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

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28.12.2012

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

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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)

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. 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 prolong the maturities for repurchase agreements ('Repo'), 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. 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 reserves amongst each other on the interbank market. 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

[1] The term 'Great Moderation' goes back to a paper by **?** to describe the decline in the output volatility in the United States since the early 1980s.

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 financial sector amplifies shocks to the real economy. 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 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 (2009) and Freixas and Jorge (2008), 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, 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) several studies 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 allow for the re-use 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 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

[2] An extensive study of unconventional monetary policy with a huge emphasis also on the central bank's balance sheet has recently been conducted by Curdia and Woodford (2010).

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. 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.

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. 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. We are able to confirm the result of Bernanke and Gertler (1999) in our model framework and suggests not to include asset prices in the interest rate rule. But this does not mean that the central 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 simulated boom-bust cycles.

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 can give recommendations about the preferable strategy based on the variances computed across different exit scenarios. 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.

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 Section 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). 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 can save by holding deposits with the interbank borrowing bank who 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 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 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 for the main refinancing operations of the central bank. It is assumed that the commercial banks are heterogenous with respect to their balance sheet structure. After netting out the common balance sheet positions among these two bank types, one type of commercial bank has a larger fraction of highly liquid assets on its balance sheet compared to the other type of commercial bank whose balance sheet contains a larger fraction of less liquid, risky assets. Hence, some commercial banks have a surplus of illiquid assets and a deficit of liquid assets when compared to the other commercial bank type. It is important to emphasize that in the following it is only the difference in the balance sheet positions across commercial banks which are considered and not the level of the balance sheet positions.[3] Table 1 depicts the individual balance sheets of the two types of commercial banks after deducting the identical positions across commercial banks

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

(a) Commercial Bank j

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

(b) Commercial Bank k

Table 1: Heterogenous Balance Sheet Structure among Commercial Banks

[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.

To motivate the presence of the interbank market it is assumed that there is a liquidity shock which affects all banks alike. Those banks with a highly liquid balance sheet are able to offset this liquidity shock by selling liquid assets.[4] However, those banks with a less liquid balance sheet can only obtain sufficient liquidity if they cancel some of their loans to the private sector. However, this is assumed to lead to an immediate loss for those banks. Hence, they prefer to demand additional liquidity either from the central bank or on the interbank market and offer the illiquid, risky asset as collateral. In the following we will refer to the former group as interbank lending banks and to the latter group as interbank borrowing banks. If the central bank does not accept the risky asset as collateral in its regular liquidity operations, that is, the haircut of the central bank is equal to one, an interbank borrowing bank has to rely on the interbank market for obtaining additional liquidity.
In the follwing subsections the model setup and the optimization problems faced by each agent are explained. First order conditions are completely delegated to Appendix 1.F.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

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

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

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

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

[4] It is assumed that the liquidity shock is sufficiently small so that banks with a liquid balance sheet have sufficient funds left after accounting for the effect of the liquidity shock on their balance sheet.

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

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \tag{3}$$

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

$$B_t = Q_t K_{t+1} - N_t \tag{4}$$

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) implemented 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

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

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.[5] The aggregate net worth position of entrepreneurs is evolving as

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

with ν and ω being the survival probability of the entrepreneur and the default probability of the project the entrepreneur invests in, respectively. Moreover, $1 - \Omega$ denotes the share of

[5]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.

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.[6]

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

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

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

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

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

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

The parameter a determines the speed of convergence back to the fundamental price Q_t and b is given by $b \equiv a(1-\delta)$.[7] 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 Producer

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

$$\max_{I_t} E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \left[Q_t \left[I_t - \frac{\kappa_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] - I_t \right]. \tag{10}$$

The aggregate capital stock evolves according to

$$K_{t+1} = (1-\delta)K_t + \left(1 - \frac{\kappa_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t \tag{11}$$

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 can be found. A detailed description can be found for example in Dib (2009).

[6]For an introduction on asset price bubbles we refer to the seminal paper by Blanchard and Watson (1982).

[7]In the case of rational bubbles this value would be one, see Blanchard and Watson (1982).

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:

$$\Pi_t^R = \sum_{k=0}^{\infty} \xi_p^k E_{t-1}\left[\Lambda_{t,k}\frac{P_t^* - P_{t+k}^w}{P_{t+k}} Y_{t+k}^*(R)\right] \tag{12}$$

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.

2.5 Commercial Bank j / Interbank Borrowing Bank

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 $D_t(j)$. These funds are invested in loans to entrepreneurs $B_t(j)$. A commercial bank j by assumption has a larger amount of 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 $D_t(j)$

Table 2: Balance Sheet of a Commercial Bank j

As explained at the beginning of Section 2 Tablee 2 depicts the difference in the balance sheet positions between a commercial bank type j and a commercial bank of type k and not

the level of the balance sheet positions itself. That is, if the amount of $B_t(j)$ on the asset side of a commercial bank of type j is positive this implies that its position in entrepreneurial loans is larger than the equivalent position of a commercial bank of type k.
Each commercial bank *j* maximizes its profit which is given by the following equation

$$\Pi_t(j) = \frac{R^B_{t-1}}{\pi_t}B_{t-1}(j) - \frac{R^D_{t-1}}{\pi_t}D_{t-1}(j) - \frac{R^{IB}_{t-1}}{\pi_t}IB_{t-1}(j) \tag{13}$$

$$- \frac{\kappa_d}{2}\left(\frac{R^D_{t-1}}{R^D_{t-2}} - 1\right)^2 \frac{R^D_{t-1}}{\pi_t}D_{t-1}(j) - \frac{\kappa_b}{2}\left(\frac{R^B_{t-1}}{R^B_{t-2}} - 1\right)^2 \frac{R^B_{t-1}}{\pi_t}B_{t-1}(j) \tag{14}$$

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.

