central bank behavior is represented by an interest rate rule. Only recently several studies deal with unconventional monetary policy, e.g. Gertler and Karadi (2009) and Gertler and Kiyotaki (2010). These two papers, however, focus on the the extraordinary role of central banks as a direct lender to enterprises. Our study, however, models a central bank which is not involved in direct lending to entrepreneurs but rather to banks. We think that this is a much more realistic assumption when considering the behavior of central banks during the recent financial crisis. An extensive study of unconventional monetary policy with a huge emphasis also on the central bank's balance sheet has recently been done by Curdia and Woodford (2010). What separates their paper from ours is the missing interaction of banks on the interbank sector.

Another feature that distinguishes our study from other studies mentioned above is the distinction between the fundamental price of capital, Q, equivalent to Tobin's Q and the market price of capital, S, which is considered by the commercial bank sector to assess the collateral value. In terms of modeling these two variables we relied on the setup introduced by Bernanke and Gertler (1999) who extend the BGG model by distinguishing between the fundamental and market price of capital. 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.

Finally as a second major monetary policy instrument besides the interest rate we introduce a variable haircut employed to securities that the central bank accepts as collateral in repurchase agreements with investment banks. In this context recent papers by Ashcraft *et al.* (2010), Adrian and Shin (2009), Curdia and Woodford (2010), and Schabert (2010) needs to be mentioned. The first paper builds on a model with overlapping generations whereas the second one is not model based but purely empirical. In the work of Schabert (2010) the central bank lends to households directly and there is no banking sector at all. In addition to the studies mentioned above there is a working paper by Goodfriend and McCallum (2007) that deals with haircuts.

The results of Dib (2009) show that a financial sector helps to dampen monetary policy shocks to the real economy. This is also true for our model, however, in addition we can show that if bubbles exist in prices used to assess the value of collateral the financial sector amplifies shocks to the real economy. Other major results of this paper are that a lower haircut has a major, positive impact on the whole economy in the short run. The only drawback is an increase in inflation after the liquidity supply has increased. Furthermore we show that Bernanke and Gertler (1999) were correct in their conclusion of not including asset prices in the interest rate rule. The incorporation of asset prices in the haircut rule, however, reduces immensely the macroeconomic volatility in simulated boom-bust cycles. Finally after the burst of an asset price bubble which results in a recession a central bank thinking about an exit strategy should always communicate the exit date and credibly stick to it to ensure a smooth evolution of macroeconomic aggregates.

This paper is structured in the following way. In Section 2 the model setup is explained. The calibration to the data is shown in Section 3. We proceed in chapter 4 by stating important results such as impulse response functions, comparative statics and the exit strategy. Section 5 finally concludes.

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). The households consume a final good sold by the retailer and supply 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 can save by holding deposits with the commercial bank who uses these deposits together with interbank liquidity obtained from the investment bank to grant loans to entrepreneurs. In the relationship between the commercial bank and the entrepreneur 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 banks: commercial banks and "investment banks". By definition investment banks do neither lend nor borrow to households. The amount of interbank liquidity a commercial bank can obtain from the investment banks depends on the value of the collateral the commercial bank can offer. The collateral value depends both on the size of the collateral pool as well as the market price S. To obtain liquidity from the central bank, the investment bank has two assets at its disposal: government bonds and financial claims on the asset portfolio of commercial banks. However, the central bank decides which assets she accepts as collateral in repurchase agreements and at what price and hence about the liquidity supplied vis-a-vis the investment bank sector. In this section the model setup and the optimization problems faced by each agent are explained. First order conditions are completely delegated to the appendix.

2.1 Households

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:

$$U_t = \frac{C_t(h)^{1-\gamma_c}}{1-\gamma_c} + \frac{(1-L_t(h))^{1-\gamma_h}}{1-\gamma_h} \quad (1)$$

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

$$C_t(h) + D_t(h) = W_t L_t(h) + \frac{R^D_{t-1}}{\pi_t} D_{t-1}(h) + P_t(h) - T_t(h) \quad (2)$$

Households save in the form of one-period deposits that they cede the commercial banks at a gross interest rate 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, investment banks, the central bank and retailers. $T_t(h)$ are the lump sum taxes that the government collects from household h.

2.2 Entrepreneurs

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

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \quad (3)$$

Technology 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 her net worth N_t needs to be financed by a loan B_t taken out from the commercial bank.

$$B_t = Q_t K_{t+1} - N_t \quad (4)$$

The interest rate charged on loans is R^B_t. Bernanke *et al.* (1999) show that an external finance premium results from the financial contract signed between a bank and the firm. Dib

(2009) implemented this financial contract in a model with a banking sector. The expected external marginal finance 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 over the net worth and is given by the following function:

$$R_{t+1}^S = \frac{R_t^B}{\pi_{t+1}} \left(\frac{S_t K_{t+1}}{N_t} \right)^{\psi} \tag{5}$$

The external finance premium given by $(S_t K_{t+1}/N_t)^{\psi}$ depends on the entrepreneur's leverage ratio. As $S_t K_{t+1}/N_t$ increases, the borrower increasingly relies on uncollateralized borrowing. If the parameter ψ is set to zero, the financial accelerator vanishes and the mark up is zero. 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. The aggregate net worth position of entrepreneurs is evolving as

$$N_t = \nu \left[R_t^S S_{t-1} K_t - \left(R_t + \frac{\mu \int \omega dF(\omega) R_t^S S_{t-1} K_t}{S_{t-1} K_t - N_t} \right) (S_{t-1} K_t - N_t) \right] + (1-\alpha)(1-\Omega) A_t K_t^{\alpha} H_t^{(1-\alpha)\Omega} \tag{6}$$

with ν and ω being the survival probability of the entrepreneur and the default probability of the project the entrepreneur invests in, respectively. 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 BGG model and allows to model exogenous asset price bubbles[1].

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

$$R_t^Q = \frac{\left(R_t^k + (1-\delta) Q_t\right)}{Q_{t-1}} \tag{7}$$

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

$$R_t^S = \frac{\left(R_t^k + (1-\delta) S_t\right)}{S_{t-1}} \tag{8}$$

Finally a relation is needed to link the fundamental return and the market return on capital

$$R_t^S = R_t^Q \left(b + (1-b)(1-(1-a)\frac{(S_{t-1} - Q_{t-1})}{S_t} + \epsilon_t^{SQ} \right) \tag{9}$$

[1] for an introduction on asset price bubbles also refer to the seminal paper by Blanchard and Watson (1982)

The parameter a determines the speed of convergence back to the fundamental price Q_t and b is given by $b \equiv a(1-\delta)^2$. 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.

2.3 Capital Producers

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

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

The aggregate capital stock evolves according to:

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

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 can be found, e.g. in Dib (2009).

2.4 Retailers

To motivate sticky prices we introduce the Calvo price setting Calvo (1983) as is common in the New-Keynesian literature. This means that each period a fraction $1 - \xi_p$ of retailers can change their prices. 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 R maximizes takes the form:

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

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 $P_t^w \equiv \frac{P_t}{X_t}$ is the nominal price of wholesale goods, with X_t as the gross markup.

[2]in the case of rational bubbles Blanchard and Watson (1982) this value would be one.

2.5 Commercial Bank

The commercial bank maximizes over both the interest R_t^D and R_t^B and takes the interest rate on the interbank market R_t^{IB} as given. The commercial bank's liability side comprises deposits $D_t(j)$ and interbank funds $IB_t(j)$ obtained from households and investment banks, respectively. These funds are invested by providing loans $B_t(j)$ to entrepreneurs which constitute the asset side of the commercial bank's balance sheet.

