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**MSc Economics**

# Monetary Policy in Models with Financial Frictions

A Master's Thesis submitted for the degree of
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MSc Economics

# Affidavit

I, Lukas Mayr

hereby declare

that I am the sole author of the present Master's Thesis,

Monetary Policy in Models with Financial Frictions

50 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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# *Abstract*

In this paper I discuss a dynamic stochastic general equilibrium model that incorporates banks as distinct economic agents. A financial friction constrains banks' ability to supply credit. In an economic recession, this friction leads to an amplification of the downturn. The model allows for an unconventional monetary policy similar to the one observed during the recent crisis. By directly supplying credit, the central bank is able to dampen economic contractions. I explain the mechanisms of the model on the basis of a simulated crisis and I discuss potential deficiencies.

One criticism of the model was that non-financial firms are financed solely via loans from banks, without being able to accumulate net worth, which they could use to self-finance a portion of their investments. As this assumption overstates the importance of the financial sector, it potentially could also overestimate the benefits of unconventional monetary policy. I change the model in order to adopt a more realistic financing structure of firms. Within my framework the benefits of unconventional monetary policy remain substantial.

In the remainder of the thesis, I introduce modifications of the model that try to capture more features observed during the Great Recession.

# Chapter 1

# Introduction

The recent crisis revealed that macroeconomic research should attach more importance to the financial sector. Although some pre-crisis models captured financial frictions in the form of credit market constraints on non-financial borrowers, the banking sector was typically not explicitly modeled. Moreover, in conventional models monetary policy was conducted only through the manipulation of interest rates according to a Taylor rule. Alternative policy actions usually have been excluded. The disruption of the financial system played an important role during this downturn and central banks took unconventional policy measures such as direct credit injections into the private sector. Thus, the gap between economic theory and reality has become apparent. In my thesis I analyze models that contributed to the current research effort of closing this gap.

I will give particular attention to a model presented by Gertler and Karadi (2011), in which banks intermediate funds from households to non-financial firms. An agency problem constrains the ability of banks to obtain deposits and therefore limits the credit supply. Due to their high degree of leverage, in an economic crisis banks' equity deteriorates. As a consequence their ability to supply credit is shortened further, which in turn leads to an amplification of the downturn. The model allows the central bank to directly supply credit to non-financial firms. Although central bank credit intermediation is assumed to be less efficient than credit intermediation of private banks, in crisis situations it dampens the investment decline and therefore the economic contraction. Hence, to some extent the model justifies policy measures that have been undertaken by several central banks during the Great Recession.

One potential shortcoming of Gertler and Karadi's model is that firms do not have equity. As a consequence their only source of financing are loans from banks. In reality firms self-finance a substantial portion of their investments, making them less dependent on banks than the model suggests. One could assume that therefore the model overstates the benefits of unconventional monetary policy, whose main purpose is to centrally supply credit in situations where private banks' ability to do so is limited. However, I show that even if one equips firms with a large amount of equity, the benefits of unconventional monetary policy are substantial.

In chapter 2 the model of Gertler and Karadi is explained in detail and all the equations of the model are presented. Chapter 3 explains the main mechanism of the model on the basis of a simulated crisis. An assessment of the model is undertaken in chapter 4. In this section potential deficiencies and weaknesses of the model are discussed. The discussion includes the above mentioned argument, initially formulated by Cole (2011), who criticizes that in the model firms finance their investments solely via credit from banks and are not able to accumulate retained earnings. In chapter 5 I change the model in order to take this point of criticism into account and I show that the model's qualitative implications are not affected by this change. In chapter 6 I present two modifications of Gertler and Karadi's model. The first by Gertler et al. (2012) focuses on the reasons that led banks to adopt risky balance sheet structures. The second by Gertler and Kiyotaki (2010) includes an interbank market in order to capture a disruption in interbank borrowing as it was observed during the crisis. Chapter 7 concludes.

# Chapter 2

# Model

In this section I describe the model of Gertler and Karadi (2011). The model is based on the monetary dynamic stochastic general equilibrium (DSGE) framework developed by Christiano et al. (2005) and Smets and Wouters (2007), among others. Additionally, the model incorporates a financial friction that induces a financial accelerator mechanism as in Bernanke et al. (1999). While their model abstracts from a financial sector and, along with other classic papers on financial frictions[1], emphasizes credit market constraints on non-financial borrowers, Gertler and Karadi incorporate banks as distinct economic agents.

In total, the model consists of five types of agents: Households, financial intermediaries (private banks), intermediate goods producers (firms), capital producers and monopolistically competitive final goods producers (retailers). The high number of types enables the separation of certain features of the model. Capital adjustment costs are captured within the capital producing sector and price rigidities within the final goods producing sector.

The role of banks is to intermediate funds from households to intermediate goods producers. A moral hazard problem constrains the ability of private banks to obtain deposits from households and hence the credit supply. Contrary to conventional models, monetary policy is conducted via both manipulation of interest

[1]See Calstrom and Fuerst (1997), Bernanke and Gertler (1989) and Kiyotaki and Moore (1997), to mention a few.

rates and credit policy. It is assumed that central bank credit intermediation involves efficiency costs but contrary to private banks, the central bank is not constrained in obtaining funds. As will be shown in chapter 3 in crisis situations this advantage outweighs the disadvantage and by acting as substitute for distressed private banks, the central bank is able to dampen the downturn.

## 2.1 Households

Identical households are described by the interval $[0, 1]$. Within each household a fraction $f$ of its members are bankers, the remaining fraction $1 - f$ are workers. Every banker runs a financial intermediary, of which profits are returned to its respective household. In order to ensure that bankers do not accumulate enough wealth to make the financial friction obsolete, it is assumed that every period a banker becomes a worker with a certain probability $1 - \theta$. A similar fraction of workers become bankers every period. On aggregate the flows between workers and bankers are such that the fraction $f$ remains constant.

Workers supply labor to intermediate goods producers and return wages to their household. Within each household there is perfect consumption insurance such that every member consumes the same amount of the final goods aggregator in every period.

Households save by lending to both private banks and the government. It is assumed that a household holds deposits only at banks it does not own.

The household internalizes consumption habits. It maximizes lifetime utility

$$\max_{C_{t+i}, L_{t+i}} E_t \sum_{i=0}^{\infty} \beta^i \Big( \ln(C_{t+i} - hC_{t+i-1}) - \frac{\chi}{1+\varphi} L_{t+i}^{1+\varphi} \Big)$$

with $0 < \beta < 1$, $0 < h < 1$, $\chi > 0$ and $\varphi > 0$ subject to the budget constraint

$$C_t + B_t = W_t L_t + \Pi_t - T_t + R_{t-1} B_{t-1}.$$

Every period $t$ households consume $C_t$ and buy riskless claims $B_t$, which include both privately and publicly issued debt, i.e.

$$B_t = B_t^P + B_t^G.$$

The variable $B_t^P$ describes deposits from households at private banks, $B_t^G$ are government bonds. Both types of claims pay the riskless gross real interest rate $R_t$. The other variables that contribute to the households disposable income are real wage $W_t$, which is obtained from labor $L_t$, net payouts from ownership of financial intermediaries and non-financial firms, $\Pi_t$, and lump sum taxes, $T_t$.

Denoting the household's marginal utility of consumption by

$$\varrho_t \equiv \frac{1}{C_t - hC_{t-1}} - \beta h E_t\Big[\frac{1}{C_{t+1} - hC_t}\Big]$$

and its marginal rate of substitution between consumption in $t+i$ and consumption in $t$ by

$$\Lambda_{t,t+i} \equiv \frac{\varrho_{t+i}}{\varrho_t},$$

the household's first order conditions are given by the labor supply equation

$$\varrho_t W_t = \chi L_t^{\varphi} \tag{2.1}$$

and the consumption Euler equation

$$E_t[\beta \Lambda_{t,t+1} R_t] = 1. \tag{2.2}$$

## 2.2 Financial Intermediaries

The incorporation of a financial sector (financial intermediaries, private banks) is a key difference to standard DSGE models. In this section I will explain the moral hazard problem within the financial sector that introduces a financial friction, which in turn affects aggregate real variables. As it involves more technicalities, a detailed discussion of banks' optimization problem is deferred to Appendix A.

Banks intermediate funds from households to intermediate goods producers (firms). A financial intermediary indexed by $j$ buys financial claims $S_t^j$ from firms at price $Q_t$. Hence, $S_t^j$ is the amount of credit supplied from bank $j$. It finances its assets via net worth (equity capital) $N_t^j$ and deposits $B_t^j$, which it obtains from households. Therefore, bank $j$'s balance sheet is given by

$$Q_t S_t^j = N_t^j + B_t^j. \tag{2.3}$$

The bank earns the stochastic return $R_{t+1}^k$ on its assets, while it has to pay the deterministic return $R_t$ on its liabilities.[2] Hence, its net worth evolves according to

$$\begin{aligned} N_{t+1}^j &= R_{t+1}^k Q_t S_t^j - R_t B_t^j \\ &= (R_{t+1}^k - R_t) Q_t S_t^j + R_t N_t^j. \end{aligned} \tag{2.4}$$

By choosing the quantity of assets $S_t^j$ the banker maximizes her expected discounted terminal wealth

$$V_t^j(N_t^j, S_t^j) = E_t \Big\{ (1-\theta)\beta\Lambda_{t,t+1} N_{t+1}^j + \theta\beta\Lambda_{t,t+1} \max_{S_{t+1}^j} V_{t+1}^j(N_{t+1}^j, S_{t+1}^j) \Big\}, \tag{2.5}$$

which she returns to her household in the period she becomes a worker. The value $V_t^j(N_t^j, S_t^j)$ is equal to the expected discounted net worth in period $t+1$ multiplied with the probability $1-\theta$ of becoming a worker plus expected discounted terminal wealth in period $t+1$ times the probability $\theta$ of staying a banker.