$$D_t(j) = \left(\frac{R^D_t(j)}{R^D_t}\right)^{\epsilon_d} D_t \tag{15}$$

$$B_t(j) = \left(\frac{R^H_t(j)}{R^H_t}\right)^{-\epsilon_h} B_t \tag{16}$$

In return for the loan $B_t(j) = Q_t K_t - N_t$ to the entrepreneur a commercial bank j obtains collateral worth $Q_t K_t$. 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 $Q_t K_t$, the value of the asset-backed security portfolio of bank j is given by

$$ABS_t(j) = S_t K_t \tag{17}$$

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. However, because an interbank lending bank k encounters transaction costs which are proportional to the collateral value and which are denoted by $(1 - m_t)S_{t+1}K_t$. 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 $m_t \mathbb{E}_t S_{t+1} K_t$. 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[8]

$$R_t^{IB} IB_t \leq m_t \mathbb{E}_t S_{t+1} K_t \tag{18}$$

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 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[9]:

$$m_t = \rho_m m_{t-1} - 2 \cdot u_t + \epsilon_t^m \tag{19}$$

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

$$B_t(j) = D_t(j) + IB_t(j) \tag{20}$$

2.6 Commercial Bank k / Interbank Lending Bank

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 has a higher fraction of its funds invested in liquid assets. Thus, the balance sheet depicted in Table 3 contains liquid assets in the amount G_t after the common position held by all banks independent of their type are netted out. 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 $D_t(j)$

Table 3: Balance Sheet of a Commercial 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

[8]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)

[9]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

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

$$\Pi_t^{IB}(k) \quad = \quad R_t^{Spread}\left(IB_t(k) + M_t^D(k) - X_t(k)\right) + R_t IB_t(k) - R_t^{IB} M_t^D(k) + R_t^{IB} X_t(k) \tag{21}$$

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[10].

$$R_t^{Spread} = R_t^{IB} - R_t \tag{22}$$

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[11]

$$M_t(k) = IB_t(k)^{\zeta} X_t(k)^{\zeta} \tag{23}$$

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

$$M_t(k) = G_t(k) + (1 - h_t) ABS_t^{PD}(k) \tag{24}$$

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

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

[11]Excess reserves can be interpreted as a riskless investment opportunity for a commmercial bank k.

repurchase agreements depends on the decision of the central bank. If $h_t = 1$ the central bank does not accept asset-backed securities.[12] 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.

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.

$$R_t = \rho_r R_{t-1} + \phi_\pi(\pi_{t+1} - \bar{\pi}) + \phi_y(Y - \bar{Y}) + \epsilon_t^R \tag{25}$$

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

$$h_t = \rho_h h_{t-1} + c(S_t - \bar{S}) - \varepsilon_t^h \tag{26}$$

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 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

$$\Pi_t^{cb} = \frac{R_{t-1}}{\pi_t} M_{t-1}^{cb} - \frac{R_{t-1}^{DF}}{\pi_t} X_{t-1}. \tag{27}$$

[12]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 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.

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.

$$B_t = \gamma^j B_t(j) \tag{28}$$

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

$$\gamma^j D_t(j) = \gamma^P D_t(h) \tag{29}$$

Total interbank lending has to satisfy

$$\gamma^j IB_t(i) = \gamma^k IB_t(k) \tag{30}$$

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

$$M_t^{CB} = \gamma^k M_t^k(k) \tag{31}$$

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

$$ABS_t = S_t K_t \tag{32}$$

The maximum amount of collateral the commercial banks j can offer to commercial banks k is then given by (32). Summing across the demand for collateral by commercial banks k and the supply of collateral by commercial banks j the following condition holds

$$ABS_t = \gamma^k ABS_t(k) = \gamma^j ABS_t(j) \tag{33}$$

Finally, goods market clearing requires

$$Y_t + G_t \quad = \quad C_t + Q_t \left(K_t^h - (1-\delta)K_{t-1}^h\right) + \text{Adj. costs} \tag{34}$$

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[13]. 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 0.008. The coefficient determining the markup 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 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 com-

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

parison 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.G.

4 Results

In this section we discuss the results of the model. In the impulse response analysis done in Section 4.1 we discuss how the model developed in Section 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[14] 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 incorporating an interbank market on the model dynamics. In Section 4.2 we answers 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. 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 within the model framework proposed in Section 2.

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

[14]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

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.H.1.

Figure 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 the commercial banks 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 production function of the commercial bank k.[15] 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, 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 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[16]. 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 also excess reserves go up. This is the only time that both quantities move in the same direction.[17] 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

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

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

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

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 commercial banks j enter in direct relation with the central bank to obtain their funding.

In Figure 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.[18] In this case, for the first time, the impulse responses of market price and fundamental price are not identical (see Figure 5). 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 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 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. 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

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

greatly reduced once the interbank market is eliminated. In this case the interbank market amplifies shocks to the market price of capital S_t.

4.2 Boom-Bust Cycles

In this subsection we apply the methodology of Bernanke and Gertler (1999) and Bernanke and Gertler (2001) to a model framework with a microfounded interbank market and where the central bank has an additional central bank instrument, namely, the haircut rule given in equation (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[19]: 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 4. 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 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 4: Boom-Bust Cycle Analysis: Cases

[19] 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

Figure 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 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 5: 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 $c > 0$ 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 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 response coefficient to output as well the argumentation of Bernanke and Gertler (1999) no longer holds. This means that case 6 where the central bank reacts to deviations of output and asset prices should stabilize the macroeconomic variables more than in case 5 where the central bank does not respond 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 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 6: Stabilization Gains II

Based on the results in Table 6 which depicts the variances of the variables plotted in Figure 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.

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 by which 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.[20]

In Figure 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

[20]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.

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 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 the asset price, 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 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 abandoning the 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 as well before returning fast to their steady states. Only inflation takes longer to adjust. Table 7 shows the variances of the four variables plotted in figure 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 7: Exit from Haircut Policy

Figure 9 shows the analysis when the central bank exits its haircut policy after twenty-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.

	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 8: Exit from Haircut Policy plus Taylor-Rule

The conclusion drawn from the variances in Table 8 is that less volatility in inflation comes at the cost of more volatility in the other variables. Again the anticipated exit is preferable to an unanticipated exit.

Finally, in Figure 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 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 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 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. This is confirmed by the variances produced by the simulation and which are depicted in Table 9.

	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 9: Exit from Constant Loan-to-Value Ratio

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 with the haircut a collateral policy as well. 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, 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. However, in this model framework 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, 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 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.