Table 1: Balance sheet of commercial bank j

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

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

$$\Pi_t^{CoB} = \frac{R_{t-1}^B}{\pi_t}B_{t-1}(j) - \frac{R_{t-1}^D}{\pi_t}D_{t-1}(j) - \frac{R_{t-1}^{IB}}{\pi_t}IB_{t-1}(j) \tag{10}$$

$$- \frac{\kappa_d}{2}\left(\frac{R_{t-1}^D}{R_{t-2}^D} - 1\right)^2 \frac{R_{t-1}^D}{\pi_t}D_{t-1}(j) - \frac{\kappa_b}{2}\left(\frac{R_{t-1}^B}{R_{t-2}^B} - 1\right)^2 \frac{R_{t-1}^B}{\pi_t}B_{t-1}(j) \tag{11}$$

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

$$D_t(j) = \left(\frac{R_t^D(j)}{R_t^D}\right)^{\epsilon_d} D_t \tag{12}$$

$$B_t(j) = \left(\frac{R_t^H(j)}{R_t^H}\right)^{-\epsilon_h} B_t \tag{13}$$

The pledge of the entrepreneurs contains the fundamental value of capital. However, as soon as the collateral is pledged to the commercial bank, in an act of securitization, the commercial banks take the market price of capital S_t into account and not the fundamental price Q_t. In return for the loan the commercial bank obtains collateral worth Q_tK_t. However the loan granted is only $Q_tK_t - N_t$. So we assumed that the commercial bank can only partially securitize its loan portfolio. So both components S_tK_t and N_t are weighted by the parameter o. This assumption is necessary because otherwise part of the financial market would be decoupled from the rest of the economy and would no longer need real activity to survive on its own[3]. Asset-backed securities are then defined as

$$ABS_t^{CoB}(j) = (K_t(j)E_t(S_{t+1}))^\tau - (N_t)^{\tau-1} \tag{14}$$

The commercial bank is also subject to a borrowing constraint vis-a-vis the investment bank, i.e. in order to obtain interbank liquidity the commercial bank pledges its asset backed securities as collateral. This constraint takes the following form:

$$R_t^{IB} IB_t \leq m_t ABS_t^{CoB} \tag{15}$$

where m_t is the loan-to-value ratio that is set to 0.75 in steady state and responds to deviations of the market price of capital from the fundamental price, u_t, to incorporate the reluctance of "investment banks" 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[4]:

$$m_t = \rho_m m_{t-1} - 2 \cdot u_t + \epsilon_t^m \tag{16}$$

We assume that the borrowing constraint is satisfied with equality. Gerali *et al.* (2009) use also a similar borrowing constraint and refer to Iacoviello (2005) when assuming that it is always binding if the size of the shock is sufficiently small such that the economy remains in the neighborhood of the steady-state.

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

$$B_t(j) = D_t(j) + IB_t(j) \tag{17}$$

2.6 Investment Banks

The investment bank[5] in our set acts as a friction on the interbank market and behaves as an agent on its own. The motivation for the modeling of a hierarchical interbank market is twofold. First due to the structure found in the US where only Primary Dealers are able to deal with the central bank whereas a vast group of commercial banks is not allowed to directly deal with the monetary authority. Second, while in Europe in theory about 2500 banks are allowed to participate in the bidding process in main refinancing operations of the ECB only about 12% [6] participate regularly. The other banks rely on interbank funding.

[3]Christiano *et al.* (2007) assume similarly that entrepreneurial net worth is not accumulated over time but consumed every period by consumers and entrepreneurs every period so that loans are still needed and that capital cannot only be acquired by net worth

[4]In section 4.4 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

[5]The investment bank in our model should not be confused with the common notion of an investment bank and its responsibilities in the real world

[6]Gray and Stella (2008)

Therefore we see this modeling strategy as a feasible way to represent the structure found in reality. Unlike the commercial bank, the "investment bank" does not maximize over an interest rate but with respect to interbank lending and excess reserves. The interest rate on the interbank market R_t^{ib} is the outcome of the profit-maximizing behavior of both the commercial bank and the "investment bank". She takes the policy rate R_t set by the central bank as given. The liabilities of the individual investment bank consist of the central bank liquidity obtained via OMOs. The assets are composed of loans to commercial banks and excess reserves.

Each investment bank maximizes its profit function which has the following form.

Table 2: Balance sheet of the Investment Bank

Assets	Liabilities
Interbank Loans $IB_t(k)$	Loans from CB $M_t^D(k)$
Excess Reserves $X_t(k)$	

$$\Pi_t^{PD}(k) = R_t^{Spread}\left(IB_t(k) + M_t^D(k) - X_t(k)\right) + R_t IB_t(k) - R_t^{IB} M_t^D(k) + R_t^{IB} X_t(k) \quad (18)$$

which is mathematically the same as $R_t^{IB} IB_t(k) - R_t(M_t^D(k) - X_t(k))$ but emphasizes that the investment bank 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[7].

$$R_t^{Spread} = R_t^{IB} - R_t \quad (19)$$

We assume that investment bank's demand for central bank liquidity depends on the optimally chosen value for interbank lending and excess reserves as follows[8]:

$$M_t(k) = IB_t(k)^{\zeta} X_t(k)^{1-\zeta} \quad (20)$$

Unlike the Cobb-Douglas production function that takes labor and capital as input factors and yields goods as output, this one takes the other route and uses money M as sole input factor and delivers interbank funds and excess reserves output in its maximization calculus. The investment bank also faces a constraint when taking out a Repo loan from the central bank.

$$M_t^D(k) = G_t(k) + (1 - h_t) ABS_t^{PD}(k) \quad (21)$$

The liquidity obtainable by each individual investment bank is denoted by $M_t^D(k)$. The right hand side shows the two types of collateral accepted by the central bank: government bonds G_t and asset-backed securities $ABS_t(k)$. However, if the latter can be used as collateral in Repo transactions depends on the decision of the central bank. If $h_t = 1$ the central bank

[7] Compare also Graph 2 with the interbank rate fluctuating around the policy rate

[8] Excess reserves can be interpreted as a riskless investment opportunity for the investment bank

does not accept ABS as collateral in Repo transactions. 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. The lower it gets, the higher the volume of ABS accepted or put differently, it applies a lower discount to risky securities. Government bonds are set such that the liquidity demand equation (21) is satisfied.

2.7 Central Bank

The balance sheet of the central bank in the economy is highly stylized. On the liability side there is money in circulation M_t^{CB} that the central bank gives to the investment banks and an equity term E_t^{CB}. Equity results from the fact that the central bank is able to choose a haircut on ABS in Repo transactions. On the asset side the central bank has both government bonds (and ABS) that are eligible assets in open market operations. By adjusting

Table 3: Balance sheet of the Central Bank

Assets	Liabilities
Government Bonds G_t	Money in circulation M_t^{CB}
(Asset-backed securities ABS_t^{CB})	Equity E_t^{CB}

the haircut at which it purchases the collateral it can vary the amount of liquidity that it grants the investment bank. The haircut h_t fixed by the central bank is specified by the following process

$$h_t = \rho_h h_{t-1} + cS_t - \varepsilon_t^h \tag{22}$$

In general the money stock in the economy is rising, the smaller the haircut. That is, the trade-off the central bank faces when maximizing interbank activity/reducing interbank turmoil comes at the cost of building up inflationary pressures. In order to analyze the liquidity policy of the central bank and the exit strategy after a severe recession this process also features a shock term ε_t^h. The shock is assumed to be normally distributed with variance σ_h^2.

Besides steering the liquidity situation on the interbank market, the central bank also has a broader macroeconomic view and responsibility. As usual this is implemented by an interest rate rule. If contemporaneous inflation is above its target the central bank reacts by increasing the short rate. In addition it also reacts to deviations of output from its long run trend.

$$R_t = \rho_r R_{t-1} + \phi_\pi(\pi_{t+1} - \bar{\pi}) + \phi_y(Y - \bar{Y}) + \epsilon_t^R \tag{23}$$

We do not postulate that the haircut rule and the interest rate rule are both equally important and can stimulate economic activity in the same way. Predominant is still the interest rate rule with its connection to the real economy and thereby securing the households' well being.

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 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

$$\Pi_t^{cb} = \frac{R_{t-1}}{\pi_t} M_{t-1}^{cb} - \frac{R_{t-1}^{DF}}{\pi_t} X_{t-1}. \tag{24}$$

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

2.8 Aggregate conditions

Finally, the following aggregate conditions have to hold. Borrowings of entrepreneurs and lendings by commercial banks need to coincide.

$$B_t = \gamma^{CoB} B_t(j) \tag{25}$$

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

$$\gamma^{CoB} D_t(j) = \gamma^P D_t(p) \tag{26}$$

Total interbank lending has to satisfy

$$\gamma^{CoB} IB_t(i) = \gamma^{PD} IB_t(k) \tag{27}$$

Money provided by the central bank has to equal the demand for money by the investment banks.

$$M_t^{cb} = \gamma^{PD} M_t^{PD}(k) \tag{28}$$

The collateral markets for asset-backed securities (ABS) between commercial banks and investment banks as well as investment banks and the central bank have to satisfy the following conditions.

$$ABS_t^{pd} = \gamma^{CoB} ABS_t^{CoB}(j) \tag{29}$$

$$ABS_t^{cb} = ABS_t^{pd} \tag{30}$$

The goods market clearing finally requires

$$Y_t + G_t = C_t + Q_t \left(K_t^h - (1-\delta) K_{t-1}^h \right) + Adj.costs \tag{31}$$

3 Calibration

One crucial task of calibrating this model is to deal with a real sector where one period usually corresponds to one quarter as macroeconomic aggregates like GDP are updated on a quarterly basis. In contrast, information about financial variables are updated in a much higher frequency. The compromise that we find here is to calibrate the model to monthly data[9]. 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 implies 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 for both consumption and labor. The fraction of capital employed in the production process α is not time-variant either and is set to 0.33 a value commonly found in the literature. With respect to the rate of depreciation that is commonly calibrated to be 10% a year, we set the monthly depreciation rate to be 0.008. The coefficient determining the mark-up ϵ_p is time-invariant and set to 6 as e.g. in Bernanke *et al.* (1999). However, the fraction of retailers being able to set prices each period is set slightly higher than in the monthly specification. Normally it is 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 rates are taken from Gerali *et al.* (2009) and taken by three as their calibration is quarterly. So, 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 the survival rate of entrepreneurs is set to 0.95 in line with Bernanke and Gertler (1999).