Let us now turn to the above mentioned moral hazard problem. Every period the banker can choose to divert a fraction $\lambda$ of her assets and transfer them to her household. While depositors can afterwards force the intermediary into bankruptcy and recover the remaining fraction $1-\lambda$ of assets, it is too costly for them to recover the diverted fraction. The banker will not choose this option if she gains more by staying in business than by diverting assets, i.e. if the incentive

[2] Note that I deviate from the notation of Gertler and Karadi (2011) with respect to timing in order to emphasize the fact that the riskless return is known at $t$, while the risky return is not. Nevertheless, both $R_t$ and $R_{t+1}^k$ describe returns from the same period.

compatibility constraint

$$V_t^j(N_t^j, S_t^j) \geq \lambda Q_t S_t^j \tag{2.6}$$

holds. Households are willing to supply funds (deposits) to the bank only if this condition is fulfilled. Hence, the banker maximizes 2.5 subject to 2.6 and a non-negativity constraint on assets $S_t^j$. A detailed discussion of this optimization problem is deferred to Appendix A, where I also show that expected discounted terminal wealth 2.5 can be written as

$$V_t^j(N_t^j, S_t^j) = \nu_t Q_t S_t^j + \eta_t N_t^j. \tag{2.7}$$

Defining the gross growth rates of assets and net worth by $x_{t,t+1} \equiv Q_{t+1}S_{t+1}^j / Q_t S_t^j$, respectively $z_{t,t+1} \equiv N_{t+1}^j / N_t^j$, the variable

$$\nu_t = E_t \Big\{ (1-\theta)\beta\Lambda_{t,t+1}(R_{t+1}^k - R_t) + \theta\beta\Lambda_{t,t+1} \max_{S_{t+1}^j}[x_{t,t+1}\nu_{t+1}] \Big\}$$

describes the expected discounted marginal value of an additional unit of assets $S_t^j$ when holding net worth $N_t^j$ constant and

$$\eta_t = E_t \Big\{ (1-\theta)\beta\Lambda_{t,t+1}R_t + \theta\beta\Lambda_{t,t+1} z_{t,t+1}\eta_{t+1} \Big\}$$

is the marginal value of having an additional unit of net worth when holding the quantity of assets constant. Plugging 2.7 into equation 2.6, one obtains

$$\nu_t Q_t S_t^j + \eta_t N_t^j \geq \lambda Q_t S_t^j. \tag{2.8}$$

Therefore the optimization problem is equivalent to maximizing 2.7 subject to 2.8 (and a non-negativity constraint for $S_t^j$).

Consider the case where $0 < \nu_t < \lambda$. As the marginal value of additional assets is positive, the banker wants to expand them as much as possible. She obtains funds from households only up to the point where the incentive constraint is binding.

Hence, in this case

$$Q_t S_t^j = \frac{\eta_t}{\lambda - \nu_t} N_t^j = \phi_t N_t^j \tag{2.9}$$

holds. The variable $\phi_t$ describes the bank's leverage ratio. Note that this leverage ratio depends negatively on the parameter $\lambda$ because with a higher fraction of assets, which the banker can divert, it is more difficult to obtain funds from households. Because this is the most interesting case, in the following I will assume a binding incentive constraint.[3]

Since neither $\eta_t$ nor $\nu_t$ depend on firm-specific factors, one can sum across individuals to obtain the aggregate intermediary demand for assets

$$Q_t S_t^P = \phi_t N_t, \tag{2.10}$$

where $N_t$ and $S_t^P$ denote aggregate net worth, respectively assets, of private banks.

From equations 2.4 and 2.9 it follows that bank $j$'s net worth law of motion is given by

$$N_{t+1}^j = [(R_{t+1}^k - R_t)\phi_t + R_t]N_t^j. \tag{2.11}$$

One can observe that the sensitivity of net worth to the realization of $R_{t+1}^k$ depends positively on the banks' leverage ratio. The higher the leverage ratio, the more vulnerable is the bank to low realizations of $R_{t+1}^k$.

Moreover, also the growth rates of net worth

$$z_{t,t+1} = \frac{N_{t+1}^j}{N_t^j} = (R_{t+1}^k - R_t)\phi_t + R_t$$

and assets

$$x_{t,t+1} = \frac{Q_{t+1} S_{t+1}^j}{Q_t S_t^j} = \frac{\phi_{t+1}}{\phi_t}\frac{N_{t+1}^j}{N_t^j} = \frac{\phi_{t+1}}{\phi_t} z_{t,t+1}$$

can be expressed independently of $j$.

[3] In fact, Gertler and Karadi (2011) argue that under reasonable parameter values the constraint always binds within a local region of the steady state. I discuss the other cases from the microeconomic view of the bank in Appendix A.

Aggregate net worth is the sum of the net worth of existing bankers $N_t^e$ and the net worth of new bankers $N_t^n$:

$$N_t = N_t^e + N_t^n \tag{2.12}$$

New bankers receive start-up funds from their respective household. These start-up funds are a fraction $\omega$ of the effective value of last period's privately intermediated assets:

$$N_t^n = \omega Q_t \xi_t S_{t-1}^p \tag{2.13}$$

The variable $\xi_t$ denotes an exogenous capital/asset quality shock. A negative realization of this shock will be the initiator of a crisis (see chapter 3).

From equation 2.11 and the fact that only a fraction $\theta$ of bankers survive every period, it follows that

$$N_t^e = \theta[(R_t^k - R_t)\phi_{t-1} + R_t]N_{t-1}. \tag{2.14}$$

Combining equations 2.12, 2.13 and 2.14 yields the following law of motion for aggregate net worth of banks:

$$N_t = \theta[(R_t^k - R_t)\phi_{t-1} + R_t]N_{t-1} + \omega Q_t S_{t-1}^p \tag{2.15}$$

## 2.3 Intermediate Goods Producers

In Gertler and Karadi's model, intermediate goods producers (firms), which are perfectly competitive, are not able to use retained earnings to fund their investments. They are therefore solely dependent on funds from banks. Cole (2011) criticized this assumption, which led me to change the model by endowing some firms with equity. As is shown in chapter 5, this did not affect the qualitative results. For the moment, however, consider the original specification by Gertler and Karadi (2011).

At the end of every period $t$ firms issue financial claims $S_t$ in order to acquire capital $K_{t+1}$ for use in production in period $t+1$. Claims are bought from both private banks and the central bank at price $Q_t$. The number of claims equals the units of capital bought from capital goods producers. Hence, the aggregate balance sheet of intermediate goods producers is given by

$$Q_t K_{t+1} = Q_t S_t, \tag{2.16}$$

with

$$S_t = S_t^p + S_t^g.$$

The variable $S_t^g$ describes credit intermediated by the central bank (government). Credit intermediation from banks to intermediate goods producers is assumed to be frictionless.

After production intermediate goods producers sell their output $Y_t^m$ to final goods producers at the (real) price $P_t^m$. Denoting total factor productivity by $A_t$, the utilization rate of capital by $U_t$ and an exogenous capital quality shock by $\xi_t$, the production function is given by

$$Y_t^m = A_t (U_t \xi_t K_t)^\alpha L_t^{1-\alpha}. \tag{2.17}$$

Note that negative realizations of $\xi_t$ are associated with crises situations, in which the effective quality of capital $\xi_t K_t$ declines.

It is assumed that the depreciation of capital depends on the utilization rate:

$$\delta(U_t) = \tilde{\delta} + \frac{b}{1+\zeta} U_t^{1+\zeta}$$

As the replacement price of used capital is normalized at unity, the first order condition for the utilization rate is given by

$$P_t^m \alpha \frac{Y_t^m}{U_t} = \delta'(U_t) \xi_t K_t. \tag{2.18}$$

Further, the firm chooses labor demand in order to equalize marginal product and marginal cost:

$$P_t^m(1-\alpha)\frac{Y_t^m}{L_t} = W_t \tag{2.19}$$

Given that intermediate goods producers do not have own funds to finance their capital acquisitions, they earn zero profits and have to pay the full return on capital

$$R_{t+1}^k = \frac{\left[P_{t+1}^m \alpha \frac{Y_{t+1}^m}{\xi_{t+1}K_{t+1}} + Q_{t+1} - \delta(U_{t+1})\right]\xi_{t+1}}{Q_t} \tag{2.20}$$

to the lending banks. Obviously, a crucial determinant of the risky rate $R_{t+1}^k$ is the realization of the capital valuation shock $\xi_{t+1}$.