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Appendix

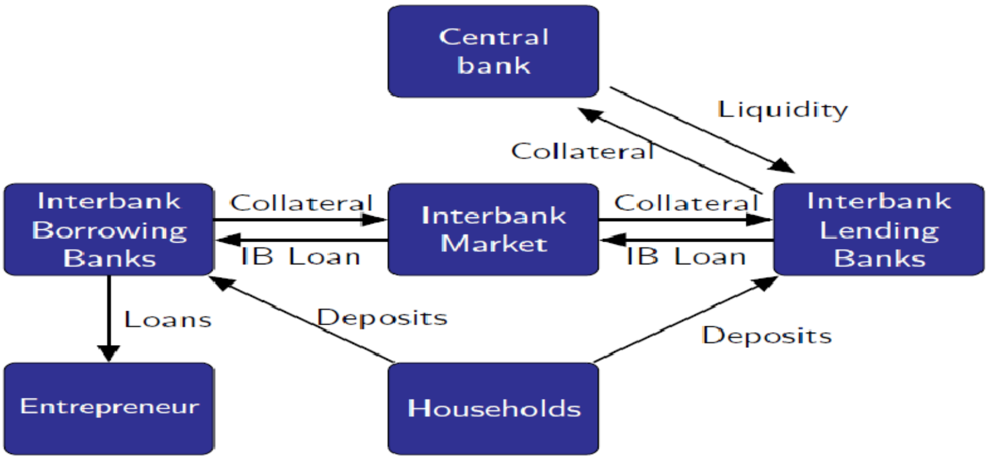

Figure 1: Model Graph

1.F Model Equations

1.F.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

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

Commercial Bank j

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

Commercial Bank k

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

1.F.2 Log-linearized Equations

Real Sector

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

Financial Sector

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

Shocks

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

1.G 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 10: Calibrated Model Parameters