The values in the interest rate rule are set in accordance with Taylor (1993). With respect to the autoregressive parameters in the AR(1) processes we increased all values in comparison to existing studies as those were chosen to match quarterly time series dynamics. So in our study all of them range in the zone from 0.95 in the case of government expenditure to 0.99 in the case of the central bank tools, haircut and interest rate.

The one parameter that is completely unknown in the literature is the intensity of interbank loans or excess reserves in the production function of the investment banks. We set it to 0.9

[9] This approach is also often used in the macro-finance literature, see for example Borgy *et al.* (2011)

which seems reasonable and 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 the appendix.

4 Results

In this section we discuss the results of the model. In section 4.1 impulse responses to the most relevant shocks are discussed. Furthermore we examine whether different kinds of shocks are amplified or dampened in the presence of an interbank market to emphasize the importance of the interbank market for the behavior of the model economy. In the case without interbank market we neglect the investment bank and have therefore no interbank lending, no excess reserves and the interbank rate is set to be identical to the policy rate. The commercial bank is in this case in direct contact with the central bank[10]. In this context we are not examining the reaction of the variables (see subsection before) but just the magnitude of the deviation from steady state of these two different model setups. Secondly, sections 4.2 answers the question whether in our model framework central banks should "lean against the wind", i.e. react to asset prices or not. Boom-bust cycles caused by market price fluctuations are simulated following the procedure laid out in Bernanke and Gertler (1999). Finally, in section 4.3 three different exit strategies for the central bank are analyzed. 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 the appendix.

4.1 Impulse Responses to shocks

In this section we examine the model dynamics to four types of shocks: a monetary policy shock, a shock to the haircut applied to risky assets, a shock to technology and to the market price of capital.

Figure 1 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 investment banks declines and the interest rate for interbank loans increases. This in turn lets the commercial banks demand less interbank funds. At the same time a higher interest rate induces the investment bank to hold more excess reserves at the central bank.

[10]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

This countercyclical movement of interbank loans and excess reserves is due to the specification of the production function of the investment bank[11]. 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, e.g. 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. Finally also the decline in the fundamental price of capital and therefore also in the value of ABS is stronger if the interbank market is shut down.

If the central bank lowers the haircut on ABS (as is the case in Figure 2), 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 secondly as mentioned above one time period corresponds to one month[12]. 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 ABS. 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 also excess reserves go up. This is the only time that both quantities move in the same direction [13]. 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 investment bank 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 nil because commercial banks enter in direct relation with the central bank to obtain their funding. So the stimulus by a negative haircut shock only functions with an interbank market and more precisely only with the hierarchical structure that we setup.

In Figure 3 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, e.g. Bernanke *et al.* (1999) and Christensen and Dib (2008). As the technology shock leads to a decrease in the policy rate,

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

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

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

the interbank lending rate decreases as well which in turn leads to higher 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 ABS 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 [14]. In this case, for the first time, the impulse responses of market price and fundamental price are not identical (see Figure 4). While both prices increase, the market value rises ten times as much, driving up the value of the asset-backed securities above their fundamental value as their value depend 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 riskfree 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. ABS and liquidity show similar responses across the 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 acts as an amplifying mechanism.

4.2 Monetary policy in times of Boom-Bust cycles

This subsection applies the same methodology as Bernanke and Gertler (1999) and Bernanke and Gertler (2001) enriched by a microfounded interbank market and an additional central bank instrument. The question we try to answer is whether central banks should "lean

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

against the wind", i.e. if a central bank should respond to deviations of asset prices from their fundamental value. We plot six variables[15]: Output and inflation to analyze the impact on macrovolatility, interest rate spread and excess reserves to consider financial markets and the fundamental and the market price of capital. In all figures in this subsection we compare four different cases that are also specified in the appendix. These cases differ in their role of output and asset price deviations for the setting of the policy instruments.

Figure 5 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 5 & 6) 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. 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. As can be seen cases 5 and 6 are very similar throughout and deliver more macrostability but are less smooth in the financial variables compared to the cases 1 and 2. This is opposed to the position of Bernanke and Gertler (1999) who claim that the interest rate should not respond to asset price deviations. 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 Figure 6 we come to the core of the debate between Bernanke and Gertler (2001) and Cecchetti *et al.* (2002). The latter argue that once the interest rate rule contains also a response to output the argumentation of Bernanke and Gertler (1999) no longer holds. This means that case 7 where the central bank reacts to deviations of output and asset prices should be more stable in terms of macroeconomic volatility than case 3 where the central bank does not respond to asset prices. We can confirm the result of Cecchetti *et al.* (2002) for inflation and partly for output as well as for the price of capital. On the financial side, however, cases 3 and 7 give similar results with case 3 exhibiting a little less volatility. The overall performance can be dramatically improved however if the haircut rule is allowed to respond to asset prices either without (case 9) or with (case 11) the interest rate exhibiting "leaning again the wind" behavior. So macrostability in this setup is primarily achieved by the liquidity management of the haircut rule and not by the interest rate policy.

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 analyze the optimal exit date within our model. Nevertheless we are able to analyze the response of the economy to

[15]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

an exit. Methodologically we follow Angeloni *et al.* (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 by which risky assets are purchased at lower haircuts than usual (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 (3) an exit from a policy that keeps the loan-to-value ratio at unusual high values[16]. Note that both the haircut rule and the loan-to-value ratio respond to asset price deviations.

In Figure 7 we depict six 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. It is obvious that until this period the economy's response is identical to the "no exit"-case. Afterwards, given that the haircut is no longer responding to the asset price output and inflation drop immediately and considerably, as liquidity is reduced sharply. Also the prices of capital reduce unexpectedly before returning gradually to the steady state value. The last path depicted in Figure 12 belongs to a situation where the agents anticipate correctly from the very beginning that after 24 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 1 on as the expectation of the central bank abandoning the liquidity provision drives up output after a few periods and letting inflation fall from the start. Once the haircut rule is actually shut down, also 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. In a nutshell, if the central bank succeeds in convincingly communicating their exit strategy to the agents, the economy experiences lower volatility.

Figure 8 shows the analysis when the central bank exits its haircut policy after 24 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 bottom line for the central bank is that less volatility in inflation comes at the cost of more volatility in the other variables.

[16] 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.

Finally, in Figure 9 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 24 periods and letting it return to its steady-state value at a speed governed by a pure AR(1) afterwards. In the "no exit"-case the loan-to-value ratio would be constantly above the steady state value leading to very little macroeconomic volatility as can be seen in Figure 9. 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 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 ABS. Once the loan-to-value ratio returns to its normal level, the ABS increase 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.

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 from individual optimizing behavior of banks in the presence of an interbank market. By this modeling device unconventional monetary policy can be analyzed which includes not only a simple interest rate rule but also collateral policy. 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 enhance it by equally 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 an asset price bubble occurs. Once this market is drying up or risks to be malfunctioning due to a financial crisis, central banks have to react and stimulate the liquidity situation on this market by other measures than ordinary interest rate setting. 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. However, both financial and macroeconomic volatility are lowest if asset price deviations are taken into consideration in the haircut rule. After a negative shock to the market prices of financial assets banks could reduce further macroeconomic volatility if they announce an exit date and stick to it. 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 already some type of shocks included 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.

References

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

Allen, F., Carletti, E., and Gale, D. (2009). Interbank Liquidity and central bank intervention. *Working Paper*.

Angeloni, I., Faia, E., and Winkler, R. (2010). Exit Strategy. *Working Paper*.

Ashcraft, A., Garleanu, N., and Pedersen, L. H. (2010). Two Monetary Tools: Interest-Rates and Haircuts. *Working Paper*.

Bernanke, B. and Gertler, M. (1999). Monetary Policy and Asset Price Volatility. *Economic Review*, pages 17–51.