## 2.4 Capital Producers

Perfectly competitive capital producers are owned by households. At the end of every period $t$ they buy capital from intermediate goods producers. They repair depreciated capital at a cost of one per unit, build new capital and sell the whole capital stock to intermediate goods producers at a price of $Q_t$ per unit. It is assumed that producing new capital is subject to adjustment costs, while repairing depreciated capital is not. Defining gross capital created by $I_t$, net investment by

$$I_t^n \equiv I_t - \delta(U_t)\xi_t K_t$$

and the steady state level of investment by $I$, discounted expected profits of capital producers are given by

$$\max_{I_t^n} E_t \sum_{s=t}^{\infty} \beta^{s-t}\Lambda_{t,s}\Big\{(Q_s-1)I_s^n - f\left(\frac{I_s^n + I}{I_{s-1}^n + I}\right)(I_s^n + I)\Big\}.$$

The function

$$f(x) = \frac{\eta_i}{2}(x-1)^2$$

describes the adjustment costs associated with changes in net investment.

The first order condition determines the price of capital

$$Q_t = 1 + f(.) + \frac{I_t^n + I}{I_{t-1}^n + I} f'(.) - E_t\Big[\beta\Lambda_{t,t+1}\Big(\frac{I_{t+1}^n + I}{I_t^n + I}\Big)^2 f'(.)\Big]. \tag{2.21}$$

## 2.5 Final Goods Producers

Final goods producers (retailers) are monopolistically competitive. Out of each intermediate good they produce one differentiated final good. The final output composite $Y_t$ is a typical Dixit-Stiglitz aggregator

$$Y_t = \Big(\int_0^1 Y_{f,t}^{\frac{\epsilon-1}{\epsilon}} df\Big)^{\frac{\epsilon}{\epsilon-1}},$$

where

$$Y_{f,t} = \Big(\frac{P_{f,t}}{P_t}\Big)^{-\epsilon} Y_t$$

is the output produced by retailer $f \in [0,1]$ and

$$P_t = \Big(\int_0^1 P_{f,t}^{1-\epsilon} df\Big)^{\frac{1}{1-\epsilon}}$$

is the aggregate price level. It is assumed that each period with probability $1-\gamma$ a firm is able to adjust its price, while with probability $\gamma$ it is not. Prices are indexed to lagged inflation. The parameter $\gamma_p$ determines the degree of price indexation. If in a period $t$ a retailer is able to change its price, it chooses $P_{f,t}$ such that it maximizes expected discounted profits

$$\max_{P_{f,t}} \Big\{ \Big[\frac{P_{f,t}}{P_t} - P_t^m\Big] Y_{f,t} + E_t \sum_{i=1}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \Big[\frac{P_{f,t}}{P_{t+i}} \prod_{k=1}^{i} \Pi_{t+k-1}^{\gamma_p} - P_{t+i}^m\Big] Y_{f,t+i} \Big\},$$

where $\Pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate between $t$ and $t+1$. Defining steady state markup as

$$\mu \equiv \frac{\epsilon}{\epsilon - 1},$$

the first order conditions are given by

$$\Big[\frac{P_{f,t}}{P_t} - \mu P_t^m\Big] Y_{f,t} + \sum_{i=1}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \Big[\frac{P_{f,t}}{P_{t+i}} \prod_{k=1}^{i} \Pi_{t+k-1}^{\gamma_p} - \mu P_{t+i}^m\Big] Y_{f,t+i} = 0. \tag{2.22}$$

Hence, the aggregate price level evolves according to

$$P_t = \Big[(1-\gamma) P_{f,t}^{1-\epsilon} + \gamma \Big(\Pi_{t-1}^{\gamma_p} P_{t-1}\Big)^{1-\epsilon}\Big]^{\frac{1}{1-\epsilon}}. \tag{2.23}$$

## 2.6 Central Bank

A main feature of the model is that monetary policy is not only conducted by affecting interest rates via a Taylor rule (conventional monetary policy), but also via credit policy (unconventional monetary policy). The government (central bank) can engage in direct credit intermediation. Total assets intermediated are the sum of assets intermediated by private banks and assets intermediated by the central bank:

$$Q_t S_t = Q_t S_t^p + Q_t S_t^g \tag{2.24}$$

The central bank finances its claims $S_t^g$, which it obtains from intermediate goods producers, by issuing bonds $B_t^g$ to households. As private banks, the central bank obtains the risky return $R_{t+1}^k$ for its assets and pays the riskless return $R_t$ for its liabilities. Contrary to private banks, the government is not balance sheet constraint. However, the disadvantage of central bank lending is that it involves an efficiency cost $\tau$ per unit of credit supplied.

If a fraction $\psi_t$ of total assets is intermediated by the government, total assets can be written as

$$Q_t S_t = \phi_t N_t + \psi_t Q_t S_t = \frac{\phi_t}{1-\psi_t} N_t.$$

Therefore, government lending increases the ratio of total assets to banks' net worth.

While it is assumed that during normal times conventional monetary policy is sufficient, during economic crises the central bank additionally conducts unconventional monetary policy. In these situations the central bank injects credit according to the rule

$$\psi_t = \psi + vE_t\Big[(R^k_{t+1} - R_t) - (R^k - R)\Big], \tag{2.25}$$

where $\psi$ is the steady state fraction of assets intermediated by the central bank (typically zero or very small) and $R^k - R$ is the steady state premium. As credit spreads rise in crisis situations, the central bank responds by increasing the credit supply (assuming a positive feedback parameter $v$).

As already noted, the second policy rule is a standard Taylor-type interest rate rule

$$i_t = (1 - \rho_i)\Big[i + \kappa_\pi \pi_t + \kappa_y(\log Y_t - \log Y^n_t)\Big] + \rho_i i_{t-1} + \varepsilon^m_t, \tag{2.26}$$

where $i$ is the steady state nominal interest rate, $Y^n_t$ is the natural (flexible price equilibrium) output and $\rho_i$ is an interest rate smoothing parameter. The relationship between nominal interest rate $i_t$ and real interest rate is given by the Fisher equation

$$1 + i_t = R_t E_t[\Pi_{t+1}].$$

Further, it is assumed that the government's budget is balanced. Government expenditures $G$, which are assumed to be constant, and efficiency costs of government credit intermediation are financed via lump sum taxes and net returns from government bonds:

$$G + \tau\psi_t Q_t K_{t+1} = T_t + (R^k_t - R_{t-1})B^g_{t-1}$$

## 2.7 Aggregate Resource Constraint

The model's assumptions imply that output is the sum of consumption, investment (including associated adjustment costs), government expenditures and efficiency costs of government credit intermediation. Therefore, the aggregate resource constraint is given by

$$Y_t = C_t + I_t + f\Big(\frac{I_t^n + I}{I_{t-1}^n + I}\Big)(I_t^n + I) + G + \tau\psi_t Q_t K_{t+1}. \tag{2.27}$$

Further, the law of motion law of motion for capital can be written as

$$K_{t+1} = \xi_t K_t + I_t^n.$$

This completes the description of the model's equations.

# Chapter 3

# Crisis Simulation

In this section, the main mechanism of the model is explained on the basis of a simulated crisis. Gertler and Karadi (2011) define a crisis as a negative shock to capital quality $\xi_t$. They argue that one should think of this shock as a rare event, which conditional on occurring obeys an AR(1) process:

$$\log(\xi_t) = \rho_\xi \log(\xi_{t-1}) + \varepsilon_t^\xi$$

The (quarterly) auto-correlation parameter is $\rho_\xi = 0.66$. A negative realization of $\varepsilon_t^\xi$ results in a deterioration in banks' assets, which produces an enhanced decline in their net worth due to their high degree of leverage. Gertler and Karadi claim to capture the broad dynamics of the sub-prime crises in this way.

In Table 3.1 I present the parameter values of the model. Following Gertler and Karadi (2011), I calibrated the parameters such that in steady state the utilization rate $U$ is equal to one, the depreciation rate $\delta$ is equal to 0.025, the leverage ratio $\phi$ is equal to four, the annual interest rate spread is one hundred basis points and the average horizon of a banker is one decade.

The following analysis considers the evolution of several variables after a negative 5% shock to capital quality. In Figure 3.1 Gertler and Karadi's model is compared to the model, where the financial friction is eliminated (DSGE). Since the purpose

TABLE 3.1: Calibration

| Parameter | Value | Explanation |
|---|---|---|
| Households: | | |
| $\beta$ | 0.990 | Discount factor |
| $h$ | 0.815 | Habit parameter |
| $\chi$ | 3.409 | Relative utility weight of labor |
| $\phi$ | 0.276 | Inverse Frish elasticity of labor supply |
| Financial Intermediaries: | | |
| $\lambda$ | 0.381 | Fraction of assets that bankers can divert |
| $\omega$ | 0.002 | Proportional transfer to entering bankers |
| $\theta$ | 0.972 | Survival rate of bankers |
| Intermediate Goods Producers: | | |
| $\alpha$ | 0.330 | Effective capital share |
| $\tilde{\delta}$ | 0.020 | Intercept in capital depriciation function |
| $b$ | 0.038 | First derivative of capital depriciation function |
| $\zeta$ | 7.200 | Elasticity of marginal depreciation w.r.t. utilization rate |
| Capital Producers: | | |
| $\eta_i$ | 1.728 | Inverse elasticity of net investment w.r.t. price of capital |
| Final Goods Producers: | | |
| $\epsilon$ | 4.167 | Elasticity of substitution |
| $\gamma$ | 0.779 | Probability of keeping prices fixed |
| $\gamma_p$ | 0.241 | Measure of price indexation |
| Government: | | |
| $\kappa_\pi$ | 1.500 | Inflation coefficient in Taylor rule |
| $\kappa_y$ | 0.125 | Output gap coefficient in Taylor rule |
| $\rho_i$ | 0.000 | Smoothing parameter in Taylor rule |
| $g$ | 0.200 | Fraction of steady state output used for government expenditures |
| $\psi$ | 0.000 | Fraction of assets intermediated by central bank in steady state |
| $\tau$ | 0.001 | Efficiency cost of government credit intermediation |

of this figure is to demonstrate the effect of the financial friction, for the moment I abstract from credit policy ($v = 0$).