1.H Dynamic Analysis

1.H.1 Impulse Response Analysis

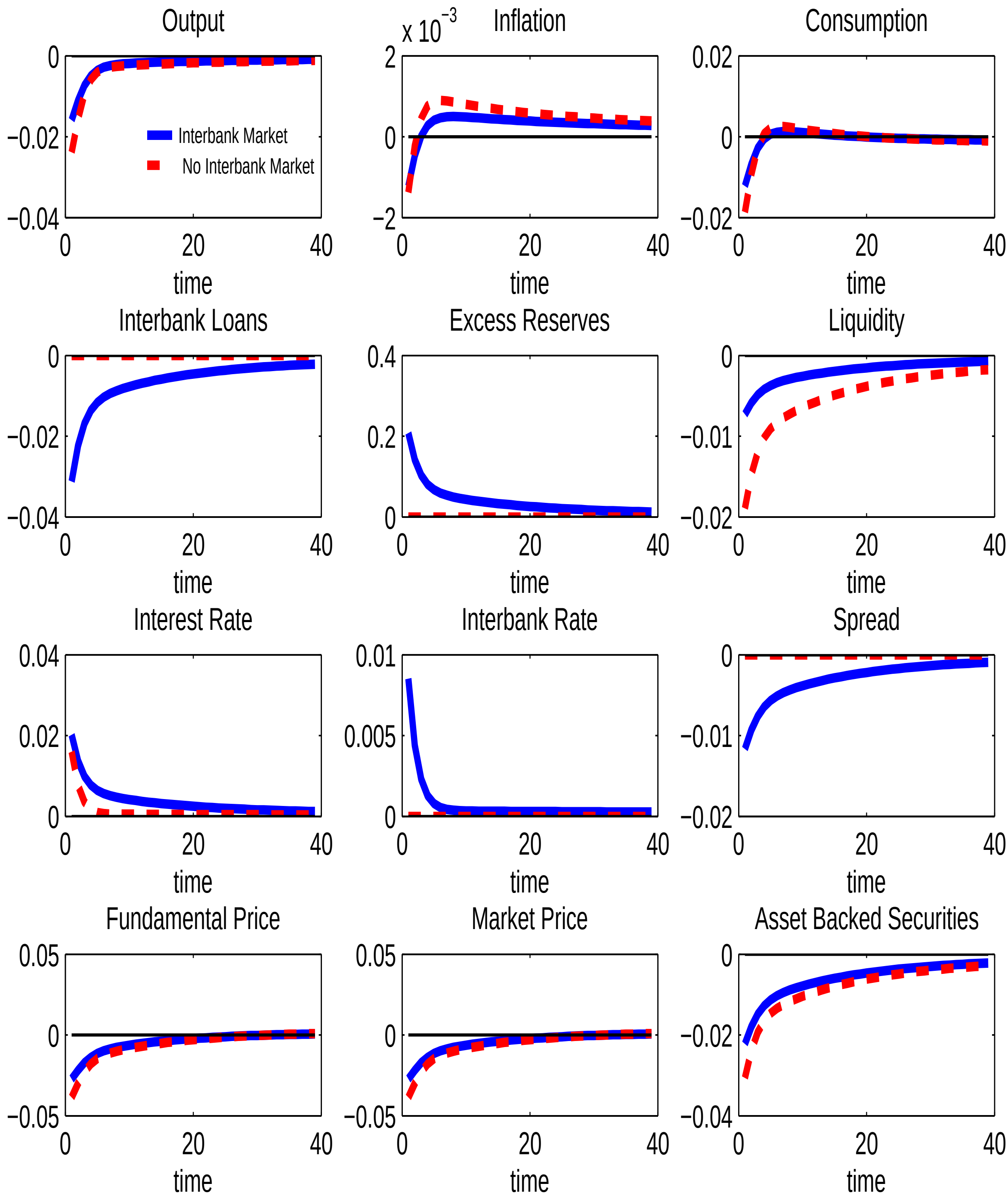

Figure 2: Interest Rate Shock

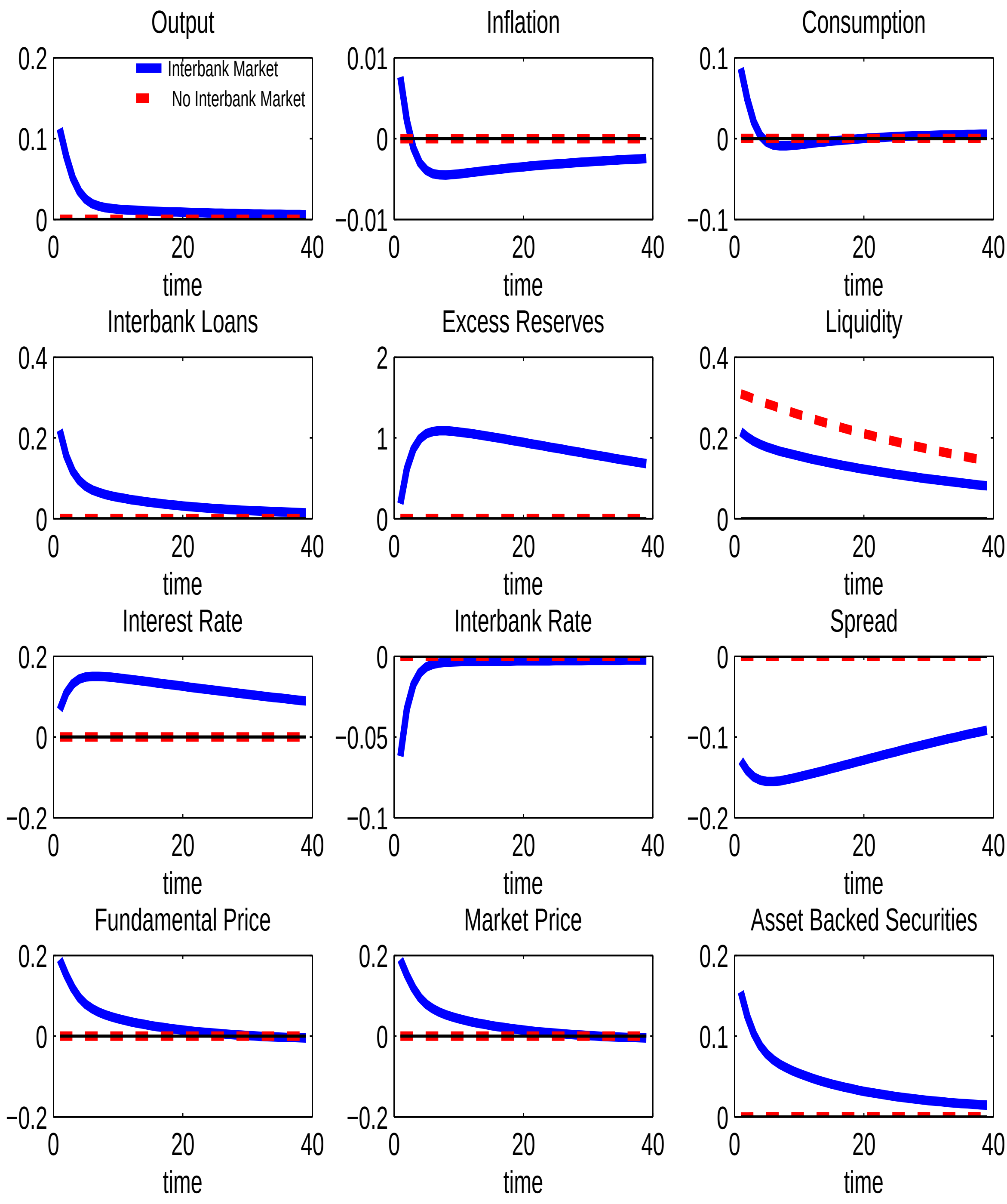