Bernanke, B. and Gertler, M. (2001). Should Central Banks Respond to Movements in Asset Prices. *American Economic Review Papers and Proceedings*, **91**(2), 253–257.

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

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

Borgy, V., Mesonnier, J.-S., Laubach, T., and Renne, J.-P. (2011). Fiscal Policy, Default Risk and Euro Area Sovereign Bond Spreads. *Working Paper*.

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

Cecchetti, S. G., Genberg, H., and Wadhwani, S. (2002). Asset Price in a Flexible Inflation Targeting Framework. *NBER Working Paper Series*, (8970).

Christensen, I. and Dib, A. (2008). The financial accelerator in an estimated New Keynesian model. *Review of Economic Dynamics*, **11**, 155–178.

Christiano, L., Eichenbaum, M., and Evans, C. L. (2005). Nominal Rigidities and the Dynamic Effects of a shock to Monetary Policy. *Journal of Political Economy*, **113**(1), 1–45.

Christiano, L., Motto, R., and Rostagno, M. (2007). Shocks, Structures or Monetary Policies? The Euro Area and US after 2001. *ECB Working Paper Series*, **No. 774**.

Curdia, V. and Woodford, M. (2010). The Central-Bank Balance Sheet as an Instrument of Monetary Policy. *Working Paper*.

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

Dib, A. (2009). Banks, Credit Market Frictions and Business Cycles. *Working paper*.

Ewerhart, C. and Tapking, J. (2008). Interbank Lending, Collateral, and the 2007 Liquidity Crisis. *Working paper*.

Freixas, X. and Jorge, J. (2008). The Role of Interbank Markets in Monetary Policy: A Model with Rationing. *Journal of Money, Credit and Banking*, **40**(6), 1151–1176.

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

Gertler, M. and Karadi, P. (2009). A model of unconventional Monetary Policy. *Working Paper*.

Gertler, M. and Kiyotaki, N. (2010). Financial Intermediation and Credit Policy in Business Cycle Analysis. *forthcoming in: Hankbook of Monetary Economics*.

Goodfriend, M. and McCallum, B. (2007). Banking and interst rates in monetary policy analysis: A quantitative exploration. *Journal of Financial Intermediation*, **17**, 63–88.

Gray, S. and Stella, P. (2008). IMF Assesses Central Banks' Reaction. *IMF Survey Magazine, Policy*.

Iacoviello, M. (2005). House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle. *American Economic Review*, **95**(3), 739–764.

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

Schabert, A. (2010). Optimal Central Bank Lending. *Working Paper*.

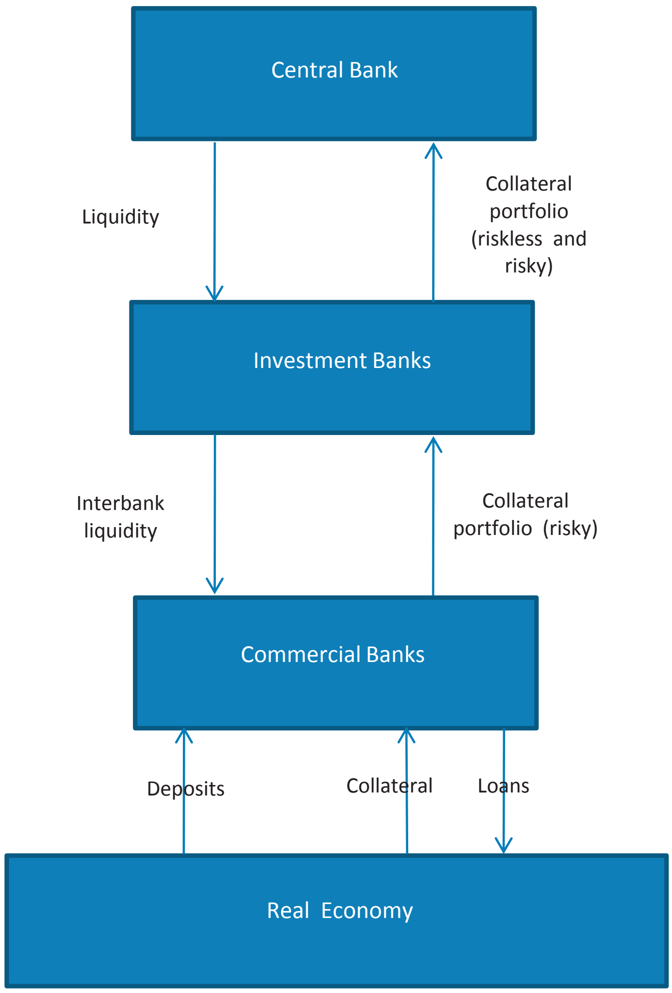
Smets, F. and Wouters, R. (2003). An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, **1**(5), 1123–1175.

Taylor, J. (1993). Discretion Versus Policy Rules in Practice. *Carnegie-Rochester Series on Public Policy*, **39**, 195–214.

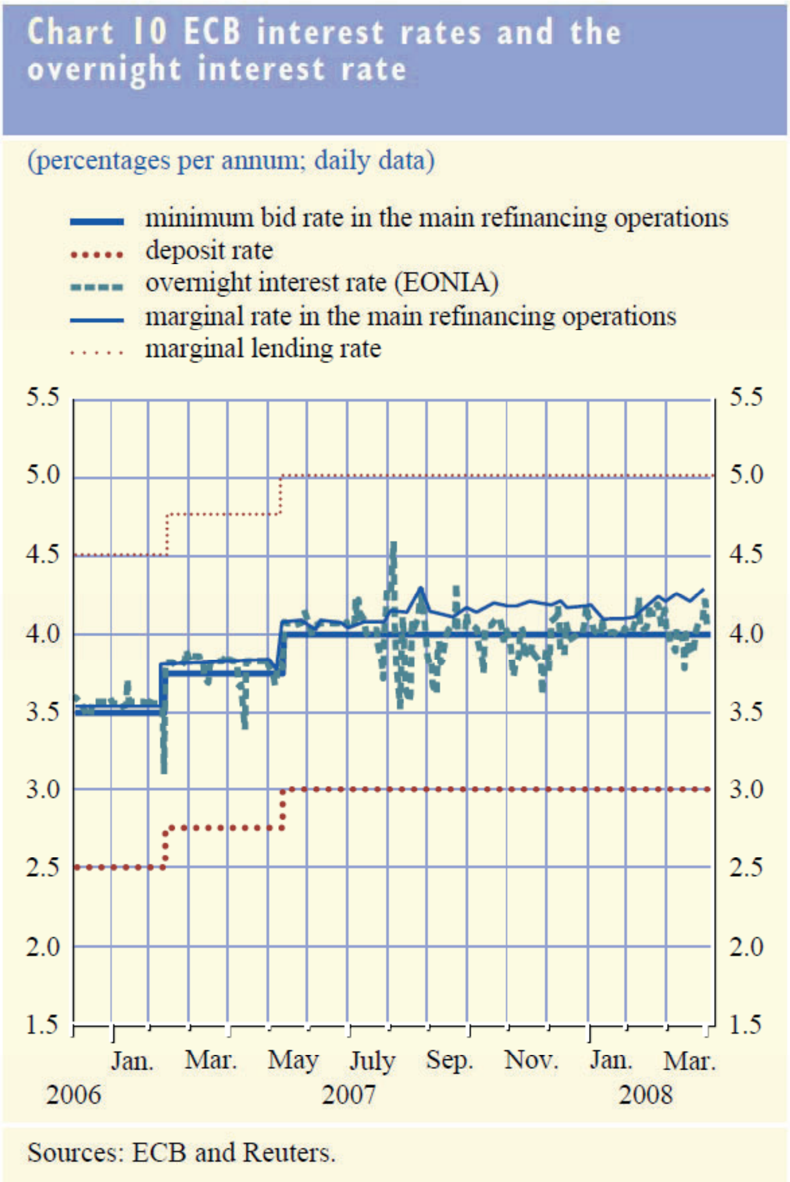
A Appendix

A.1 Graphics for Illustration

Graph 1: Model Economy



Graph 2: Behavior of the ECB interest rates and overnight interest rate



A.2 First order conditions

A.2.1 Patient Households

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

A.2.2 Entrepreneurs

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

A.2.3 Capital Producers

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

A.2.4 Retailer

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

A.2.5 Commercial Bank

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

A.2.6 Investment Bank

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

A.3 Log-linearized Equations

Real Economy:

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

Financial System:

$$
\begin{aligned}
R_t^B &= \frac{(\kappa_b R_{t-1}^B + \beta \kappa_b R_{t+1}^B + (\epsilon_b - 1) R_t^{IB})}{(\epsilon_b - 1 + \kappa_d(1+\beta))} \\
R_t^D &= \frac{(\kappa_d R_{t-1}^D + \beta \kappa_d R_{t+1}^D + (1 + \epsilon_d) R_t^{IB})}{(1 + \epsilon_d + \kappa_d(1+\beta))} \\
B_t &= \frac{Q_{ss} K_{ss}}{B_{ss}}(Q_t + K_t) - \frac{N_{ss}}{B_{ss}} N_t \\
D_t &= \frac{B_{ss}}{D_{ss}} B_t - \frac{IB_{ss}}{D_{ss}} IB_t \\
MBS_t^{CoB} &= (1-\emptyset)\frac{Q_{ss}K_{ss}}{MBS_{ss}^{CoB}}((Q_{t+1} + U_{t+1}) + K_t) - \emptyset \frac{N_{ss}}{MBS_{ss}^{CoB}} N_t \\
M &= \frac{G_{ss}}{M_{ss}} G_t - HC_{ss}\frac{MBS_{ss}^{CoB}}{M_{ss}} HC_t + (1 - HC_{ss})\frac{MBS_{ss}^{CoB}}{M_{ss}} MBS_t^{CoB} \\
R_t^{spread} &= \frac{R_{ss}^{IB}}{R_{ss}^{spread}} R_t^{IB} - \frac{R_{ss}}{R_{ss}^{spread}} R_t \\
M_t &= \zeta IB_t + (1-\zeta) X_t \\
X_t &= \frac{1}{\zeta}\left(\frac{R_{ss}^{spread}}{(R_{ss}^{spread} - R_{ss}^{IB})} R_t^{spread} - \frac{R_{ss}^{IB}}{(R_{ss}^{spread} - R_{ss}^{IB})} R_t^{IB} - \lambda_t\right) + IB_t \\
IB_t &= \frac{1}{\zeta}\left(\left(R_{ss}^{spread}(1 + \frac{(1 - HC_{ss})}{m_{ss}} R_{ss}^{IB}) + R_{ss} - (R_{ss}^{IB})^2 \frac{(1 - HC_{ss})}{m_{ss}}\,)\,)\right.\right. \\
&\quad (\,(+\lambda_{ss}\frac{(1 - HC_{ss})}{m_{ss}} R_{ss}^{IB}\Big) \,/\, \Big(\lambda ss \zeta X_{ss}^{(1-\zeta)}\Big)\Big)^{-1} \\
&\quad \left(\frac{(1 + m_{ss} - HC_{ss})}{m_{ss}} R_{ss}^{IB} R_{ss}^{spread} R_t^{spread} + \left(R_{ss}^{spread} + \lambda_{ss} - 2R_{ss}^{IB}\right)\,)\right. \\
&\quad (\frac{1 - HC_{ss}}{m_{ss}} R_{ss}^{IB} R_t^{IB} + R_{ss} R_t + \left(\left(R_{ss}^{spread} + \lambda_{ss} - R_{ss}^{IB}\right)\frac{R_{ss}^{IB}}{m_{ss}}\right) HC_{ss} HC\Big) + X_t
\end{aligned}
$$

Shocks:

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

A.4 Calibrated Parameters

Table 4: Parameter values in the model

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 5: Parameter values in the various Boom-Bust cycle cases

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

A.5 Dynamic Analysis

A.5.1 Impulse Responses to Main Shocks and the importance of the interbank market

Figure 1: Responses to an Unanticipated Positive 25 bp Increase in the Policy Rate:

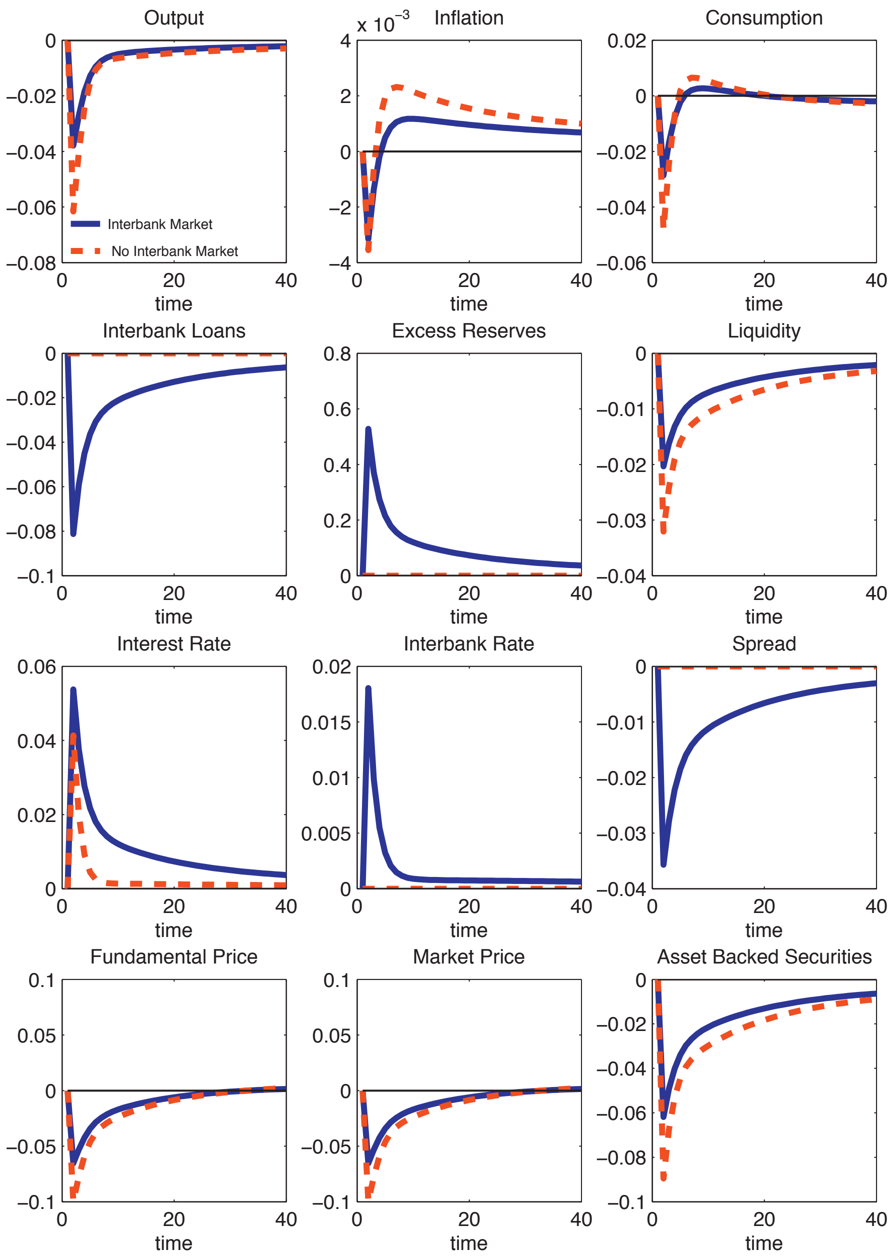


Figure 2: Responses to 10% Decrease in the Haircut:

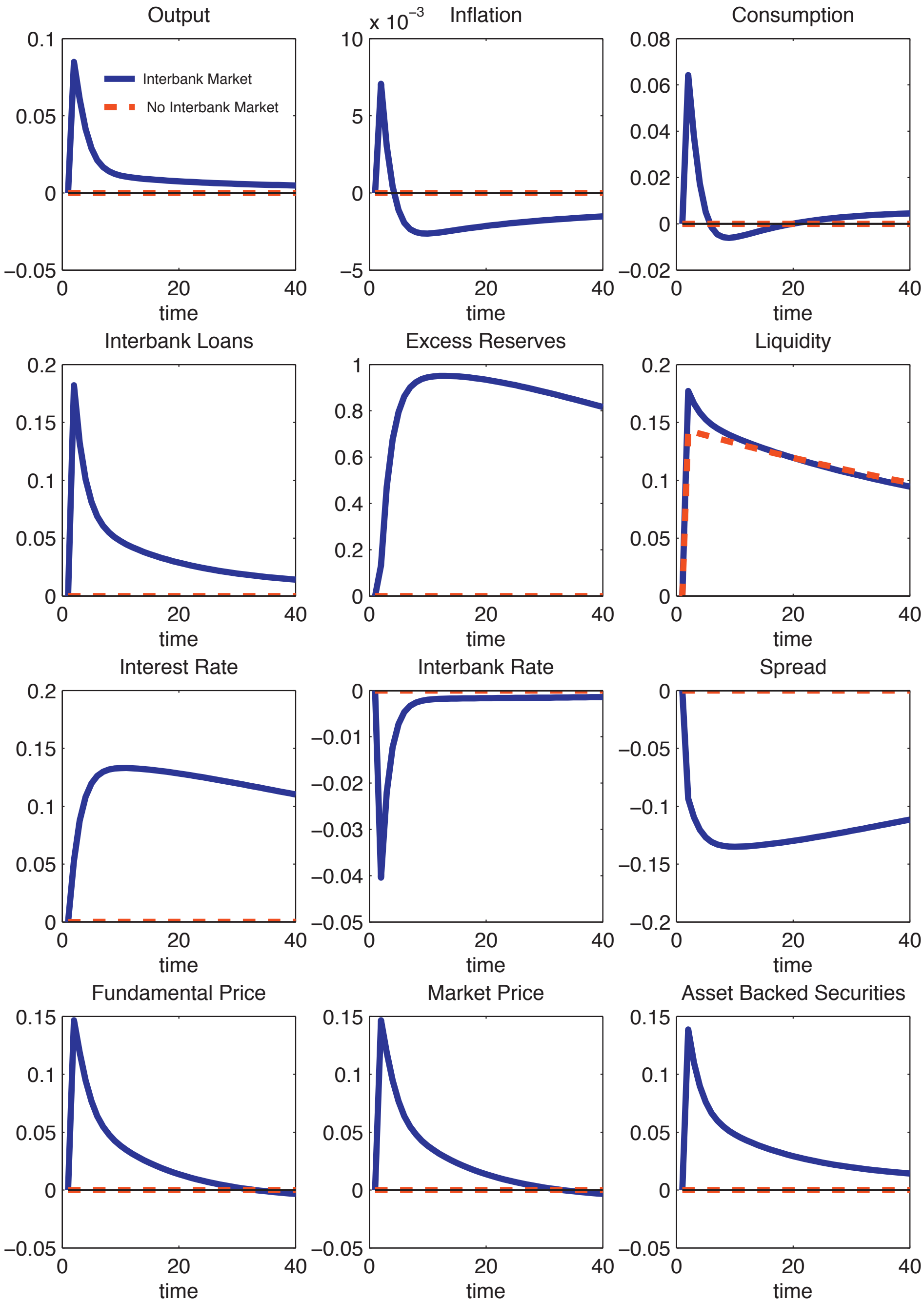


Figure 3: Responses to a 1% Increase in Technology:

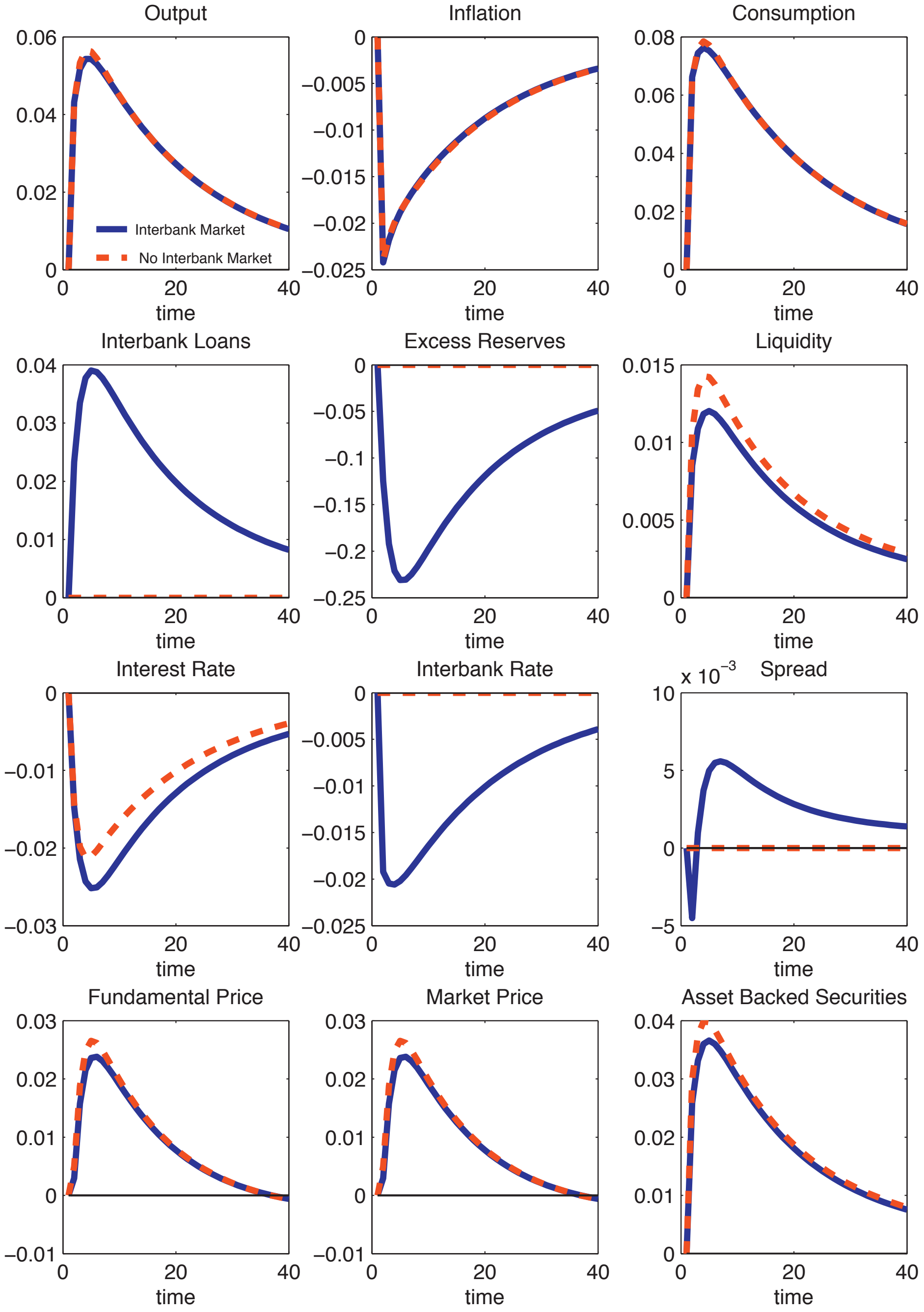
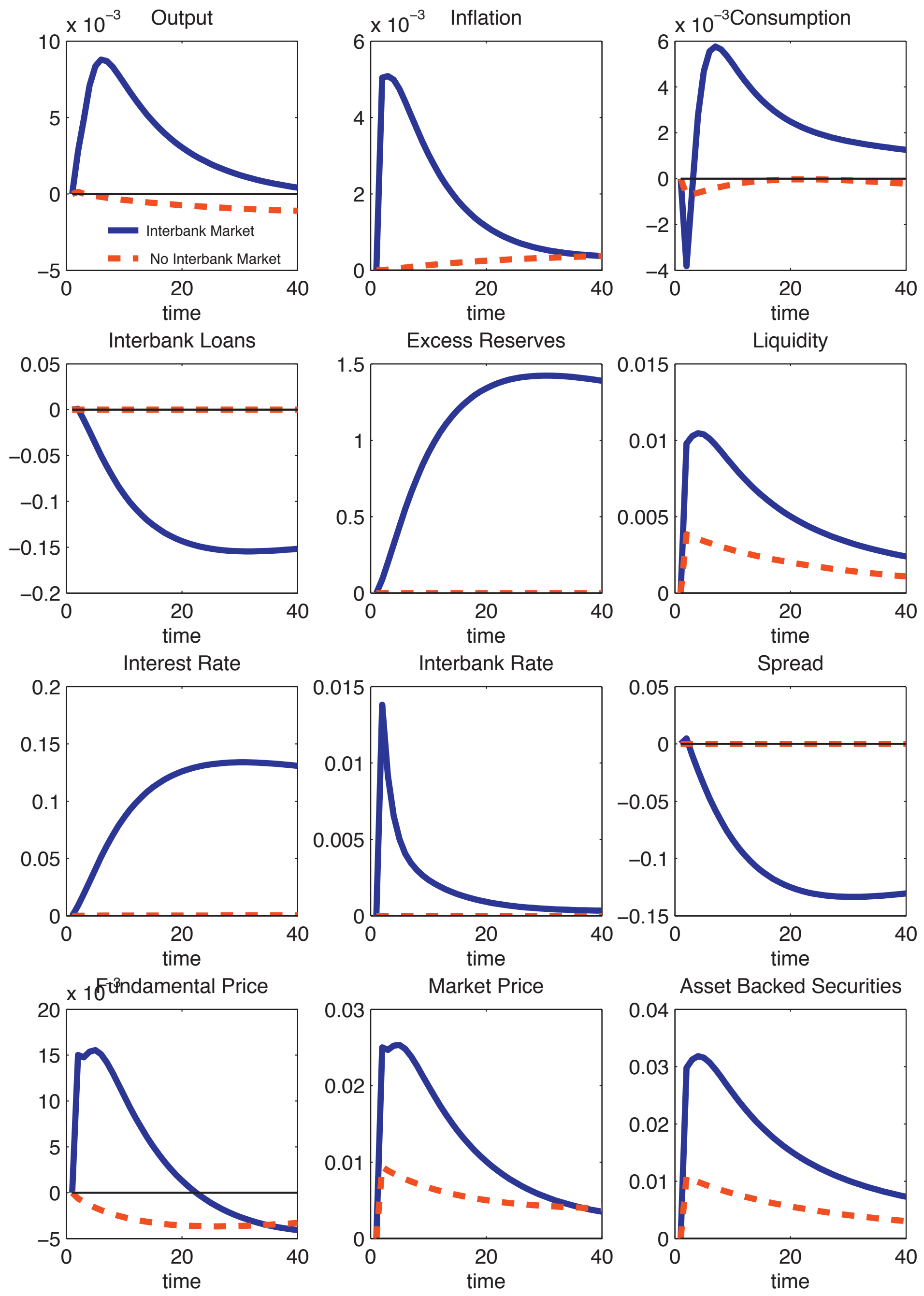