One can observe that the downturn in the frictionless model is less severe than in the model presented in chapter 2. The phenomenon that financial frictions lead to an amplification of shocks was discussed in the literature before it became popular to include banks as distinct economic agents.[1] Here, the capital valuation shock immediately affects the rate of return $R_t^k$, which banks obtain from their assets. As noted earlier, because banks are leveraged, the negative realization of $R_t^k$ leads to a sharp decline in their net worth. The leverage constraint then requires banks to reduce their demand for assets and therefore their supply of credit. As a result the premium $E[R_{t+1}^k] - R_t$ rises, increasing the cost of credit and reducing capital demand. The reduced demand for both assets and capital implies a reduction in asset prices $Q_t$, weakening banks' balance sheets further and enhancing the downturn. As a result investment declines by more than in the standard DSGE model leading to a more severe contraction in output and consumption. Subsequently, banks start accumulating net worth again, allowing

[1]See for example Bernanke et al. (1999).

them to increase the credit supply. This reduces credit spreads and moves the economy slowly back to the steady state.

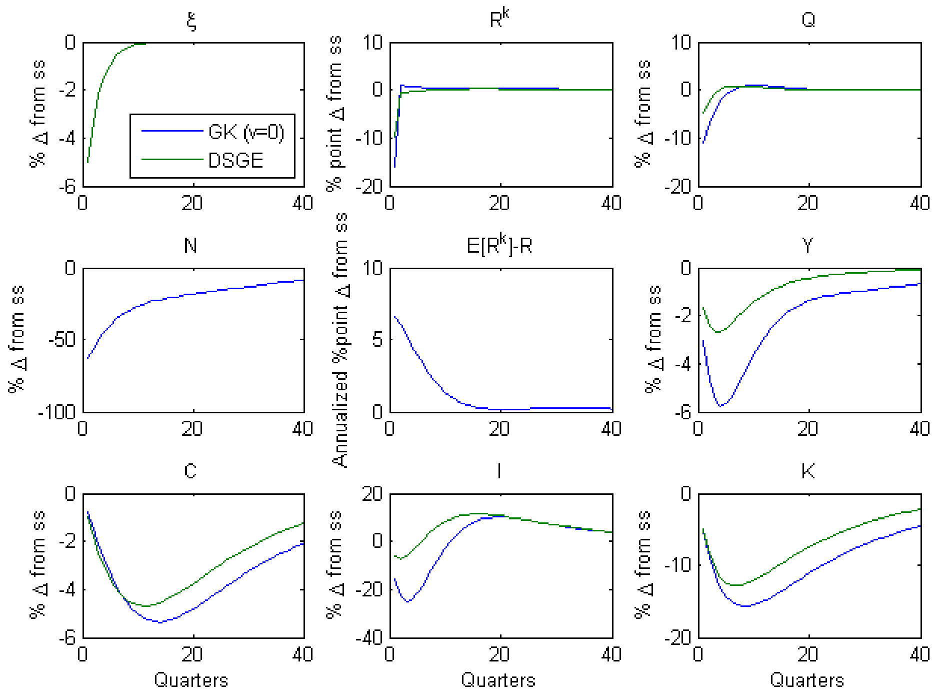


FIGURE 3.1: Crisis without unconventional monetary policy

The impulse responses for the case, in which the government reacts to a movement in credit spreads by directly supplying credit to intermediate goods producers is depicted in Figure 3.2. As Gertler and Karadi (2011), I consider a more moderate credit policy with a feedback parameter of $v = 10$ and a more aggressive credit policy with $v = 100$. I compare these policies to the case without government credit intermediation ($v = 0$). Besides the variables plotted in Figure 3.1, I also show the fraction $\psi_t$ of assets intermediated by the central bank.

The more aggressive the central bank reacts to a movement in credit spreads, the more muted is the economic contraction. By acting as substitute for distressed private banks, whose ability to supply credit is limited, the central bank is able to dampen the investment decline. As a result, with an aggressive credit policy, the contraction in output and consumption is muted.

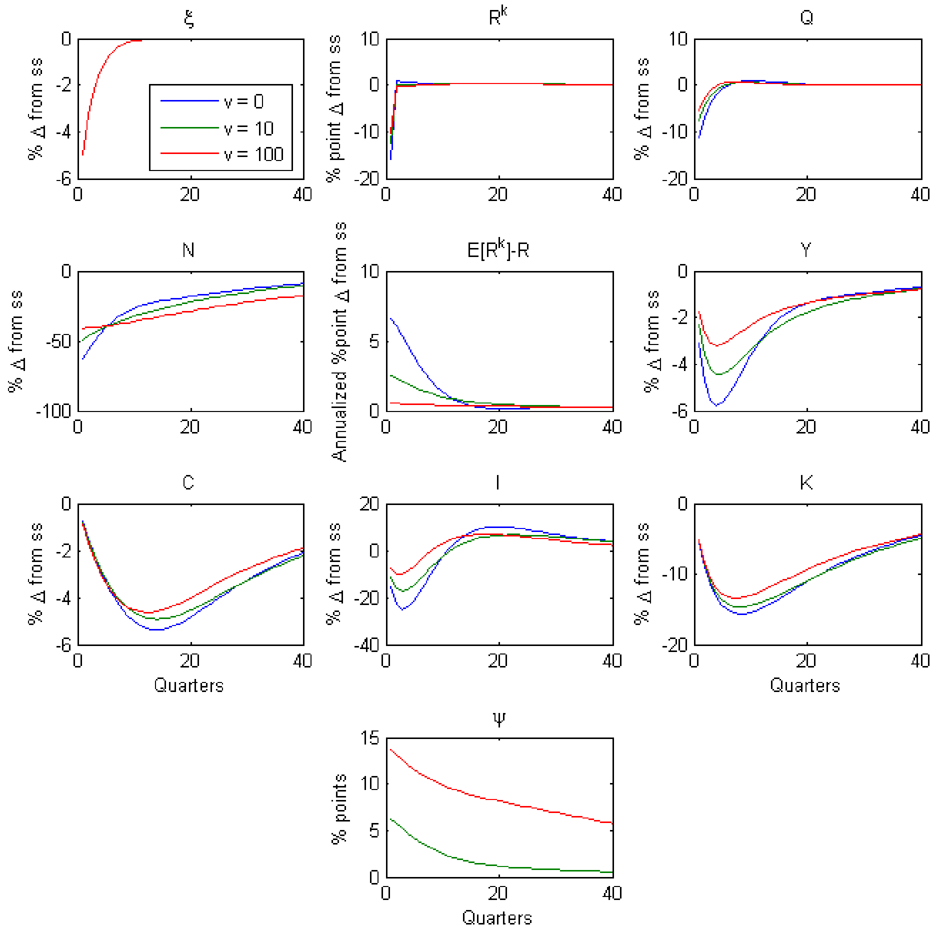


FIGURE 3.2: Crisis with unconventional monetary policy

The model suggests that in crisis situations, the central bank should engage in direct lending activities. Therefore, the model to a certain extent justifies the policies performed by several central banks during the recent years.

# Chapter 4

# Assessment of the Model

The model of Gertler and Karadi (2011) captures several features observed during the recent downturn. These features include a reduction in private credit intermediation and the possibility of central banks to directly supply credit. The model suggests that in crises situations such an unconventional policy has a dampening effect and therefore to a certain extent justifies the actions performed by several central banks during the Great Recession. The question is whether this model is a good approximation of reality.

Cole (2011) acknowledges the model of Gertler and Karadi (2011) as an important contribution to a new area in monetary policy but he also finds some deficiencies.

First, he criticizes that in every period intermediary goods producers refinance themselves from scratch without having the possibility to use retained earnings. He argues that if Gertler and Karadi's model of firm financing was correct, financial liabilities and net worth of a firm should more or less offset. But in 2008 financial assets of the non-farm non-financial corporate sector amounted to USD 13.5 trillion and tangible assets to USD 13.9 trillion. With net worth of these corporations being about USD 14 trillion, this implied that their financial assets were essentially equal to the value of their financial liabilities. This indicates that many firms are not cash constrained but instead self-finance their investments. Cole cites studies, which estimate that on average firms self-finance 80%

of their investments. In chapter 5 I change the model in order to take this point of criticism into account.

Second, he questions the assumptions that financial intermediaries start with a low level of net worth and die at a fast enough rate in order to have the incentive constraint binding. While in the model this feature constrains the lending activities of banks, in reality banks do not seem to be constrained. The model suggests that households withdraw deposits in crises situations but in 2008 deposits at U.S. banks even increased by 5%. Reasons for this include the deposit insurance provided by the government and increased risk in the bond market. Moreover, banks' excess reserves increased between August and December 2008 from USD 46 billion to USD 820 billion, while the required reserves only increased from USD 44 billion to USD 53 billion in the same period.