Figure 3: Haircut Shock

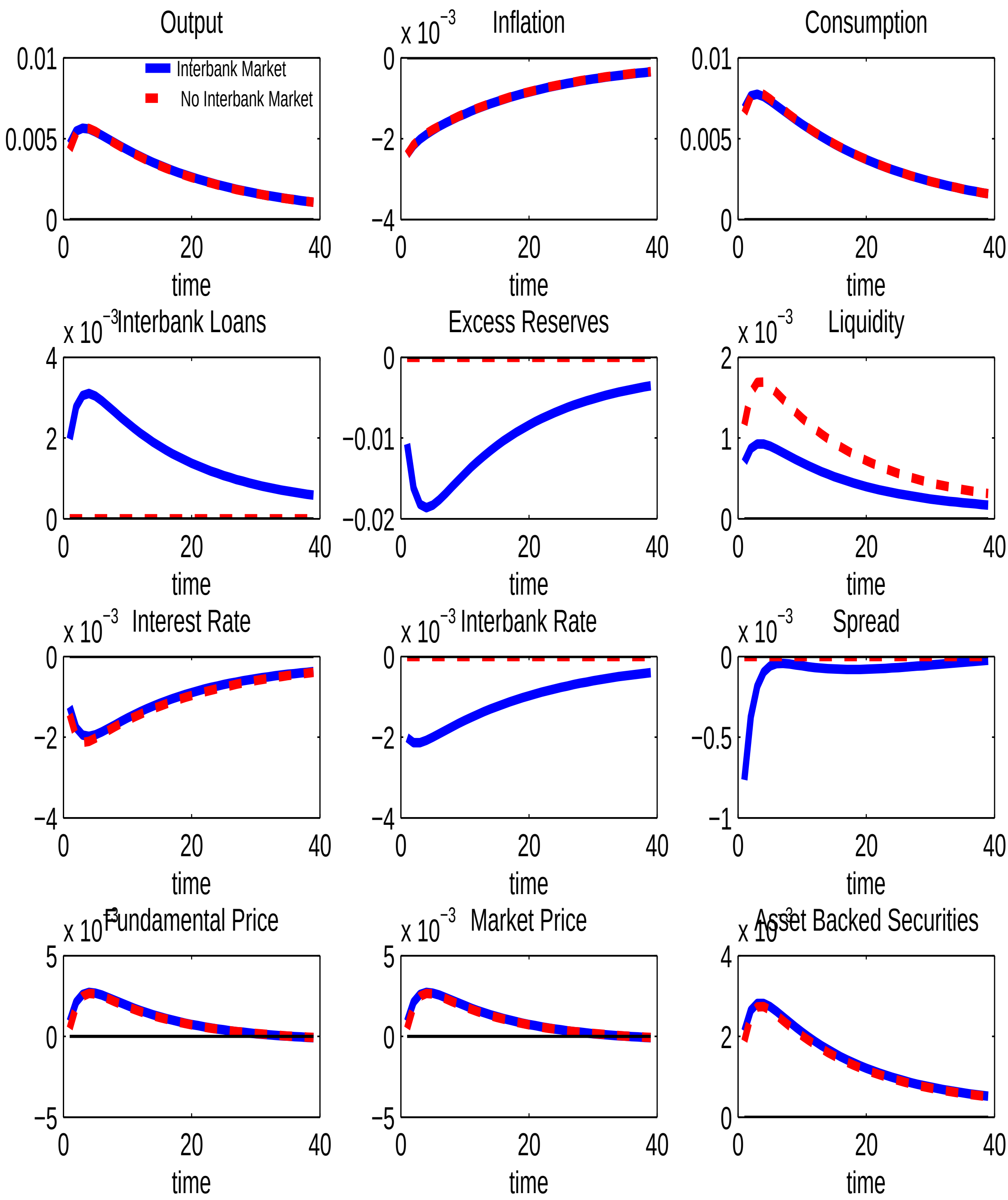

Figure 4: Technology Shock

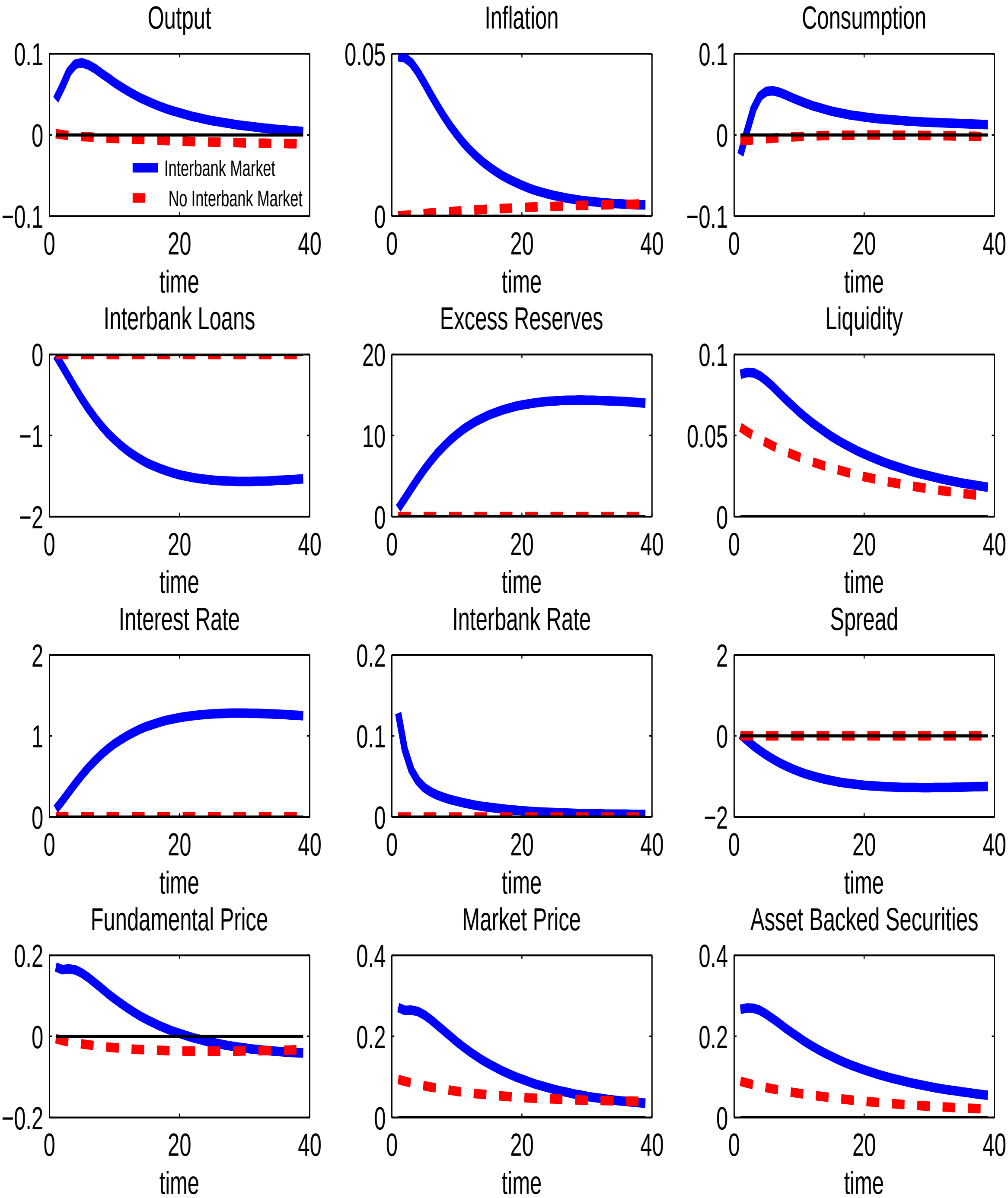

Figure 5: Market Price Shock

1.H.2 Boom-Bust Cycles

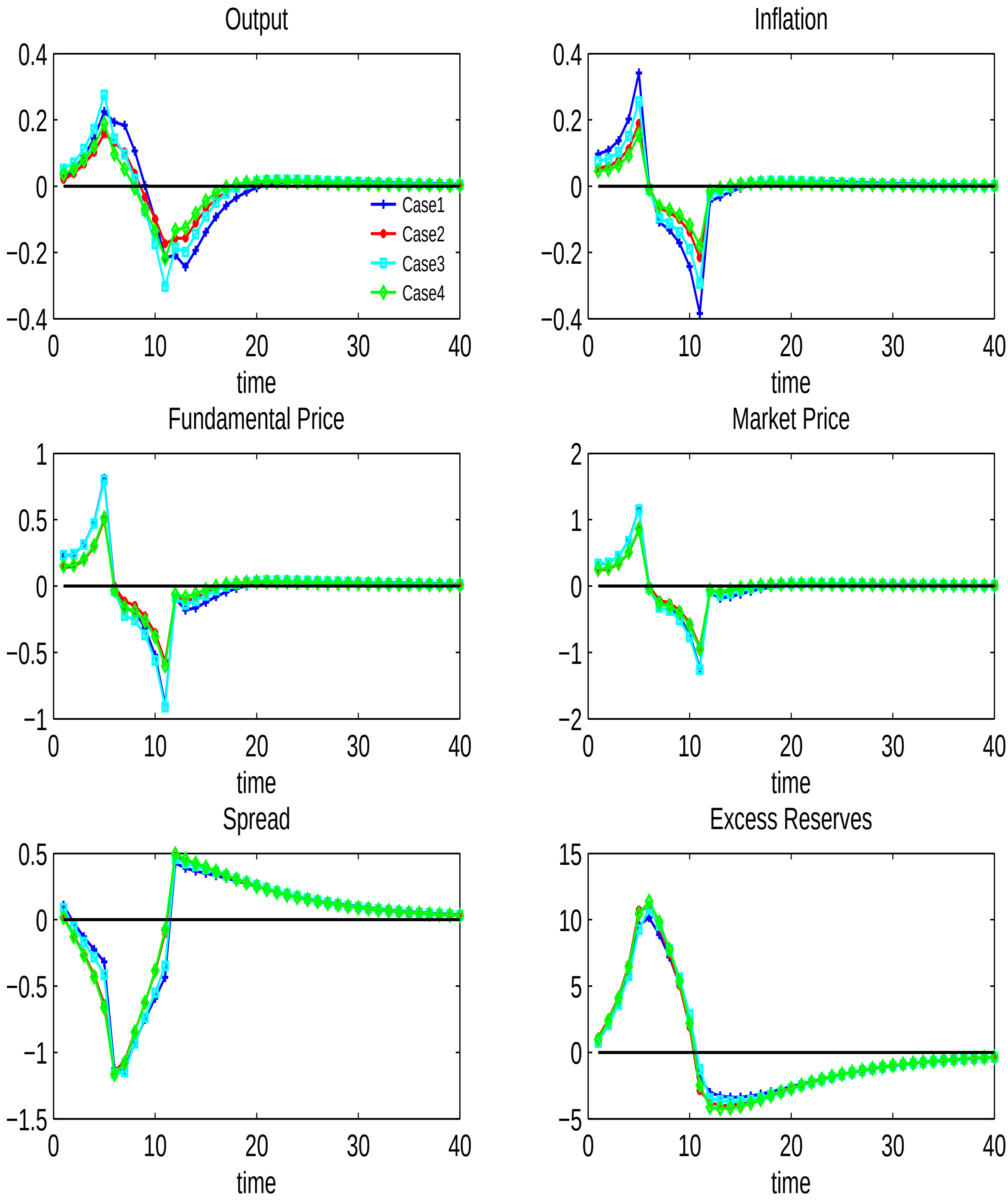

Figure 6: Boom-Bust Cycles I

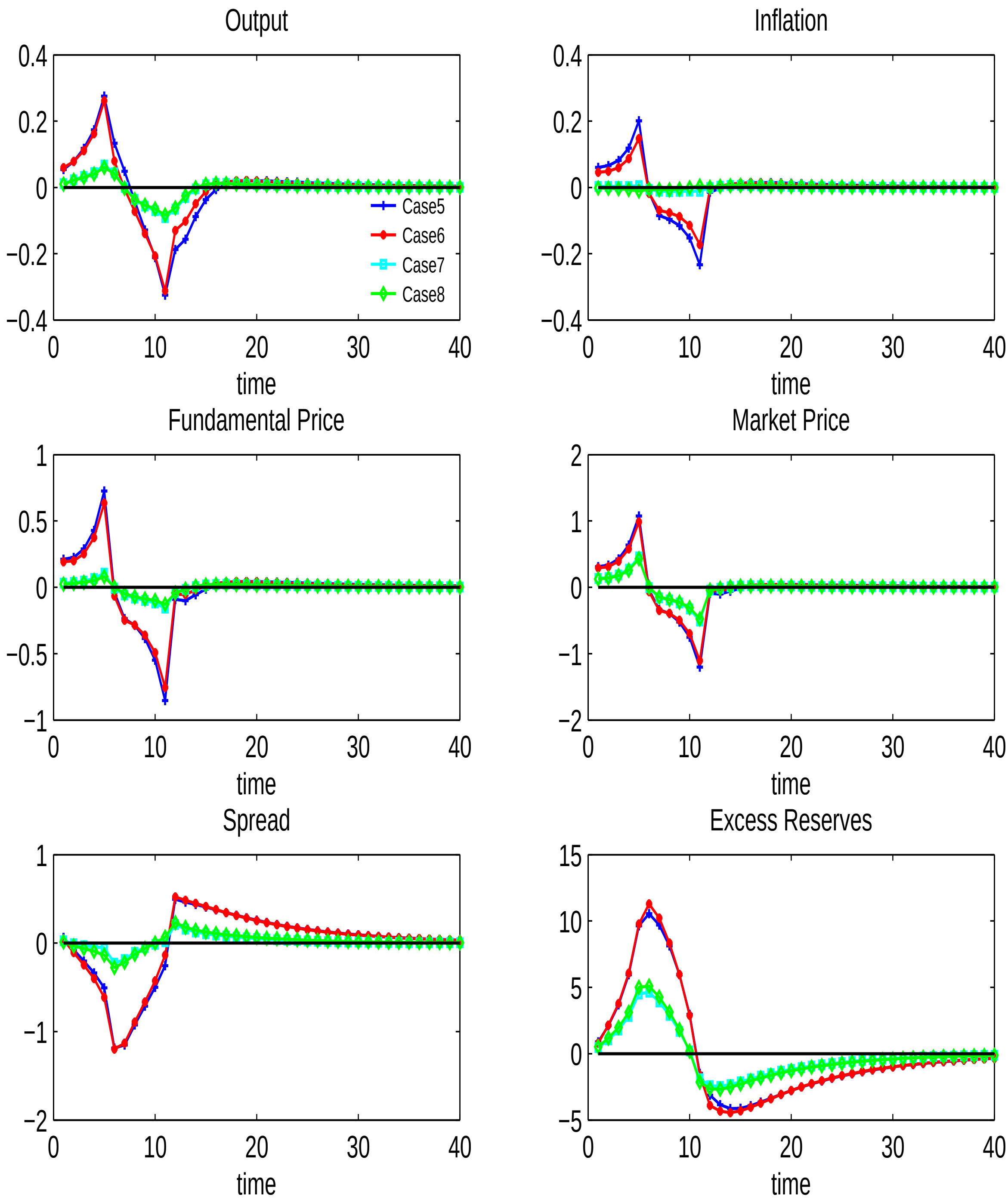

Figure 7: Boom-Bust Cycles II

1.H.3 Exit strategy

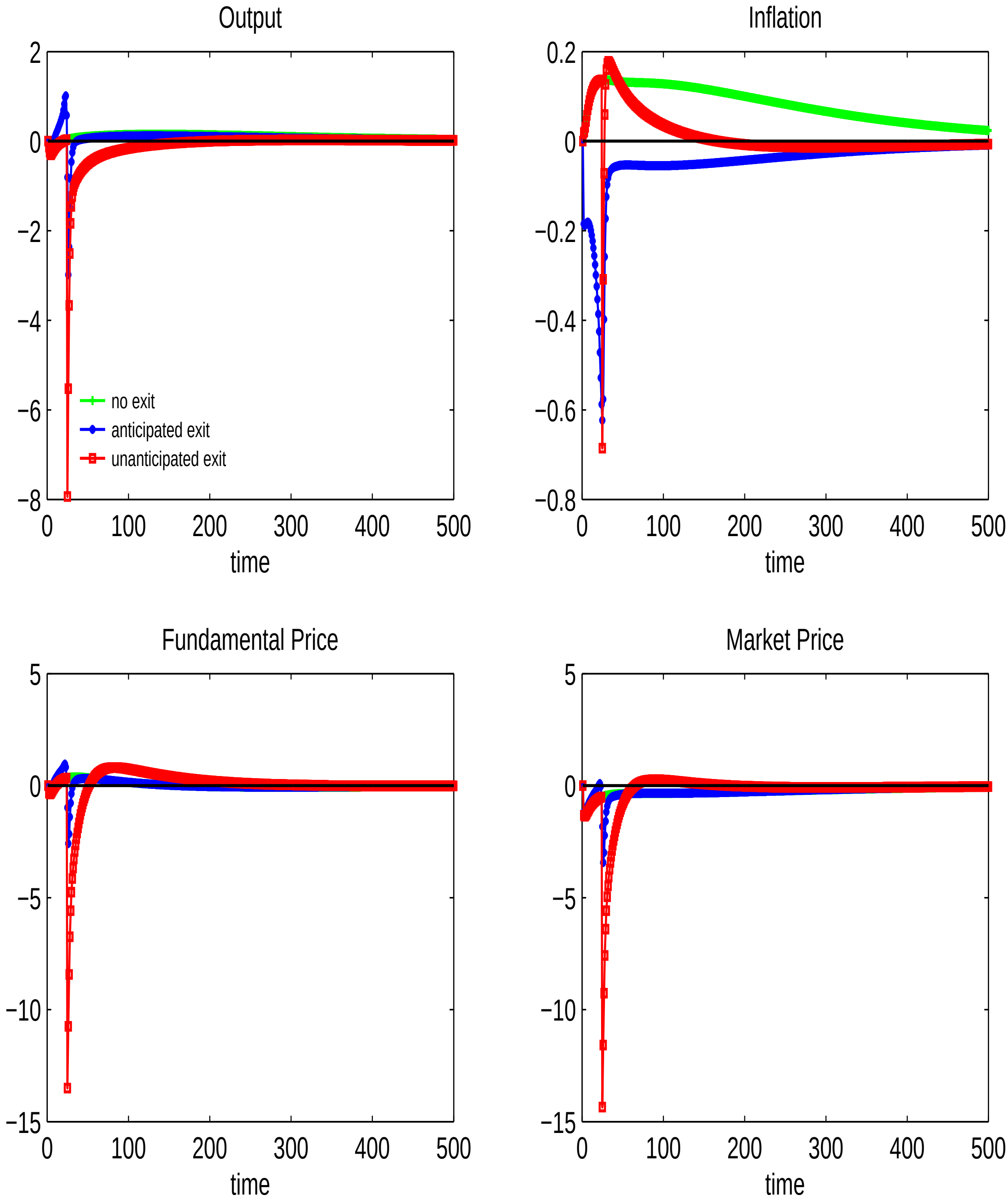

Figure 8: Exit Strategy: Haircut

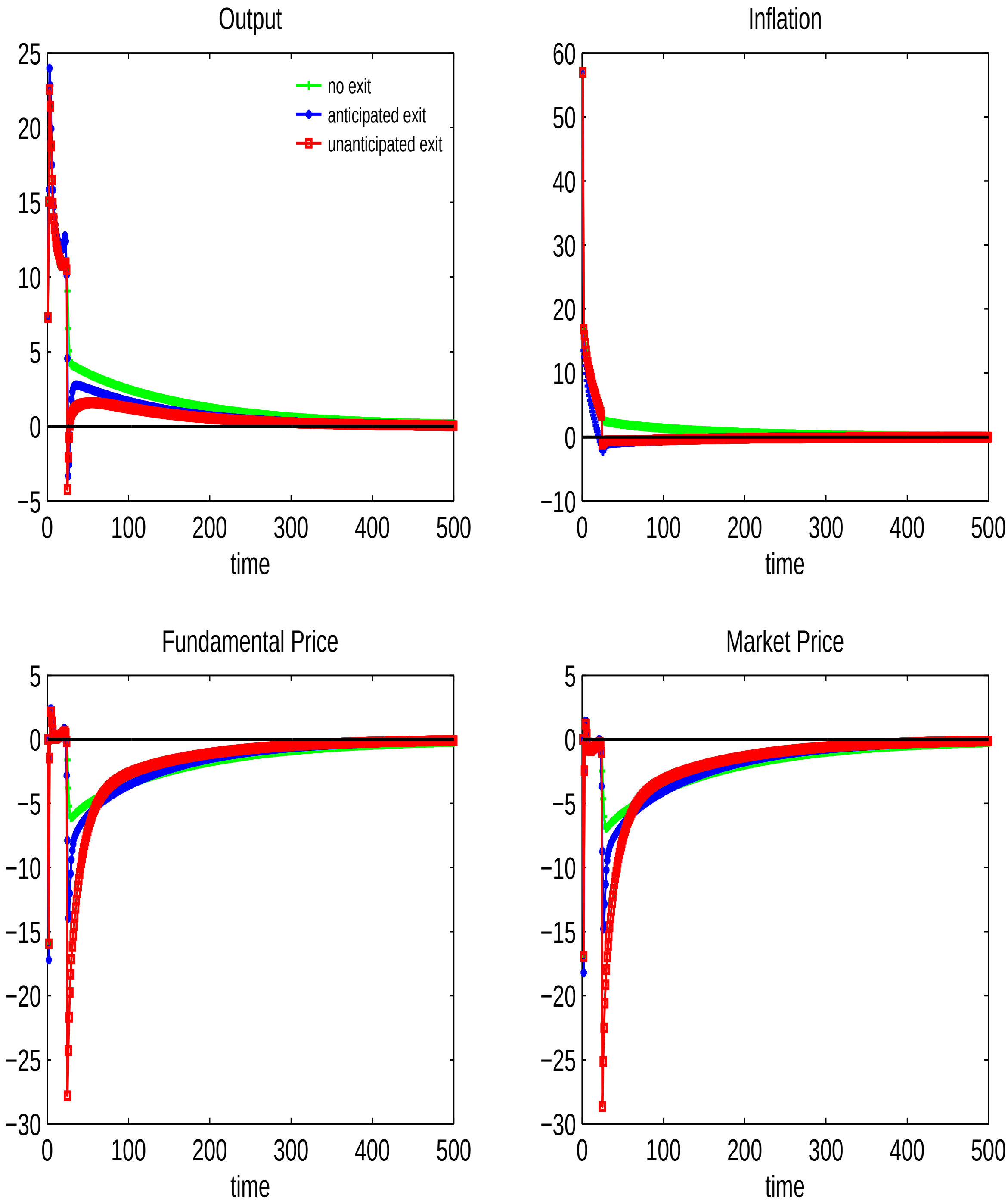

Figure 9: Exit Strategy: Haircut plus Taylor-Rule

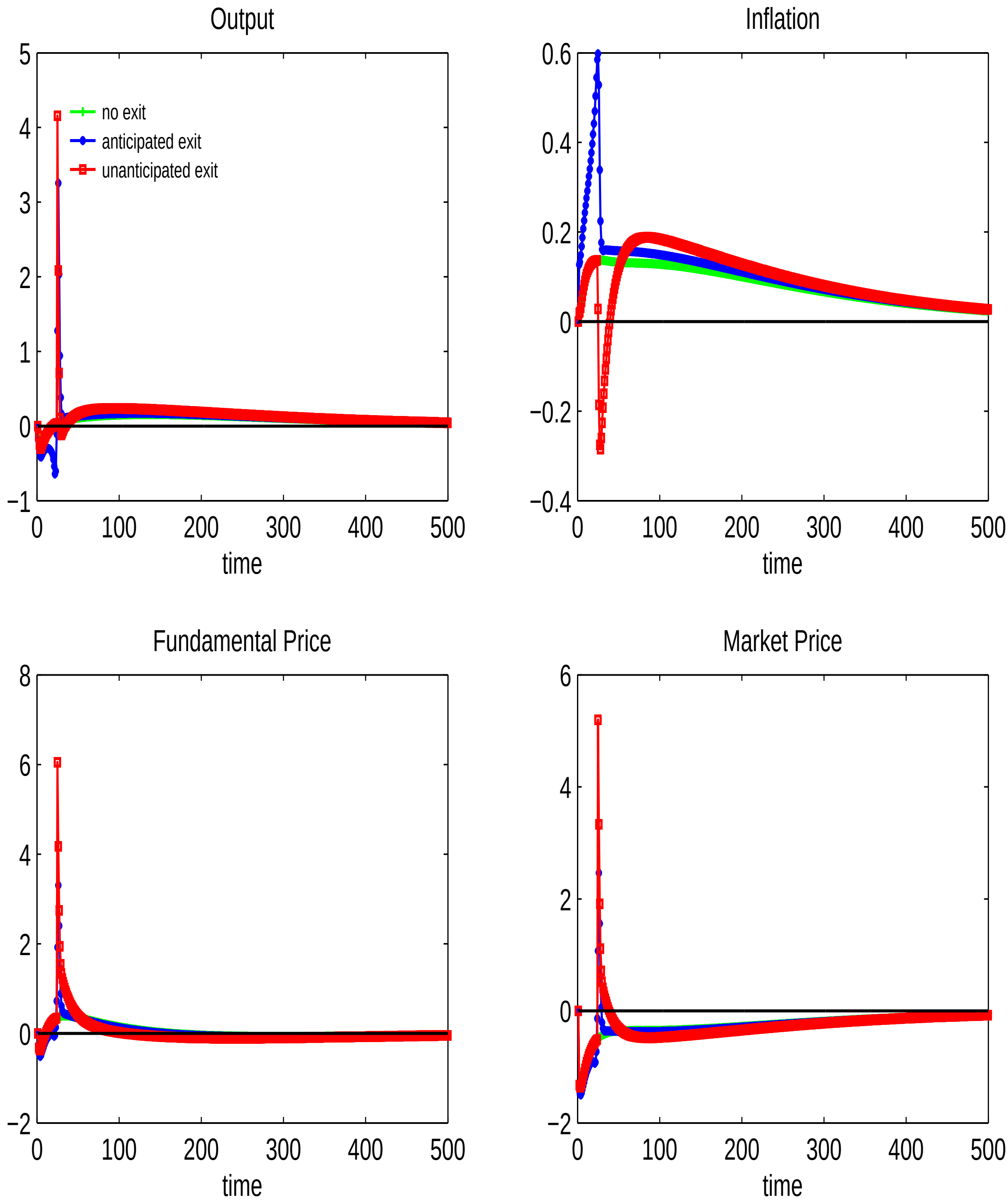

Figure 10: Exit Strategy: Loan-to-Value Ratio