Figure 4: Responses to 10% increase in the Market Price:



A.5.2 Boom-bust cycles

Figure 5: Redoing the Bernanke and Gertler (1999) exercise with an interbank market

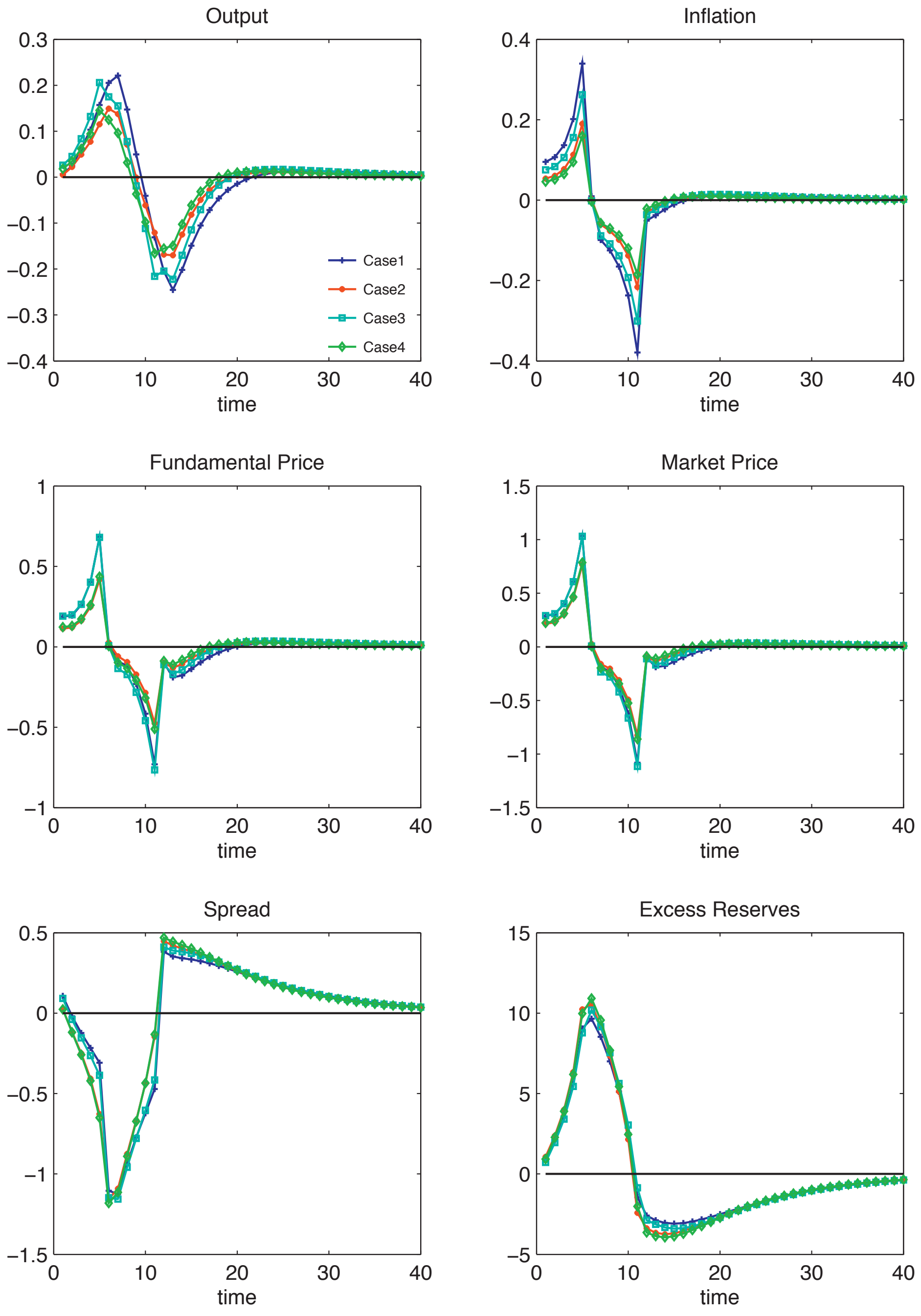
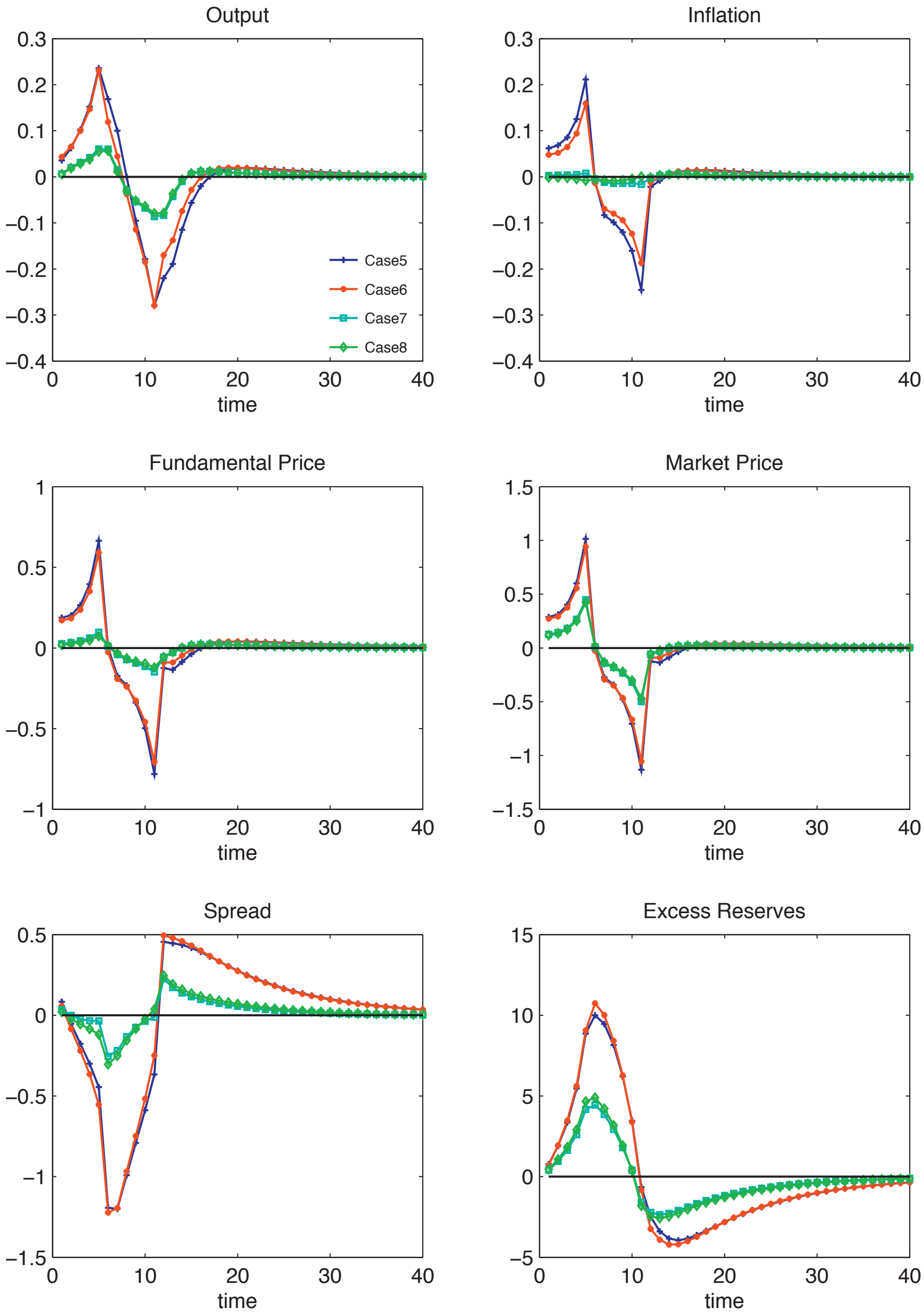