Third, Cole criticizes that in the model banks do not hedge their risk. The introduction of state-contingent claims, which would allow banks to transfer wealth across future states of the world could severly dampen the impact of shocks.

In order to understand Cole's last argument, I have to introduce an equivalent formulation of credit policy. In section 2.6 the central bank conducted credit policy by financing the claims, which it acquired from firms, via government bonds issued to households. Gertler and Karadi argue in the following way: Consider the case, where the central bank issues government bonds not to households but to financial intermediaries, who in turn fund these government debt holdings by issuing bonds to households that are perfect substitutes. If one assumes that the moral hazard problem does not apply to banks' government debt holdings, the two formulations are equivalent.[1] Basically, assuming that only funding of private assets is balance sheet constraint is the same as assuming that the government is more efficient than the household in recovering diverted assets. If the bank chooses to divert a fraction $\lambda$ of its assets, it is forced into bankruptcy. While the household is able to recover only the fraction $(1-\lambda)$ of private assets, the government is able to recover all public assets.

[1]According to Gertler and Karadi the virtue of the second formulation is that intermediary holdings of government debt are interpretable as interest bearing reserves.

What Cole criticizes is the way, in which the financial friction is set up:

> *"[...] [O]ne aspect of the modeling bothered me. The friction on financial intermediaries that [...] comes from the fear that they will steal. However, I would argue that the real concern with financial intermediaries is that they will take on excessive risk because of the skewed nature of their compensation. Substantively, a change in the friction from stealing to gambling may not change the results very much. But, it may make it seem less plausible that the government has a real advantage in recovery [sic] funds from defaulting intermediaries if they have gambled them away. Since this recovery advantage is important to generate the positive impact of nonconventional monetary policy, rethinking the friction to make it more realistic may reduce the ability of the government to stimulate the economy."* (Cole (2011): 38)

An easy way to circumvent Cole's criticism would be to stick to the original formulation of credit policy, in which the government borrows from households and directly lends to firms. However, the purpose of credit policy in the model is to mimic the actions performed by central banks, especially the Federal Reserve, during the recent crisis. As central banks mainly operate through the financial sector, I would agree that a more realistic modeling of the financial friction would be desirable. In section 6.1 I discuss a modification of the model that tries to improve upon the issue of moral hazard. In particular, banks are able to obtain funds via issuing both short term deposits and outside equity. This approach tries to capture the reasons why banks adopt risky liability structures. In this model by Gertler et al. (2012), the fraction of assets that bankers can divert is not a constant but a function of the bank's liability structure. However, the main mechanism of the financial friction is unchanged.

Given all these (potential) deficiencies I want to add that even if one accepts the model's assumptions as reasonably realistic, one has to be careful when using it as justification for the large scale credit intermediation of central banks during the recent crisis. As was shown in section 3, if the economy was originally in steady state, the model implies that unconventional monetary policy dampens the downturn after a temporary contractionary shock (a negative realization of $\varepsilon^{\xi}$). However, when comparing it to the recent crisis, one question has to be answered before considering central bank lending as valid instrument for stimulating the economy. Was the economy originally in steady state? There is broad agreement that before the outbreak of the crisis, assets, in particular real estate, have been overvalued. The model implies that the central bank should supply credit if a shock occurred, which moved asset/capital quality below its steady state value. This is not necessarily the case if asset prices have been above their steady state value before a correction moved them down.

# Chapter 5

# Extension: Firms with Equity

As discussed in chapter 4, Cole (2011) criticizes that instead of relying solely on funds from banks, in reality firms finance a large portion of their investment via their own net worth. In particular, he cites a study by Ohanian (2010), who estimates that on average firms self-finance 80% of their investment. I changed the model in order to take this point of criticism into account and I investigated whether this has qualitative and/or quantitative effects on the model's implications.

I extended the model of Gertler and Karadi (2011) by endowing some intermediate goods producers with equity, which they use to finance their capital acquisitions. In this extended model, a fraction $f^b$ of household members are bankers, a fraction $f^i$ are intermediate goods producers and a fraction $1 - f^b - f^i$ are workers. Every intermediate goods producer runs a firm, of which profits are returned to its respective household. As before, a bankers stays a bankers in the next period with probability $\theta^b$, while with probability $1 - \theta^b$ he becomes a worker. Similarly, an intermediate goods producer continues running his firm with probability $\theta^i$, while with probability $1 - \theta^i$ he becomes a worker.[1] Flows between the three different occupations are such that $f^b$ and $f^i$ remain constant over time.

[1]For simplicity, I assume that there are no direct flows between bankers and intermediate goods producers.

There are two types of perfectly competitive intermediate goods producers. Those run by household members are endowed with a start-up equity capital in the same way as bankers are. The other firms have the same properties as in the model of Gertler and Karadi. Particularly, they do not have any equity.

Accordingly, every period an equity owning firm uses all its net worth to acquire capital from capital goods producers. Profits generated from this capital are paid to the firm. If it wants to acquire more capital, it has to lend from banks and therefore competes with the other type of firms. As before, these firms have to pay all the returns on capital to the lending bank and therefore receive zero profits. Hence, without loss of generality one can assume that only firms without equity lend from banks.

Indexing equity owning firms by $j$, their net worth $n_t^j$ evolves according to

$$n_{t+1}^j = R_{t+1}^k n_t^j. \tag{5.1}$$

Aggregate net worth of intermediate goods producers ($n_t$) is the sum of net worth of existing firms ($n_t^e$) and net worth of new firms ($n_t^n$):

$$n_t = n_t^e + n_t^n \tag{5.2}$$

New intermediate goods producers receive as start-up funds a fraction of last periods effective capital stock:

$$n_t^n = \omega^i Q_t \xi_t K_{t-1} \tag{5.3}$$

Since every period, only a fraction $\theta^i$ of intermediate goods producers survives, net worth of existing firms is given by

$$n_t^e = \theta^i R_t^k n_{t-1}. \tag{5.4}$$

Combining these equations yields the following law of motion for aggregate net worth of firms:

$$n_t = \theta^i R_t^k n_{t-1} + \omega^i Q_t \xi_t K_{t-1} \tag{5.5}$$

As capital acquisitions are now financed via both, loans from banks and net worth of firms, the aggregate balance sheet equation 2.16 changes to

$$Q_t K_{t+1} = Q_t S_t + n_t. \tag{5.6}$$

Using equation 5.6, one can split up gross investment, which is defined as

$$I_t = K_{t+1} - (1-\delta)\xi_t K_t,$$

in the following way:

$$I_t = \underbrace{S_t - (1-\delta)\xi_t S_{t-1}}_{I_t^S} + \underbrace{n_t/Q_t - (1-\delta)\xi_t n_{t-1}/Q_{t-1}}_{I_t^i}$$

While $I_t^S$ denotes investment financed by issuing claims, $I_t^i$ is investment financed by the firms own net worth.

Compared to the model of section 2 there are two new parameters. For the surviving probability of intermediate goods producers, I chose the same as for banks, i.e. $\theta^i = 0.972$. I calibrated $\omega^i = 0.013$ in order to match Cole's assertion of $I^i/I = 0.8$ in steady state.

Figure 5.1 depicts the impulse responses of a negative 5% capital quality shock for both models, Gertler and Karadi's model of chapter 2 and the extended model with self-financing firms of this chapter. The feedback parameter in the credit policy rule is set to zero. Thus, there is no unconventional monetary policy.

One can observe that the economic contraction is not as severe in the extended model. The reason is that the amplification mechanism induced by the financial

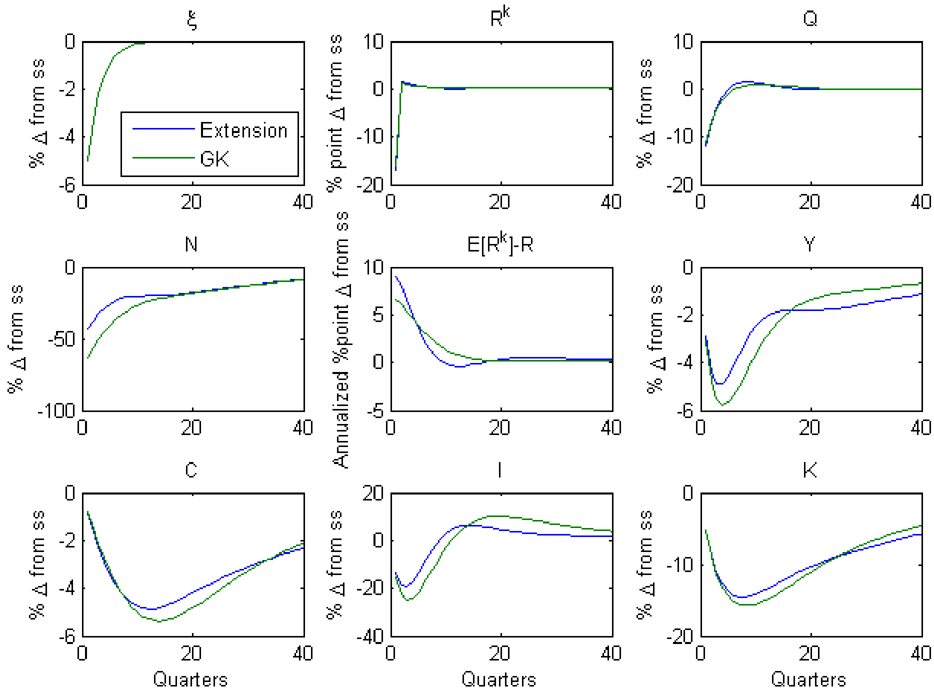


FIGURE 5.1: Comparison of Gertler and Karadi's (GK) model and the extended model with firm equity ($v = 0$)

friction is reduced. Recall from section 3 that as banks' net worth declines, due to the leverage constraint, their demand for assets decreases. This increases the premium and therefore reduces the capital demand of firms. As a consequence, asset prices decline, hurting banks' balance sheets even more. In the extended model, with a large fraction of firms not depending on banks' ability to supply credit, the investment decline is not as severe and the amplification is muted.

The most interesting question of this section is, whether the benefits of unconventional monetary policy are substantially reduced in the extended model. Intuitively, one could argue that with 80% of investment financed by firms' equity, unconventional monetary policy, whose main purpose is to centrally supply credit in situations where private banks' abilitiy to do so is limited, is not so important.

As one can observe in Figure 5.2 this argumentation is wrong or at least incomplete. The figure shows the effects of credit policy after a capital quality shock in the extended model. Compared to the model of Gertler and Karadi, the positive effects of credit policy are reduced, but they are still substantial. With an aggressive credit policy the decline in investment is muted leading to higher levels of output and consumption than in the case of no credit policy.

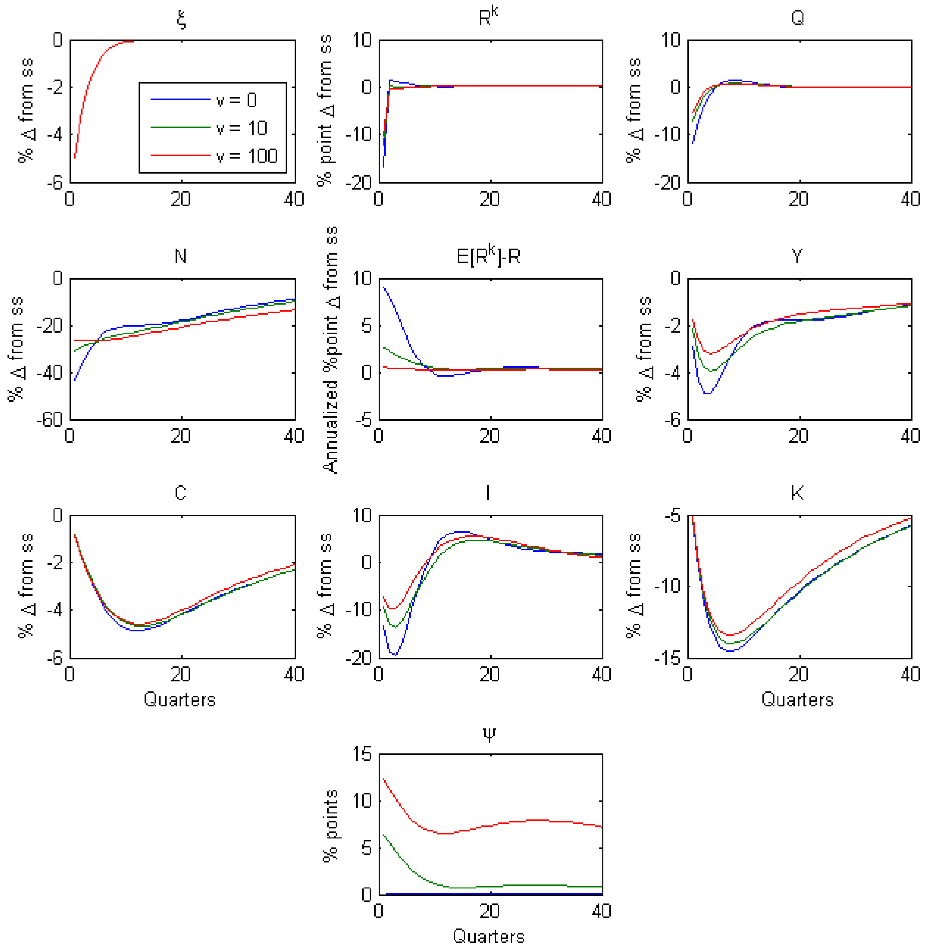


FIGURE 5.2: Credit policy in the model with firm equity

In order to understand the reason for this at first glance rather surprising result, I depict the evolution of the new variables $n_t$, $I_t^i$, $I_t^S$ as well as the fraction $I_t^S/I_t$ in figure 5.3.

First, consider the case without credit policy ($v = 0$). Due to the negative realization of $R_t^k$, net worth of firms ($n_t$) and therefore investment financed via net worth ($I_t^i$) decreases after the shock. However, in the absence of financial acceleration, this reduction is not as severe as the decline in investment financed

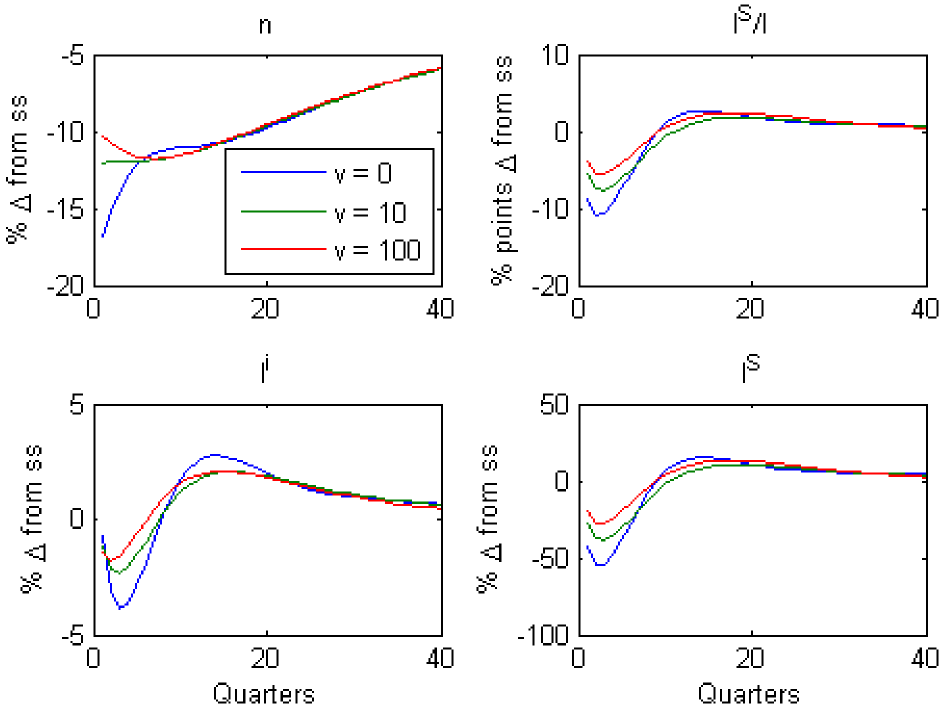


FIGURE 5.3: New variables in the model with firm equity

via credit ($I_t^S$). The latter decreases about twice as much as in the model of Gertler and Karadi (compare with $I_t$ in figure 5.1). Therefore, the fraction of investment financed by loans $I_t^S/I_t$ declines after the shock. The reason for this enhanced reduction in $I_t^S$ is the increased cost of credit indicated by the increased credit spread $E_t[R_{t+1}^k] - R_t$ in figure 5.1.

Now consider the cases with credit policy ($v = 10$ and $v = 100$). The central bank acts as a substitute for distressed private banks and therefore the decline in $I_t^S$ is substantially muted. As a consequence, the drop in $I_t^S/I_t$ is not as large as without credit policy. But unconventional monetary policy not only affects the intermediation of funds from (central and private) banks to firms, it also reduces the negative effect of the shock on self-financing firms' net worth. Through its reaction on the rise in credit spreads, the central bank stabilizes asset prices $Q_t$. As a consequence, the negative realization of $R_t^k$ is not as severe as without credit policy and the decline in firms' net worth is dampened. Therefore, not only the reduction in investment financed by credit ($I_t^S$) is muted, but also the decline in investment financed by firms' net worth ($I_t^i$).

Cole's argument that in reality firms do not finance their entire investments via funds from banks is true. However, this analysis showed that adapting a more realistic financing structure of firms does not affect the model's qualitative implications, at least in the present framework.

# Chapter 6

# Model Modifications

In this section I summarize two other contributions, which build on the model of Gertler and Karadi. For simplicity, they abstract from price rigidities and are in this sense not extensions of the model presented in section 2. However, as they keep the main mechanism but include additional features in order to capture other phenomena observed during the recent crisis, I consider them as modifications of the model. The aim of this section is not to analyze these models in the same detail as the model of Gertler and Karadi, but to present the main ideas of these contributions to the extent this is possible without introducing too much new notation. The interested reader is referred to the original papers by Gertler et al. (2012), respectively Gertler and Kiyotaki (2010).

## 6.1 Endogenous Bank Risk Exposure

Before the outbreak of the recent crisis, banks heavily relied on short term debt and were therefore highly exposed to adverse returns of their assets. While the model of Gertler and Karadi (2011) captures this phenomenon, it does not explain the reasons why banks adopt such risky balance sheet structures in the first place. In fact, in their model, issuing short term debt is the only way for banks to obtain external funds. Gertler et al. (2012) develop a model, in which banks obtain funds via issuing not only short term debt, but also outside equity. The bank's liability structure is an endogenous choice. Including this feature addresses the concern that bankers, who anticipate the government to intervene in crises situations, adopt riskier balance sheet structures. Hence, unconventional monetary policy is less desirable than in the model presented in section 2. However, a macro-prudential policy, which is able to combat this incentive for risk taking, is introduced. In this section I will summarize the main idea of the model.[1]

The household can now save not only by holding short term bonds but also by acquiring outside equity $e_t$ at price $q_t$ from banks. Therefore, its budget constraint is given by

$$C_t + B_t + q_t e_t = W_t L_t + \Pi_t - T_t + R_{t-1} B_{t-1} + R_t^e q_{t-1} e_{t-1}.$$

The variable $R_t^e$ describes the gross return on outside bank equity. Bank $j$'s balance sheet is given by

$$Q_t^j S_t^j = N_t^j + q_t e_t^j + B_t^j,$$

where $e_t^j$ is its outside equity. Hence, its net worth evolves according to

$$N_{t+1}^j = R_{t+1}^k Q_t S_t^j - R_{t+1}^e q_t e_t^j - R_t B_t.$$

Since in a crisis situation both, $R_{t+1}^k$ and $R_{t+1}^e$, decline, the bank is to a certain extent hedged against adverse realizations of $R_{t+1}^k$. This extent depends positively on the fraction of assets financed by outside equity,

$$E_t^j = \frac{q_t e_t^j}{Q_t S_t^j}.$$

Further, the model assumes that the fraction of assets, which the bank can divert, $\lambda(E_t^j)$, is not a constant but a function of $E_t^j$. At the margin it is easier for the bank to divert assets, which are funded by outside equity than by short term deposits, i.e.

$$\lambda'(E_t^j) > 0.$$

[1]Instead of using the original notation, for tractability reasons I stick to the notation of Gertler and Karadi (2011) as much as possible.

The bank's incentive constraint can now be written as

$$V_t(N_t^j, S_t^j, E_t^j) \geq \lambda(E_t^j) Q_t S_t^j.$$

Two counteractive mechanisms ensure that the bank will always choose an interior solution for the fraction $E_t^j$. First, increasing the fraction of outside equity increases the bank's expected discounted terminal wealth. The reason for this is that the bank obtains hedging value by switching from deposits to outside equity. Second, increasing the fraction of outside equity makes it easier for banks to divert assets and therefore enhances the incentive problem.

In the presence of government credit policy (equation 2.25) banks hedge by less than they otherwise would, i.e. the anticipation of government intervention in the case of crisis leads banks to issue short term debt rather than outside equity. Even without credit policy, a pecuniary externality leads financial intermediaries to issue a sub-optimally low amount of outside equity. Individual banks do not take into account that if they would issue outside equity in concert, the banking sector as a whole would be better hedged against risk, fluctuation is asset prices and economic activity dampened and welfare increased. Gertler et al. (2012) introduce a macro-prudential policy, which is designed to offset banks' incentive for risk taking. In particular, the government subsidizes outside equity issues and finances these subsidies via taxes on total assets of banks.

## 6.2 Interbank Market

The disruption of the financial system during the recent crisis included a strain in the interbank market. Gertler and Kiyotaki (2010) capture this phenomenon by introducing idiosyncratic liquidity shocks to financial intermediaries, which obtain funds not only from households but also from other banks. Their model is a combination of the model presented in section 2 and the framework of liquidity risk introduced in Kiyotaki and Moore (2012).

The model assumes a continuum of islands, on which firms and banks are situated. Each period, new investment opportunities arrive at a fraction $\pi^i$ of islands, while there are no new investment opportunities on the remaining fraction $1-\pi^i$. It is assumed that banks can only make loans to firms located on the same island.

The timing is as follows. At the beginning of every period, banks obtain deposits from households in the retail market at the deposit rate $R_t$. After the retail market closes, the mentioned investment opportunities for firms arrive randomly to different islands and the interbank market opens. Banks decide on the amount of credit they supply and on the volume of interbank borrowing.

Bank $j$'s balance sheet is now given by[2]

$$Q_t^h S_t^h = N_t^{j,h} + b_t^{j,h} + B_t^j,$$

where $h \in \{i, n\}$ denotes the type of the island, on which the bank is located ($i$ for investing, $n$ for non-investing) and $b_t^{j,h}$ is the volume of interbank borrowing. Note that due to the assumed timing, deposits from households, $B_t^j$, do not depend on the type of the island.

The bank's incentive constraint now changes to

$$V_t(N_t^{j,h}, S_t^{j,h}, b_t^{j,h}, B_t^j) \geq \lambda(Q_t^h S_t^{j,h} - \omega_b b_t^{j,h}),$$

where the parameter $\omega_b \in [0,1]$ determines the degree of friction in the interbank market. This modification of the incentive constraint should account for the fact that banks are (in case of a strictly positive $\omega_b$) more efficient than households in recovering assets from borrowing financial intermediaries.

The case $\omega_b = 1$ characterizes a frictionless interbank market. Banks are not able to divert assets financed by loans from other banks. From the bank's optimization problem, it follows that in this case, asset prices at investing and non-investing islands are equal, i.e.

$$Q_t^i = Q_t^n = Q_t.$$

[2]Again, I change the original notation in a way to make it as consistent as possible to the notation used in the previous sections of this thesis.

Intuitively, the reason for this is that banks from investing islands want to borrow from banks from non-investing islands as long as the value of the assets they finance with these loans is higher than the cost of borrowing. At the same time banks from non-investing islands are willing to lend to other banks as long as the value from these loans is higher than the value obtained by acquiring assets on their own island. The binding incentive constraint implies on the individual level

$$Q_t S_t^{j,h} - b_t^{j,h} = \phi_t N_t^{j,h}$$

and since both, $\phi_t$ and $Q_t$, do not depend on the specifics of the bank, aggregation yields

$$Q_t S_t^p = \phi_t N_t.$$

Hence, a setting with a perfect interbank market is isomorphic to the one discussed in section 2.

Let us now consider the other extreme case with $\omega_b = 0$. In this case, diverting assets financed by other banks is as easy as diverting assets financed by households. If the incentive constraint for banks on investing islands binds, banks on non-investing islands use their funds to re-finance existing investments rather than to lend them to banks of the other type. Because, through new investment opportunities, asset supply on investing islands is increased but the interbank market is not able to fully adjust asset demand, this friction induces a wedge between the asset prices on investing- and those on non-investing islands. In particular, asset prices on investing islands are lower:

$$Q_t^i < Q_t^n$$

As a consequence expected returns on financial claims are higher on investing- than on non-investing islands, implying a higher marginal value of expanding assets and therefore a higher leverage ratio.

In a crisis situation as discussed in chapter 3, due to banks' higher leverage, the amplification mechanism is enhanced on investing islands. Asset prices fall by more than they otherwise would, reducing investing banks ability to obtain funds on the interbank market even further. As a result overall investment is reduced compared to the situation of a frictionless interbank market, implying a magnified downturn.

# Chapter 7

# Conclusion

In this thesis I discussed models that incorporate a financial friction within the banking sector. In crises situations this friction leads to an amplification of the downturn. The models allow for an unconventional monetary policy, which mimics the measures undertaken by several central banks during the Great Recession. The models suggest that in an economic crisis direct central bank lending is a valid instrument in order to dampen the recession.

One criticism of these models was that within their framework non-financial firms depend solely on funds from banks, without being able to use other sources of financing. As during economic crises the availability of bank credit is limited, this potentially overstates both the the amplification effects in a recession and the benefits of unconventional monetary policy. I changed one particular model in order to adopt a more realistic financing structure of firms. Within my framework, the mentioned reactions are reduced to some extent, while the model's qualitative implications remain unchanged. By acting as substitute for distressed private banks, the central bank is able to dampen the drop in investment financed by loans relative to investment financed by firms' own net worth. Moreover, this policy has a stabilizing effect such that even the decline in the latter is muted.

As models of unconventional monetary policy with frictions in the financial sector are contributions to a relatively new area of Monetary Economics, they naturally suffer from various (potential) deficiencies. The criticism includes the way in which the financial friction is modeled and that the extent to which banks are constrained in their lending activities is at odds with the data. Mentioning these deficiencies, one has to acknowledge these models as important contributions to an area of economic research that was noticed too little before the recent crisis.

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# Appendix A

# Optimization Problem of Banks

In this Appendix I discuss the bankers optimization problem in more detail. First, I show equivalence of the two expressions for expected terminal wealth 2.5 and 2.7 and therefore two equivalent ways of writing down the optimization problem. Second, I will use the more tractable version to derive the bank's optimal choice for all possible cases.

## A.1 Equivalence of Optimization Problems

Define the bank's value function $\tilde{V}_t(N_t^j)$, given net worth $N_t^j$, as the maximum expected terminal wealth that can be achieved by choosing the optimal level of assets $S_t^j$ out of the set of achievable quantities of assets

$$\mathcal{A}_t^j = \{S_t^j | S_t^j \geq 0 \text{ and } V_t(N_t^j, S_t^j) \geq \lambda Q_t S_t^j\}.$$

Formally, the value function is given by [1]

[1] Note, that the value function has a time index. With a slight abuse of notation this time index should capture the fact, that the value function depends not only on the state variable $N_t^j$ and the choice variable $S_t^j$ of bank $j$ but also on the time varying variables $R_t$, $R_t^k$ and $\Lambda_{t,t+1}$, which are the same for all banks.

$$\tilde{V}_t(N_t^j) = \max_{S_t^j \in \mathcal{A}_t^j} V_t(N_t^j, S_t^j). \tag{A.1}$$

Then, the optimization problem of bank $j$ in period $t$ can be written in the following recursive way:

$$\begin{aligned}
\max_{S_t^j} V_t(N_t^j, S_t^j) &= \max_{S_t^j} E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}N_{t+1}^j + \theta\beta\Lambda_{t,t+1}\tilde{V}_{t+1}(N_{t+1}^j)\Big\} \\
\text{s.t. } V_t(N_t^j, S_t^j) &\geq \lambda Q_t S_t^j \\
S_t^j &\geq 0 \\
N_{t+1}^j &= (R_{t+1}^k - R_t)Q_t S_t^j + R_t N_t^j
\end{aligned} \tag{A.2}$$

The first equation states through the Bellman equation that expected terminal wealth is maximized. The second and third inequalities describe the set of attainable asset levels $\mathcal{A}_t^j$, out of which the optimal $S_t^j$ is chosen. The fourth equation is the equity law of motion 2.4, which can in principle be substituted into the expression for $V_t(N_t^j, S_t^j)$ of the first equation.

I will now show that this problem is equivalent to the following optimization problem:

$$\begin{aligned}
\max_{S_t^j} V_t(N_t^j, S_t^j) &= \max_{S_t^j}[\nu_t Q_t S_t^j + \eta_t N_t^j] \\
\text{s.t. } V_t(N_t^j, S_t^j) &\geq \lambda Q_t S_t^j \\
S_t^j &\geq 0 \\
\nu_t &= E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}(R_{t+1}^k - R_t) + \theta\beta\Lambda_{t,t+1} \max_{S_{t+1}^j \in \mathcal{A}_{t+1}^j} [x_{t,t+1}\nu_{t+1}]\Big\} \\
\eta_t &= E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}R_t + \theta\beta\Lambda_{t,t+1}z_{t,t+1}\eta_{t+1}\Big\} \\
x_{t,t+1} &= \frac{Q_{t+1}S_{t+1}^j}{Q_t S_t^j} \\
z_{t,t+1} &= \frac{N_{t+1}^j}{N_t^j}
\end{aligned} \tag{A.3}$$

The expression for $\nu_t$ describes the expected discounted marginal gain of increasing assets $Q_{t+1}S^j_{t+1}$ by one unit holding net worth $N^j_t$ constant. The variable $\eta_t$ is the expected discounted value of an additional unit of net worth $N^j_t$ holding assets $S^j_t$ constant. The variables $x_{t,t+1}$ and $z_{t,t+1}$ describe the growth rates of assets, respectively net worth, between periods $t$ and $t+1$.

I will substitute all these expressions into the first equation in order to show that these problems are actually equivalent, i.e. I will show that

$$\begin{aligned} V^j_t(N^j_t, S^j_t) &= \nu_t Q_t S^j_t + \eta_t N^j_t \\ &= E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}N^j_{t+1} + \theta\beta\Lambda_{t,t+1}\tilde{V}_{t+1}(N^j_{t+1})\Big\}. \end{aligned} \tag{A.4}$$

Plugging the expressions for $\nu_t$ and $\eta_t$ into the first equation of A.4 yields

$$\begin{aligned} V^j_t(N^j_t, S^j_t) &= E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}(R^k_{t+1} - R_t) + \theta\beta\Lambda_{t,t+1} \max_{S^j_{t+1}\in\mathcal{A}^j_{t+1}} [x_{t,t+1}\nu_{t+1}]\Big\}Q_t S^j_t \\ &\quad + E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}R_t + \theta\beta\Lambda_{t,t+1}z_{t,t+1}\eta_{t+1}\Big\}N^j_t. \end{aligned}$$

Using the definitions of the growth rates $x_{t,t+1}$ and $z_{t,t+1}$ as well as the linearity of the expectations operator, this is the same as

$$\begin{aligned} V^j_t(N^j_t, S^j_t) &= E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}(R^k_{t+1} - R_t)Q_t S^j_t + \theta\beta\Lambda_{t,t+1} \max_{S^j_{t+1}\in\mathcal{A}^j_{t+1}} [\nu_{t+1}Q_{t+1}S^j_{t+1}] \\ &\quad + (1-\theta)\beta\Lambda_{t,t+1}R_t N^j_t + \theta\beta\Lambda_{t,t+1}\eta_{t+1}N^j_{t+1}\Big\}. \end{aligned}$$

Rearranging terms yields

$$\begin{aligned} V^j_t(N^j_t, S^j_t) &= E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}\Big[(R^k_{t+1} - R_t)Q_t S^j_t + R_t N^j_t\Big] + \\ &\quad \theta\beta\Lambda_{t,t+1} \max_{S^j_{t+1}\in\mathcal{A}^j_{t+1}} \Big[\underbrace{\nu_{t+1}Q_{t+1}S^j_{t+1} + \eta_{t+1}N^j_{t+1}}_{V^j_{t+1}(N^j_{t+1}, S^j_{t+1})}\Big]\Big\}. \end{aligned}$$

Finally, by plugging in the equity law of motion and equation A.1 one obtains the second equation of A.4

$$V^j_t(N^j_t, S^j_t) = E_t\Big\{(1-\theta)\beta\Lambda_{t,t+1}N^j_{t+1} + \theta\beta\Lambda_{t,t+1}\tilde{V}^j_{t+1}(N^j_{t+1})\Big\}.$$

Hence, equivalence of the problems A.2 and A.3 is shown.

## A.2 Solution

In this section I will solve the bank's optimization problem A.3. Ommitting the definitions of $\nu_t$, $\eta_t$, $x_{t,t+1}$ and $z_{t,t+1}$, the problem is

$$\begin{aligned} \max_{S_t^j} \Big[\nu_t Q_t S_t^j + \eta_t N_t^j\Big] & & \\ \text{s.t. } \nu_t Q_t S_t^j + \eta_t N_t^j &\geq \lambda Q_t S_t^j \\ S_t^j &\geq 0. \end{aligned} \tag{A.5}$$

The marginal value of an additional unit of net worth, $\eta_t$ is always strictly positive.[2] One needs to distinguish four cases for the marginal value of an additional unit of assets, $\nu_t$:

**Case 1:** $\nu_t < 0$

From the definition of $\nu_t$ it can be seen that this case occurs if the expected discounted risk premium $E_t\Big[\beta\Lambda_{t,t+1}(R_{t+1}^k - R_t)\Big]$ is negative, implying an expected risky return $R_{t+1}^k$ on assets that is below the riskless return $R_t$ the bank has to pay for its debt. It is easily seen that $S_t^j = 0$ (and therefore $B_t^j = -N_t^j$) is the optimal solution. Hence, the bank will not supply any credit to intermediate goods producers and instead of aquiring deposits from households, it will lend its entire net worth to the household at the riskless rate.[3]

**Case 2:** $\nu_t = 0$

Assets do not provide value but they also do not harm the bank. Therefore, the

[2]Here, I use the assumptions that the rate of intertemporal elasticity of substitution between consumption in period $t$ and consumption in period $t+1$, $\Lambda_{t,t+1}$, as well as the riskfree interest rate $R_t$ are strictly positive for any $t$.

[3]The possibility of banks lending to households is not explicitly discussed in Gertler and Karadi (2011) although implicitly assumed.

financial intermediary is indifferent between any asset level. Hence, any feasible choice of assets is optimal, i.e. $Q_t S_t^j \in [0, \frac{\eta_t}{\lambda} N_t^j]$.

**Case 3:** $0 < \nu_t < \lambda$

This is the interesting case, which is relevant in this thesis.[4] Since expanding assets provides positive value to the bank, it wants to choose $S_t^j$ as high as possible. However, at some point the value of diverting assets would be higher than the value of staying in business and the bank will not obtain funds from households to finance such high asset levels. Therefore, the incentive constraint is binding and the optimal feasible level of assets is $Q_t S_t^j = \frac{\eta_t}{\lambda - \nu_t} N_t^j$.

**Case 4:** $\nu_t \geq \lambda$

As in the previous case, the bank wishes to expand its assets ad infinitum. Contrary to the previous case, it is able to do so since the value of staying in business is always higher than the value of diverting assets. The incentive constraint

$$\underbrace{(\lambda - \nu_t) Q_t S_t^j}_{\leq 0} \leq \underbrace{\eta_t N_t^j}_{>0}$$

is always fulfilled and the optimal value of $S_t^j = \infty$.

Note that this section discussed from a microeconomic view what the bank would do in the several cases. No statement is made about whether all these cases can actually occur in equilibrium.

[4] In fact, parameter values are chosen in a way such that only this case occurs.