Figure 6: Extending Bernanke and Gertler (1999) to "lean against the wind" using the haircut



A.5.3 Exit strategies

Figure 7: Unanticipated exit from a constant lower haircut:

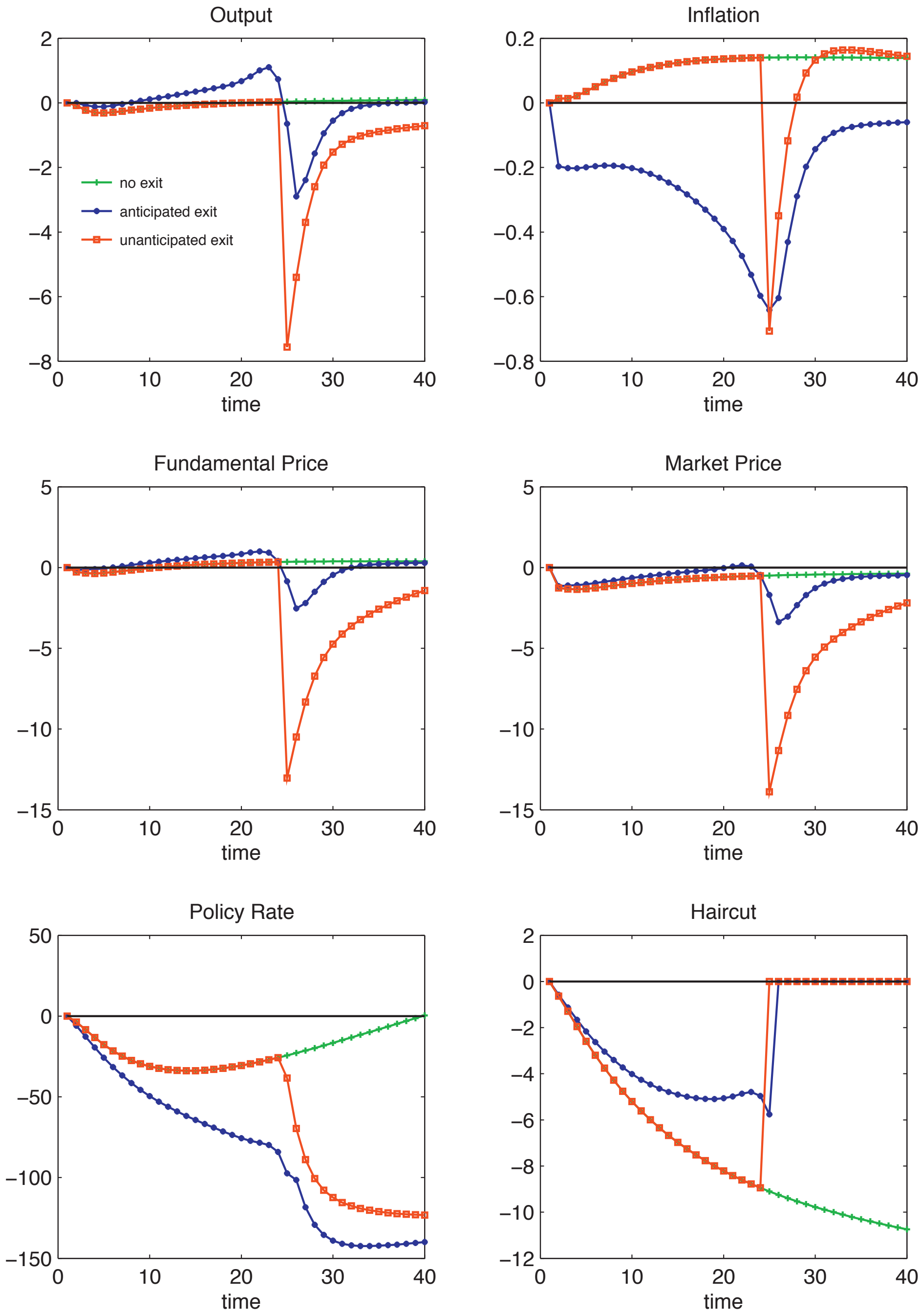


Figure 8: Unanticipated exit from a constant lower haircut plus return to Taylor-rule:

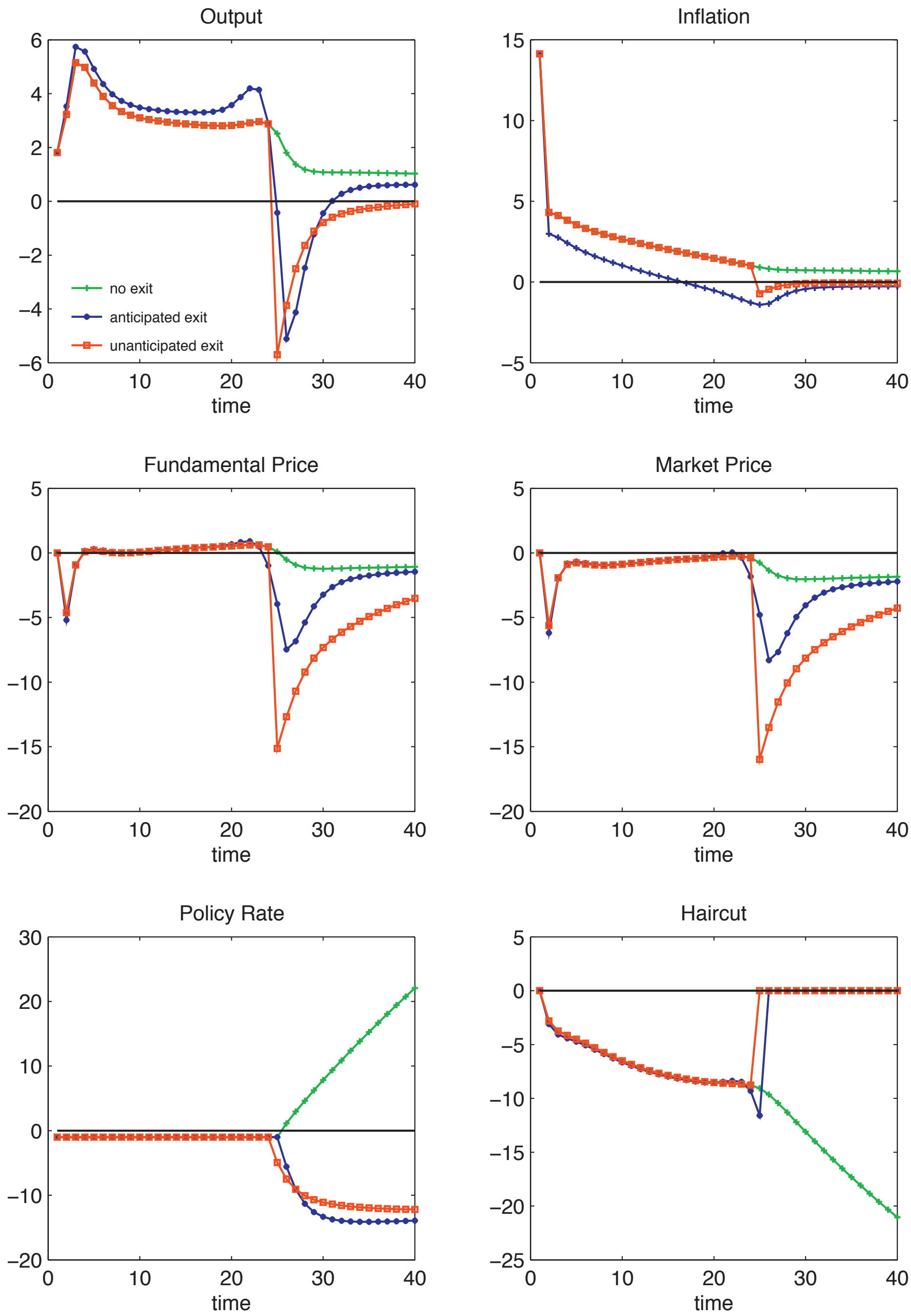


Figure 9: Unanticipated exit from a constant higher loan-to-value ratio: