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## Macroeprudential Policy in the New Keynesian World

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# Macroprudential Policy in the New Keynesian World\*

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## Abstract

We integrate banks and the coexistence of bank and bond financing into an otherwise standard New Keynesian Framework. Macroprudential policies in the form of varying aggregate capital requirements and interest rate policies of the central bank are used to stabilize shocks, to moderate bank credit cycles, and to induce more efficient allocation of resources across sectors. We study the interplay of these instruments. We examine how policy-making could be operationalized by second-order approximations of household welfare yielding loss for monetary and macroprudential policy-making. Finally, we investigate the optimal policy rules for monetary and macroprudential policy makers. The optimal policy rules indicate that the central bank should focus exclusively on price stability and the macroprudential policy maker should react to both output variation and financial instability. For the latter, the state of the credit cycle is a better indicator than direct measures of financial risk.

Keywords: central banks, banking regulation, capital requirements, optimal monetary policy.

JEL: E520, E580, G280

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\*A precursor paper integrated aggregate bank-capital requirements into the Barro-Gordon model (Gersbach and Hahn (2011)). We would like to thank Michael Fischer, our discussants Harris Dellas and Jörn Tenhofen at the Swiss National Bank Research Conference 2016, Lars E.O. Svensson and conference participants.

# 1 Introduction

## 1.1 Motivation

Macroprudential and monetary policies are the two policy areas which aim at three objectives: banking stability, price stability and output stability. How these policies should be conducted and organized is a major issue, and since the global financial melt-down, policy-makers and academics are working on solutions. This task is complicated by two problems.

First, pursuing one objective may undermine fulfilling the other objectives. This is well-known for potential inflation-output tradeoffs. It has also been a long-standing issue whether and how changes in the monetary stance can strengthen or undermine financial stability. Pursuing financial stability, in turn, may affect output. For instance, if aggregate capital requirements are relaxed in a downturn to counteract an output decline, the banks' balance sheets may weaken, thereby increasing vulnerabilities in the financial system.

Second, policy-makers do not have enough instruments to attain the three key objectives—price, output and financial stability. The central bank's instrument is the short-term interest rate. While this instrument is sufficient to stabilize demand shocks, the stabilization of supply shocks such as cost-push shocks involves tradeoffs between output and price stability. Macroprudential policies have one additional macro tool—varying bank capital requirements, which can be enhanced by targeted interventions in the financial sector. Hence there are only two independent macro instruments to attain three objectives.

Several proposals how monetary and macroprudential policies could be organized and conducted, will be reviewed in Section 1.3. The purpose of this paper is to integrate the banking sector into an otherwise standard New Keynesian Framework in order to develop a microfounded model that allows to study the interplay of monetary policy and macroprudential policy. Specifically, we focus on an economy in which one part of the intermediate firms has to rely on bank financing to produce. Shocks to the production of these firms may hamper their ability to repay loans, and ultimately affect the solvency of banks. Macroprudential policies, in the form of aggregate capital

requirements for the banking system, can increase the banking stability. Policy-makers have started to use a variant of this tool.<sup>1</sup> Interest rate policies can aim at stabilizing demand or supply shocks in the entire economy.

We are interested in classical questions:

- How should monetary policy and macroprudential policy be used to stabilize shocks in the economy and to safeguard financial stability, price stability and output stability?
- Should macroprudential policy makers focus on price and output stability as well?
- Which policy maker should focus on financial instability and which variable serves better as an indicator for financial instability?

To address these questions, one needs an appropriate framework. In this paper we explore how the New Keynesian approach to monetary policy could be extended to encompass banks and the coexistence of bank and bond financing, and thus allow the analysis of the interplay of monetary and macroprudential policies. We will first integrate bank and bond financing in the New Keynesian Framework. Firms in one sector rely on bank financing and on bond financing in the other sector. We will then provide a first round of applications.

## 1.2 Approach and Results

In order to integrate banks and financing modes into the New Keynesian Model, we start from four key observations.

- A subset of firms is financed by banks, while the remaining firms obtain funds directly from households through the capital market. The share of bank-financed firms is generally important, but varies widely across countries. It is particularly high in many continental European countries. Moreover, the relative size of financing modes depends on the state of the economy. (see e.g. De Fiore and Uhlig (2011) and Laeven and Valencia (2013) for these differences).

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<sup>1</sup>Today, it comes in the form of countercyclical capital requirements and has been included in national law in many countries. It is already used in some countries (see <https://www.bis.org/bcbs/ccyb/>, retrieved on 15th March 2017).

- Firms that turn to banks and obtain bank loans are more risky than firms that finance themselves through bond markets. These risks translate into default risk of banks and risk premia in loan interest rates.<sup>2</sup>
- Defaults of banks impose additional costs on households, e.g. in the form of bailout costs.
- Households face costs when they acquire and hold risky assets like bank equity. For example, households need time (or pay fees) to assess the return prospects of risky assets. As a consequence, safe assets are preferred to risky assets, unless the returns of the latter compensate these costs beyond standard risk premia.

We embed these features into a standard New Keynesian Model. There are a banking sector and two types of intermediate firms: risky firms that can only obtain funds from banks and safe firms that can issue bonds to finance themselves. In addition, the government implicitly backs deposits to make these assets safe.<sup>3</sup>

There are two major policy instruments. Macroprudential policy, in the form of time-varying aggregate capital requirements, balances costs of bank equity, costs of bank defaults, and potential misallocation of resources across sectors. Typically, higher aggregate capital requirements increase the costs of bank equity, reduce bank defaults and reduce investments channeled through the banking sector. Interest rate policies secure the typical purpose of influencing aggregate output and inflation. These policy instruments are complemented by sales taxes/subsidies to bank- and bond-financed firms.

We proceed as follows: In the first part, we derive the microfoundation of the aggregate relationships. In particular, we derive the sequential equilibrium, given some policy path for the interest rate, aggregate capital requirements, and a path of sales taxes/subsidies for both sectors. In this equilibrium—among other things—banks choose capital structures in each period, such that capital requirements are binding

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<sup>2</sup>See De Fiore and Uhlig (2011) for theory and evidence, Denis and Mihov (2003) for evidence, Bolton and Freixas (2000) for a theory why firms with comparatively high output risk turn to banks, and Gersbach and Rochet (2015) for a general equilibrium analysis of this set-up.

<sup>3</sup>A variant of the model is to consider explicit deposit insurance, which can easily be integrated into our model.

and loan rates increase with the stringency of capital requirements, while loan sizes decline.

We next determine the welfare optimal steady state for the calibrated model and log-linearize the model around this steady state. We illustrate the properties of steady state for different levels of capital requirements. Typically, for low levels of aggregate capital requirements, the allocation of resources across sectors is inefficient, too many resources are channeled through the banking sector, and too few through the capital market. Appropriate macroprudential policies that prescribe particular levels of aggregate capital requirements (and as a consequence individual capital requirements) are welfare-improving, as they can correct the misallocation of resources across sectors and improve resource allocation over time. Too high aggregate capital requirements, however excessively shift resources to safe firms and entail large costs of equity management.

In the second part, we provide a first round of applications of the framework for the calibrated model. We begin with some examples how the economy reacts to shocks when monetary policy-making follows Taylor-type rules. We next derive a formula for welfare for arbitrary policies by deriving second-order approximation to welfare around the steady state. This provides a starting point for a great variety of further possible policy-making investigations. In particular, our calibration exercise reveals the following insights. The optimal policy rules prescribe that the central bank focuses exclusively on price stability. The macroprudential policy-maker, however, should react to both output variation and financial instability. The latter is best proxied by changes in the credit cycle. Direct measures of default risk such as the spread between the loan rate and the deposit rate are less suitable.

### **1.3 Literature**

We integrate banks and financial stability concerns into the New Keynesian Framework, leaving all other essential parts of this framework intact. However, integrating the four features discussed above into the New Keynesian Framework is a major undertaking.

Several papers already combine monetary and macroprudential policy-making. Angeloni and Faia (2013) show how bank capital requirements can mitigate the consequences of bank runs when monetary policy follows interest rate rules. Christensen et al. (2011) consider the feedback of more risky projects by banks to aggregate credit to GDP.<sup>4</sup> Another branch of this literature has focused on optimal policies. Among others, De Paoli and Paustian (2013) and Collard et al. (2017) characterize Ramsey-optimal policies. The latter, in particular, show that prudential policies prevent excessive risk-taking by banks while monetary policy aims at smoothing business cycles. This is an important benchmark for how such policies could or should be conducted jointly.

Our contribution to this literature is as follows: First, we embed the four features mentioned above into an otherwise standard New Keynesian Framework. This allows a comparison with standard results in monetary policy-making. Second, we investigate how such an economy responds to shocks affecting bank-financed or capital-market-financed firms and aggregate shocks. Third, we derive the unconditional optimal welfare formula and focus on institutional questions how policy-making can be operationalized by Taylor-type rules for monetary policy and macroprudential policy.

Several frameworks for monetary and macroprudential policies have been proposed.<sup>5</sup> Detailed outlines, rationales and assessment can be found in Gersbach and Hahn (2011), Schoenmaker and Wiertz (2016), Borio (2014), Claessens et al. (2013) and Jonsson and Moran (2014). As these frameworks, our model shares the view that constraints on leverage and credit expansion are a key angle of macroprudential policies. Authors, however, differ as to how effective countercyclical policies can be and whether macroprudential policies should aim at smoothing credit cycles. We use macroprudential policies in the form of varying aggregate capital requirements for the banking system and investigate how such policies have to be conducted and organized.

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<sup>4</sup>Loisel (2014) assesses the conclusions that can be drawn from the early literature on what monetary and macroprudential policy rules can achieve.

<sup>5</sup>A more extended framework would also include microeconomic regulation and supervision of banks (See Gersbach and Hahn (2011) for such a framework).

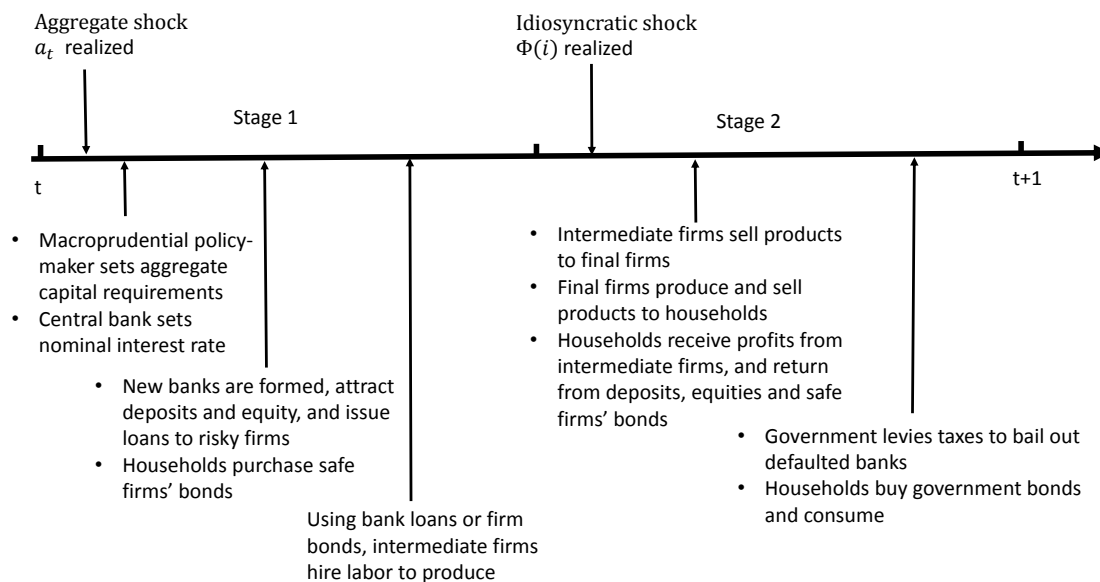


Figure 1: Sequence of events.

## 1.4 Structure of the Paper

The remainder of this paper proceeds as follows. In the next section, we present the model. After establishing the equilibrium conditions in Section 3, we characterize the steady state of the economy and show the impulse responses to various types of shocks in Section 4. We explore the optimal policy rules in Section 5. Section 6 concludes.

## 2 Model

### 2.1 Overview

There are six sectors in the model: households, banks, safe and risky intermediate firms, final firms, and the public sector, which comprises a fiscal agency, a central bank, and a macroprudential policy-maker. We start with the timeline of events in each period  $t = 0, 1, 2, \dots$ . Afterwards, we will describe the agents' optimization problems, the firms' technologies, and the market structure in more detail.

The sequence of events is shown in Figure 1. Each period  $t$  is divided into two stages. At the beginning of the first stage, aggregate productivity shocks for both sectors of



intermediate firms occur. Households are endowed with bond holdings  $B_t$ . After the shock, the central bank chooses  $I_t$ , the nominal interest rate on bonds that mature in  $t + 1$ , where one unit of the bond represents a claim on one nominal unit at maturity. Households rent out some part of their labor to safe firms in return for real claims (safe firms' bonds) against these firms in the second stage of period  $t$ . Risky intermediate firms cannot issue claims to households to hire labor because they have to be monitored closely. They have to rely on bank loans instead, where we assume that each bank serves exactly one risky firm. Hence risky firms take loans from banks and receive bank deposits at the same time. Risky firms then use these deposits to hire labor from households. Deposits are riskless because they are insured by the government. The macroprudential policy-maker sets a capital requirement  $\Gamma_t$  which banks have to fulfill in order to be allowed to operate. We will also assume that households incur costs when acquiring and holding equity, which will make equity financing more costly for banks than debt financing.

At the beginning of the second stage, idiosyncratic shocks to risky firms' productivities realize. Afterwards, safe and risky intermediate firms choose their prices, taking the amount of labor hired in the first stage as given. While safe firms face Rotemberg price adjustment costs, risky firms live only for one period and can choose the prices of their outputs freely. Safe firms can always repay their bonds, whereas some risky intermediate firms with adverse shock realizations cannot repay their loans in full. As a consequence, the corresponding bank may fail if its equity buffer is insufficient. These banks are bailed out by the fiscal agency that uses a lump-sum tax on all households and the revenues from the sales taxes on intermediate firms to guarantee that deposits are always repaid. All banks are dissolved and the remaining funds are distributed to equity holders. Profits of intermediate firms also accrue to households and bonds  $B_t$  mature. Perfectly competitive final-good firms purchase the intermediate goods and use them to produce final goods. Households acquire new bonds  $B_{t+1}$  at a price  $1/I_t$  as well as final goods. In the following, we describe the different agents in more detail.

## 2.2 Households

Each household has the instantaneous utility function:

$$u(c_t, n_t) = \frac{c_t^{1-\sigma} - 1}{1-\sigma} - \psi \frac{n_t^{1+\varphi}}{1+\varphi}. \quad (1)$$

where  $\sigma > 0$ ,  $\varphi > 0$ , and  $\psi > 0$ . It is sufficient to focus on the behavior of a representative household. At the beginning of each period, the household is endowed with  $B_t$  units of riskless government bond, where one unit of the bond is a claim on one nominal unit at stage 2.

In the first stage of each period, the household provides labor to both safe and risky intermediate firms. Safe intermediate firms provide safe bonds  $\tilde{s}_t$  with gross return  $R_t^s$  to the household in exchange for the labor  $n_t^s$ ,

$$\tilde{s}_t = \tilde{w}_t n_t^s, \quad (2)$$

where  $\tilde{w}_t$  represents the real market wage.

The household saves in bank deposits  $\tilde{d}_t$  with gross return  $R_t^d$  and bank equity  $\tilde{e}_t$ . Thus, the amount of loans bank can issue is

$$\tilde{l}_t = \tilde{d}_t + \tilde{e}_t. \quad (3)$$

Deposits are backed by the government and therefore riskless. Hence no arbitrage requires

$$R_t^d = R_t^s. \quad (4)$$

As a consequence, we will not distinguish between  $R_t^d$  and  $R_t^s$  in the following.

The representative household acquires equal amounts of equity from each bank,<sup>6</sup> which results in a riskless equity portfolio because the aggregate shocks  $a_t$  are realized at the beginning of each period and already known when asset allocations are made. The gross return on the equity portfolio is denoted by  $R_t^e$ .<sup>7</sup>

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<sup>6</sup>We effectively look for symmetric bank equity allocations. Since banks are identical at this stage, this allocation is rationalized in the equilibrium.

<sup>7</sup>The representative household holds all assets in the economy and is fully diversified. We could allow heterogeneity of bank equity holding across households to further rationalize the costs of acquiring and holding risky bank equity.

Using loans  $\tilde{l}_t$  granted by banks, risky intermediate firms hire labor  $n_t^r$  from the household

$$\tilde{l}_t = \tilde{w}_t n_t^r. \quad (5)$$

It will be useful to introduce  $s_t := R_t^s \tilde{s}_t$ ,  $d_t := R_t^s \tilde{d}_t$ ,  $l_t := R_t^s \tilde{l}_t$ , and  $e_t := R_t^s \tilde{e}_t$ . Intuitively,  $s_t$  and  $d_t$  are the funds the household receives in the second stage from investing in safe bonds  $\tilde{s}_t$  and deposits  $\tilde{d}_t$ , respectively.  $l_t$  and  $e_t$  correspond to the hypothetical funds that one would receive in stage 2 if one invested  $\tilde{l}_t$  and  $\tilde{e}_t$  at rate  $R_t^s$  in stage 1.

We model the costs of equity financing by assuming that the household needs to spend resources for monitoring and managing equities. For simplicity, we assume that the resources necessary for equity management are proportional to the dividend payments  $R_t^e \tilde{e}_t$ :

$$m_t = \chi_t R_t^e \tilde{e}_t, \quad (6)$$

where  $\chi_t$  is an exogenous positive random variable.

We introduce the premium on equity financing as  $\Delta_t^e := R_t^e / R_t^s$ . In the second stage, the household receives the gross returns on deposits, equities and safe bonds, i.e.  $d_t$ ,  $\Delta_t^e e_t$ , and  $s_t$ , respectively. In addition, safe and risky intermediate firms' profits  $z_t^s$  and  $z_t^r$  also go into the household's pocket. On the expense side, the household consumes goods  $c_t$  and pays lump-sum taxes  $\tau_t^l$ .

Using  $w_t = R_t^s \tilde{w}_t$  as well as (2)-(6), we can write the total funds the household receives from safe bonds, deposits, and equity net of equity management costs as

$$s_t + d_t + \Delta_t^e e_t - \chi_t \Delta_t^e e_t = w_t n_t + (\Delta_t^e (1 - \chi_t) - 1) e_t, \quad (7)$$

where  $n_t = n_t^s + n_t^r$  denotes total labor.

We are now in a position to state the household's budget constraint in the second stage of period  $t$  as

$$c_t + \frac{B_{t+1}}{I_t p_t} \leq \frac{B_t}{p_t} + z_t^s + z_t^r - \tau_t^l + w_t n_t + (\Delta_t^e (1 - \chi_t) - 1) e_t. \quad (8)$$

The representative household maximizes the overall utility

$$\max_{\{c_t, B_{t+1}, n_t, e_t\}_{t=0}^{\infty}} \left\{ \sum_{t=0}^{\infty} \beta^t \left( \frac{c_t^{1-\sigma} - 1}{1-\sigma} - \psi \frac{n_t^{1+\varphi}}{1+\varphi} \right) \right\} \text{ s.t. (8),} \quad (9)$$

where  $\beta$  is the discount factor with  $0 < \beta < 1$ . Let  $\lambda_t$  be the current-value Lagrange multiplier associated with (8). Then we obtain the following first-order conditions of the household problem:

$$c_t : \quad \lambda_t = c_t^{-\sigma}, \quad (10)$$

$$B_{t+1} : \quad \frac{\lambda_t}{I_t p_t} = \mathbb{E}_t \left[ \beta \frac{\lambda_{t+1}}{p_{t+1}} \right], \quad (11)$$

$$n_t : \quad \psi n_t^\varphi = \lambda_t w_t, \quad (12)$$

$$e_t : \quad \Delta_t^e = \frac{1}{1 - \chi_t}, \quad (13)$$

where the last equation is a no-arbitrage condition, which involves that investing an additional unit of funds into equity delivers the same additional payoff net of equity management costs as investing the same amount on a deposit.

### 2.3 Final-good Firms

There are infinitely many, perfectly competitive firms, which purchase intermediate goods  $y_t(i)$  at prices  $p_t(i)$  and assemble them to a final good  $y_t$ , which can be used for consumption:

$$y_t = \left( \int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}, \quad (14)$$

where  $\theta > 1$  represents the elasticity of substitution between differentiated intermediate goods.

Hence each firm's profit maximization problem can be formulated as

$$\max_{\{y_t(i)\}_{i=0}^1} \left\{ p_t y_t - \int_0^1 p_t(i) y_t(i) di \right\} \quad \text{s.t. (14)}.$$

This problem leads to the following demand for intermediate good  $i$ :

$$y_t(i) = \left( \frac{p_t(i)}{p_t} \right)^{-\theta} y_t \quad (15)$$

and the price level is

$$p_t := \left( \int_0^1 p_t(i)^{1-\theta} di \right)^{\frac{1}{1-\theta}}. \quad (16)$$

## 2.4 Intermediate Firms

In the first stage, monopolistically competitive intermediate firms attract loans from banks and households, and hire labor. In the second stage, output materializes, prices are chosen, loans are repaid, and profits are transferred to households. The total number of intermediate firms is normalized to 1. A fixed proportion  $\nu$  constitutes the sector of safe firms, who are infinitely-lived and face quadratic price-adjustment costs. The remaining  $1 - \nu$  intermediate firms, the sector of risky firms, live for one period, and can choose their prices freely. For both sectors, we introduce sales taxes or sales subsidies. This serves three purposes. These sales taxes/subsidies are tools that induce socially efficient steady states—which is not achievable by a combination of monetary policy and aggregate capital requirements alone. Sales taxes (or subsidies) are needed to correct monopoly distortions. Second, they allow to model markup shocks by considering stochastic changes of these instruments. Third, they may represent actual and potential non-optimal sales taxes set by a government that is not necessarily interested in social welfare. In the following, we will consider these two sectors of intermediate firms separately.

### 2.4.1 Safe Firms

The safe firms' production function is

$$y_t^s(i) = a_t n_t^s(i), \quad (17)$$

where  $a_t$  is aggregate productivity, which is given by

$$(\ln a_t - \ln \bar{a}) = \rho^a (\ln a_{t-1} - \ln \bar{a}) + \varepsilon_t, \quad (18)$$

where  $\rho^a \in [0, 1)$ ,  $\bar{a}$  is a positive constant, and the  $\varepsilon$ 's are independent and normally-distributed shocks with zero mean and standard deviation  $\sigma_\varepsilon$ .

In the first stage of each period  $t$ , safe firms take loans from households at a gross real rate  $R_t^s$  and use them to hire labor

$$\tilde{s}_t(i) = \tilde{w}_t n_t^s(i). \quad (19)$$

Taking into account that the value of loans in stage 2 is  $s_t(i) = R_t^s \tilde{s}_t(i)$ , safe firm  $i$ 's real profit in the second stage of period  $t$  can be written as

$$z_t^s(i) = (1 - \tau_t) \frac{p_t^s(i)}{p_t} y_t^s(i) - s_t(i) - \frac{\gamma^p}{2} \left( \frac{p_t^s(i)}{p_{t-1}^s(i)} - 1 \right)^2 y_t, \quad (20)$$

where  $\tau_t$  is a sales tax common to all intermediate-goods producers,  $p_t^s(i)$  is the price for firm  $i$ 's output, and  $\gamma^p > 0$  is the coefficient for price adjustment cost  $\frac{\gamma^p}{2} \left( \frac{p_t^s(i)}{p_{t-1}^s(i)} - 1 \right)^2 y_t$ .

Taking the wage as given, firms maximize the expected sum of discounted real profits

$$\max_{\{n_t^s(i), p_t^s(i)\}_{t=0}^{\infty}} \left( \mathbb{E}_0 \sum_{t=0}^{\infty} Q_t z_t^s(i) \right), \quad (21)$$

subject to

$$a_t n_t^s(i) \geq \left( \frac{p_t^s(i)}{p_t} \right)^{-\theta} y_t, \quad (22)$$

where future profits are discounted by

$$Q_t = \frac{\beta^t \lambda_t}{\lambda_0} = \beta^t \frac{c_0^\sigma}{c_t^\sigma}.$$

The optimal behavior of safe firms is quite standard and is examined and described in Appendix A.

## 2.4.2 Risky Firms

The risky firms' production function is

$$y_t^r(i) = (\phi(i))^\alpha A a_t n_t^r(i), \quad (23)$$

where  $\phi(i) \in [0, 1]$  with uniform distribution represents an idiosyncratic shock to firm  $i$ 's productivity. Parameter  $\alpha$  ( $\alpha > 0$ ) affects the riskiness of production, where lower values involve less risk. Parameter  $A$  affects the relative productivity of risky firms compared to the safe firms.

Importantly, while the aggregate shock,  $a_t$ , becomes commonly-known at the beginning of each period  $t$ , the idiosyncratic shock  $\phi(i)$  is realized at the beginning of the second stage of the corresponding period. Hence, in the first stage of each period, it is unknown to both the risky firms and the banks that fund these firms.

Risky firms get loans from banks

$$\tilde{l}_t(i) = \tilde{w}_t n_t^r(i) \quad (24)$$

to finance the wage bill. We assume that risky intermediate firms, like banks, live for one period. Consequently, they do not face price-adjustment cost. Thus, the risky firms' real profit in period  $t$  can be written as

$$z_t^r(i) = (1 - \tau_t) \frac{p_t^r(i)}{p_t} y_t^r(i) - R_t^r(i) \tilde{l}_t(i) \quad (25)$$

subject to

$$\phi(i)^\alpha A a_t n_t^r(i) \geq \left( \frac{p_t^r(i)}{p_t} \right)^{-\theta} y_t, \quad (26)$$

where  $\tau_t$  is a sales tax for risky firms.  $R_t^r(i)$  represents the gross return on loans paid by risky firms. It is smaller than the market loan rate  $R_t^l$  if firms default, i.e.  $R_t^r(i) < R_t^l$ . Otherwise,  $R_t^r(i) = R_t^l$ . Aggregate profits,  $z_t^r = \int_\nu^1 \int_0^1 z_t^r(i) d\phi(i) di$ , are paid out as dividends to households. We analyze the optimal behavior of risky firms in Appendix B and obtain

**Proposition 1**

(i) A risky firm's demand for bank loans is

$$l_t(i) = \frac{(A a_t)^{\theta-1} (1 - \tau_t)^\theta}{w_t^{\theta-1} (\Delta_t^l)^\theta} L^* y_t, \quad (27)$$

where  $\Delta_t^l := \frac{R_t^l}{R_t^s}$  represents the premium on bank financing<sup>8</sup>, and  $L^*$  is the root of

$$g(L) := (\theta - 1)L^{-\frac{1}{\theta}} + (1 + \alpha(\theta - 1))L^{\frac{1}{\alpha(\theta-1)}} - (\theta + \alpha(\theta - 1)) \quad (28)$$

that satisfies  $0 < L^* < 1$ .

(ii) Defaulted firms are those with realized  $\phi(i)$  below

$$\phi^c = (L^*)^{\frac{1}{\alpha(\theta-1)}}. \quad (29)$$

We observe that the risky firms' demand for loans is a decreasing function of the loan rate  $\Delta_t^l$ , the real wage  $w_t$ , and the sales tax  $\tau_t$ . It increases with aggregate productivity  $a_t$  and aggregate output  $y_t$ . Moreover, we note that the fraction of defaulting firms,  $\phi^c$ , is constant over the business cycle. However, we will see that the same is not true for the fraction of banks that default.

<sup>8</sup>The premium consists of two parts: default risk and higher costs of equity financing.

## 2.5 Banks

The banking system is characterized as follows: There is a continuum of banks.<sup>9</sup> An individual bank lives for one period and is specialized in granting loans to a risky firm. In this sense, banks are specialized in lending and do not hold a well-diversified loan portfolio.<sup>10</sup>

The banking system is competitive and operate as follows:

- Banks attract equity from households. A bank is founded if it receives a positive amount of equity.
- Banks attract deposits from households and decide on their capital structure.
- The market for loans opens. The identical pool of risky firms demands loans  $l_t(i)$  for a firm  $i$ . If a bank satisfies capital requirements (i.e.  $\frac{e_t(i)}{d_t(i)} \geq \Gamma_t$ ), it is allowed to operate and decides whether to offer its intermediation services, thereby offering loans coupled with monitoring. Market clearing yields the loan rate  $R_t^l$ .
- The productivity of risky firms is affected by idiosyncratic shocks. If a risky firm cannot pay back, banks secure the liquidation value.

To examine the equilibrium in the loan market, we assume that perfect monitoring prevails, i.e. banks can enforce the terms of the contract in the sense that they either get the repayment of the loan or the liquidation value if the firm cannot pay back. In the baseline model, we also assume that monitoring is costless.

Once banks have received equity, the objective of a bank is to maximize return on equity, taking into account limited liability, i.e. the fact that equity holders do not bear losses. By doing this, they decide about the capital structure, i.e. how many deposits they want to attract, whether they want to attract more equity, and whether they want to offer loans to risky firms. We assume that an individual bank can attract equity and deposits as long as it offers expected returns with which equity holders and depositors, respectively, are at least as well off as with other investment opportunities.

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<sup>9</sup>Since ultimately, one risky firm will obtain a loan from one bank, we assume that the measure of banks is at least  $1 - \nu$  for measuring consistency.

<sup>10</sup>We focus on banks without well-diversified loan portfolios and make a simple assumption about the specialization of banks. If banks held fully diversified portfolios, either all banks would collapse or all would be solvent.



Of course, in equilibrium, aggregate supply and demand for equity and deposits have to match, given such individual choices.

Note that in our model, the maximization of the expected return on equity is equivalent to the maximization of the utility of shareholders. The reasons are as follows. First, an individual bank's choice does not alter prices in the economy, as banks are perfectly competitive. Second, the bank's choice to lend does not open up new insurance opportunities for households. As a consequence, all shareholders will agree that the bank should maximize its expected return on equity in order to contribute the maximal expected amount to the budget of shareholders.

We now consider a representative bank's problem in more detail. Since loan and deposit markets are perfectly competitive, the bank demands an amount of deposits  $d_t(i)$  at the prevailing deposit rate without worrying about whether this is consistent with market clearing for deposits and loans. Once the bank has chosen its capital structure  $\frac{e_t(i)}{d_t(i)}$ , it decides whether to offer  $e_t(i) + d_t(i)$  as loans to risky firms or to invest in safe firms' bonds. As a tie-breaking rule, we assume that the bank grants loans to risky firms if they generate at least the same expected return on equity as for other investment opportunities.

With these remarks, the problem of a representative bank can be formulated as in Appendix C. Three results that are crucial for our model are summarized in the next three propositions. First, we characterize the equilibrium capital structures.

**Proposition 2**

*Banks always choose their capital structure to be equal to the aggregate capital requirement<sup>11</sup>*

$$e_t = \Gamma_t d_t. \tag{30}$$

Similarly to the fraction of defaulting firms, we obtain the following proposition for the fraction of defaulting banks:

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<sup>11</sup>See Gersbach et al. (2015a) on the uniqueness of bank capital structure in more general setups.

### Proposition 3

The fraction of defaulting banks is

$$\phi^\Gamma = \frac{\phi^c}{(\Delta_t^l(1 + \Gamma_t))^{\frac{\theta}{\alpha(\theta-1)}}} \in [0, \phi^c]. \quad (31)$$

This proposition implies that the fraction of defaulting banks does not depend on sales taxes, decreases with  $\Gamma_t$  and reaches 0 when banks are fully financed by equity. The number of defaulting banks is also a decreasing function of  $\Delta_t^l$ , i.e. the difference between the interest rates on loans and on deposits.

Accounting identities lead to the following relationship between the loan rate  $\Delta_t^l$  and the return on equity  $\Delta_t^e$ :

### Proposition 4

The market loan rate satisfies

$$\Delta_t^l = \frac{h^{-1}(\Gamma_t \Delta_t^e)}{1 + \Gamma_t}, \quad (32)$$

where

$$h(x) := \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left( \frac{1}{x^{\frac{\theta}{\alpha(\theta-1)}}} - x \right) \phi^c + x - 1. \quad (33)$$

As shown in Appendix C, the function  $h(\cdot)$  is a monotonically-increasing function that satisfies  $h(1) = 0$  and goes to infinity for large values of its argument. Hence, (32) establishes that the return on equity that the banks can generate,  $\Gamma_t^{-1}h((1 + \Gamma_t)\Delta_t^l)$ , is an increasing function of the loan rate that banks charge risky intermediate firms. Moreover, we can conclude that for  $\Gamma_t \rightarrow 0$ ,  $\Delta_t^l \rightarrow 1$ . Therefore, if banks are fully financed by deposits, the rate on bank loans equals the rate on deposits. Positive values of  $\Gamma_t$  result in values of  $\Delta_t^l$  that are strictly larger than one.

## 2.6 The Government

The sole function of the government is to use lump-sum taxes  $\tau_t^l$  from households and the revenues from the sales taxes on risky and safe firms to bail out banks that failed in the second stage. We assume a fraction  $\mu$  of the bailout fees is dissipated when the

government bails out the defaulted banks. With the aggregate costs of these bailouts denoted as  $bo_t$ , the government's budget constraint is

$$\tau_t^l + st_t + \frac{B_{t+1}}{I_t p_t} = (1 + \mu)bo_t + \frac{B_t}{p_t}, \quad (34)$$

where the sales taxes revenue  $st_t$  and the bailout fees  $bo_t$  are presented in Appendix D.

## 2.7 Market Clearing

Finally, we state the market clearing conditions. Goods-market clearing implies that output equals the sum of consumption, the adjustment costs for prices, the equity management costs, and the dissipation when defaulted banks are bailed out,

$$y_t = c_t + adj_t^p + m_t + \mu bo_t, \quad (35)$$

where  $adj_t^p = \frac{\gamma^p}{2} \nu \left( \frac{p_t^s(i)}{p_{t-1}^s(i)} - 1 \right)^2 y_t$ .

Equilibrium on the labor market implies that the total supply of labor has to equal the demand by both safe and risky intermediate firms:

$$n_t = n_t^s + n_t^r, \quad (36)$$

where  $n_t^s = \int_0^\nu n_t^s(i) di$  represents total labor demand by safe firms,  $n_t^r = \int_\nu^1 n_t^r(i) di$  total labor demand by risky firms.

The market for intra-period debt issued by safe firms is balanced if

$$\tilde{s}_t = \int_0^\nu \tilde{s}_t(i) di. \quad (37)$$

Finally, the following accounting identity has to hold for banks:

$$\tilde{l}_t = \tilde{d}_t + \tilde{e}_t, \quad (38)$$

where  $\tilde{l}_t = \int_\nu^1 \tilde{l}_t(i) di$  represents total loans,  $\tilde{d}_t = \int_\nu^1 \tilde{d}_t(i) di$  total deposits and  $\tilde{e}_t = \int_\nu^1 \tilde{e}_t(i) di$  total equity.

### 3 Private-sector Equilibrium

#### 3.1 Equations describing the private-sector equilibrium

In this section, we summarize the equations describing the private-sector equilibrium. For this purpose, we observe that all safe firms are identical and thus set the same price  $p_t^s := p_t^s(i)$ . This allows us to introduce  $q_t := p_t^s/p_t$  the ratio between the price of the intermediate goods produced by safe firms with respect to the aggregate price and  $\Pi_t^s := \frac{p_t^s}{p_{t-1}^s}$  the gross inflation of the intermediate goods produced by safe firms. With the help of this notation, we will now state the equations describing the evolution of the endogenous variables  $\{n_t^s(i), n_t^r(i), w_t, \Delta_t^l, \Pi_t^s, q_t, y_t, c_t\}_{t=0}^\infty$  for the paths of the exogenous shocks  $\{a_t, \chi_t, \tau_t\}_{t=0}^\infty$  and the policy instruments  $\{I_t, \Gamma_t\}_{t=0}^\infty$ .

As shown in Appendix B, a risky firm's demand for bank loans, where the loan is used to finance the wage bill  $w_t n_t^r(i)$ , is

$$w_t n_t^r(i) = \left( \frac{A a_t}{w_t} \right)^{\theta-1} \frac{(1 - \tau_t)^\theta}{(\Delta_t^l)^\theta} L^* y_t. \quad (39)$$

The optimal price-setting of safe firms results in the following standard condition for price-setting in the presence of quadratic adjustment costs (see Appendix A):

$$0 = \frac{y_t}{(q_t)^{\theta-1}} \left[ (1 - \tau_t)(1 - \theta) + \theta \frac{w_t}{q_t a_t} \right] - \gamma^p y_t \Pi_t^s (\Pi_t^s - 1) + \mathbb{E}_t \left[ \beta \frac{c_t^\sigma}{c_{t+1}^\sigma} \gamma^p y_{t+1} \Pi_{t+1}^s (\Pi_{t+1}^s - 1) \right]. \quad (40)$$

Note that, in the absence of price adjustment costs, i.e. for  $\gamma^p = 0$ , each safe intermediate firm would charge a constant markup over real marginal costs, i.e.  $q_t = \frac{p_t^s}{p_t} = \frac{\theta}{(1 - \tau_t)(\theta - 1)} m c_t^s$ , where real marginal costs are  $m c_t^s = \frac{w_t}{a_t}$ .

The demand function for the intermediate goods produced by safe firms results in the following equation (see (15) and (17)):

$$a_t n_t^s(i) = q_t^{-\theta} y_t. \quad (41)$$

Aggregate output can be computed from the final-good firms' production function and the production functions for intermediate firms (see (14), (17), and (23)):

$$y_t = a_t \left( \nu (n_t^s(i))^{\frac{\theta-1}{\theta}} + (1-\nu) \frac{\theta}{\theta + \alpha(\theta-1)} (An_t^r(i))^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}. \quad (42)$$

Accounting identities lead to a relationship between the loan rate requested by banks and banks' profits, which, in turn, leads to a relationship between the loan rate  $\Delta_t^l$  and the return on bank equity,  $\Delta_t^e$ , which has to satisfy the no-arbitrage condition  $\Delta_t^e = \frac{1}{1-\chi_t}$  (see (13)):

$$\frac{1}{1-\chi_t} = (\Gamma_t)^{-1} h((1+\Gamma_t)\Delta_t^l), \quad (43)$$

where  $h(\cdot)$  is defined in (32).

Optimal bond holdings entail a standard consumption Euler Equation (see (10) and (11)):

$$\frac{1}{I_t} c_t^{-\sigma} = \mathbb{E}_t \left[ \beta c_{t+1}^{-\sigma} \frac{1}{\Pi_{t+1}^s} \frac{q_{t+1}}{q_t} \right]. \quad (44)$$

Moreover, the marginal disutility from work has to equal the wage rate times the marginal utility of consumption (see (10) and (12)):

$$\psi(\nu n_t^s(i) + (1-\nu)n_t^r(i))^\varphi = c_t^{-\sigma} w_t. \quad (45)$$

Equilibrium on the goods market involves

$$y_t = c_t + \frac{1}{2} \gamma^p \nu (\Pi_t^s - 1)^2 y_t + \frac{\chi_t}{1-\chi_t} \frac{\Gamma_t}{1+\Gamma_t} (1-\nu) w_t n_t^r(i) + \mu \frac{\alpha(\theta-1)}{\theta + \alpha(\theta-1)} \frac{(1-\nu) w_t n_t^r(i) (L^*)^{\frac{1}{\alpha(\theta-1)}}}{(\Delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}} (1+\Gamma_t)^{\frac{\theta+\alpha(\theta-1)}{\alpha(\theta-1)}}}, \quad (46)$$

which has the interpretation that output equals consumption, the costs for price adjustment and equity management, and the dissipations when the government bails out the defaulted banks. The expression for the bailout costs is derived in Appendix D.

To sum up, the equilibrium dynamics are described by (39)-(46). It is then straightforward to determine the other variables that are not contained in this system of equations.

We summarize the findings in the following proposition:

**Proposition 5**

*For given policy instruments  $\{I_t, \Gamma_t\}_{t=0}^\infty$ , and shocks  $\{a_t, \chi_t, \tau_t\}_{t=0}^\infty$  the private sector equilibrium  $\{n_t^s(i), n_t^r(i), w_t, \Delta_t^l, \Pi_t^s, q_t, y_t, c_t\}_{t=0}^\infty$  is described by the system of Equations (39)-(46).*

### 3.2 Log-linearized equations

In this section, we state log-linearized versions of the conditions (39)-(46). We observe that we log-linearize around a steady state that does not necessarily involve zero inflation. We use the symbol  $\hat{\cdot}$  to denote log deviations from steady-state values and  $*$  for steady-state values. For the details we refer to Appendix E.

Equation (39) can be approximated as

$$\hat{w}_t + \hat{n}_t^r(i) = (\theta - 1)(\hat{a}_t - \hat{w}_t) - \theta\left(\frac{\tau^*}{1 - \tau^*}\hat{\tau}_t + \hat{\Delta}_t^l\right) + \hat{y}_t. \quad (47)$$

The Phillips curve, Equation (40), has the following log-linearized approximation:

$$\begin{aligned} 0 = & (1 - \beta)\gamma^p\Pi^*(\Pi^* - 1)(\hat{y}_t - \theta\hat{q}_t + \hat{w}_t - \hat{a}_t) \\ & + (q^*)^{1-\theta}(1 - \tau^*)(\theta - 1)\left(\hat{w}_t - \hat{a}_t - \hat{q}_t + \frac{\tau^*}{1 - \tau^*}\hat{\tau}_t\right) \\ & + \gamma^p(\Pi^*)^2\mathbb{E}_t\left[\beta(\sigma\hat{c}_t - \sigma\hat{c}_{t+1} + \hat{y}_{t+1} + 2\pi_{t+1}^s) - 2\pi_t^s - \hat{y}_t\right] \\ & + \gamma^p\Pi^*\mathbb{E}_t\left[\pi_t^s + \hat{y}_t - \beta(\sigma\hat{c}_t - \sigma\hat{c}_{t+1} + \hat{y}_{t+1} + \pi_{t+1}^s)\right]. \end{aligned} \quad (48)$$

Equation (41) has the following log-linear approximation

$$\hat{a}_t + \hat{n}_t^s(i) = -\theta\hat{q}_t + \hat{y}_t. \quad (49)$$

We obtain the following approximation to (42)

$$\hat{y}_t = \hat{a}_t + \kappa_1\hat{n}_t^s(i) + (1 - \kappa_1)\hat{n}_t^r(i), \quad (50)$$

where  $\kappa_1 \in (0, 1)$  is given in Appendix E.

Equation (43) can be approximated as

$$\frac{\chi^*}{1 - \chi^*}\hat{\chi}_t = \frac{(\kappa_2 - 1)\Gamma^* - 1}{1 + \Gamma^*}\hat{\Gamma}_t + \kappa_2\hat{\Delta}_t^l, \quad (51)$$

where the coefficient  $\kappa_2$  is given in Appendix E.

A log-linear approximation to the consumption Euler Equation, Equation (44), is

$$\hat{c}_t = -\sigma^{-1}\left(\hat{I}_t - \mathbb{E}_t[\pi_{t+1}]\right) + \mathbb{E}_t[\hat{c}_{t+1}]. \quad (52)$$

Equation (45)

$$\hat{w}_t - \sigma \hat{c}_t = \varphi \kappa_3 \hat{n}_t^s(i) + \varphi(1 - \kappa_3) \hat{n}_t^r(i), \quad (53)$$

where  $\kappa_3 \in (0, 1)$  is given in Appendix E.

A log-linearized approximation to the resource constraint, Equation (46), is given by

$$\begin{aligned} \hat{y}_t = & \frac{c^*}{y^*(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{c}_t + \frac{\nu \gamma^p \Pi^* (\Pi^* - 1)}{1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2} \pi_t^s + \frac{y^* - c^* - \frac{1}{2} \gamma^p \nu (\Pi^* - 1)^2 y^*}{y^*(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} (\hat{w}_t + \hat{n}_t^r(i)) \\ & + \frac{\kappa_4}{(1 - \chi^*)(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{\chi}_t - \frac{\kappa_5 \theta}{\alpha(\theta - 1)(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{\Delta}_t^l \\ & + \frac{\kappa_4 \alpha(\theta - 1) - \kappa_5(\theta + \alpha(\theta - 1)) \Gamma^*}{\alpha(\theta - 1)(1 + \Gamma^*)(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{\Gamma}_t, \end{aligned} \quad (54)$$

where  $\kappa_4$  and  $\kappa_5$  are given in Appendix E.

### Proposition 6

For given policy instruments  $\{\hat{I}_t, \hat{\Gamma}_t\}_{t=0}^\infty$ , and shocks  $\{\hat{a}_t, \hat{\chi}_t, \hat{\tau}_t\}_{t=0}^\infty$  the private sector equilibrium  $\{\hat{n}_t^s(i), \hat{n}_t^r(i), \hat{w}_t, \hat{\Delta}_t^l, \pi_t^s, \hat{q}_t, \hat{y}_t, \hat{c}_t\}_{t=0}^\infty$  of the log-linearized economy is described by the system of Equations (47)-(54).

## 4 Numerical Findings

### 4.1 Calibration

For the parameter values, we follow Collard et al. (2017) in setting the discount rate  $\beta = 0.993$ , the inverse of labor supply elasticity  $\varphi = 0.276$ , the relative utility weight of labor  $\psi = 3.409$ , the relative risk aversion of consumption  $\sigma = 1$ , and the elasticity of substitution of intermediate goods  $\theta = 7$  (which corresponds to a 17% markup). The persistence and the standard deviation of the productivity are set at 0.966 and 0.0068, respectively. We use  $\gamma^p = \frac{(\theta-1)\eta}{(1-\eta)(1-\beta\eta)}$  from Keen and Wang (2007) and set  $\gamma^p = 93.4$  such that the Phillips Curve has the same slope as in Collard et al. (2017), where the Calvo parameter is  $\eta = 0.779$ .

We choose the fraction of safe firms  $\nu = 0.616$  such that the total revenue of the safe (bond-financed) firms is 1.5 times the total revenue of the risky (bank-financed) firms

in steady state (see De Fiore and Uhlig (2011) and Gersbach et al. (2015b)). We select  $\alpha = 0.118$  such that the charge-off rate on loans

$$\int_0^{\phi^c} \frac{R_t^l - R_t^r(i)}{R_t^l} d\phi(i) = \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} (L^*)^{\frac{1}{\alpha(\theta - 1)}}$$

is equal to the empirical value 0.97%.<sup>12</sup> In addition, we set the steady-state value for the coefficient of equity management  $\chi_t$  to the value 0.0521, which results in an equity premium of 5.5% (U.S. data over 1900-2015<sup>13</sup>). The coefficient of bailout dissipation is set at  $\mu = 0.93$  capturing output losses and tax distortions which amounts to 0.34% quarterly output losses.<sup>14</sup> We normalize the steady-state productivity of safe firms to  $a^* = 1$  and set  $A$  such that it satisfies  $\frac{\theta}{\theta + \alpha(\theta - 1)} A^{\frac{\theta - 1}{\theta}} = 1$ , which means that, loosely speaking, safe firms and risky firms are equally productive on average (see (42)).

For simplicity, we assume that the government does neither tax nor subsidize intermediate firms, i.e.  $\tau^* = 0$ , on the steady state. We assume  $B_t = 0$ , such that the government relies on the lump-sum taxes to bail out defaulted banks.

We will log-linearize the model around the unconditionally optimal (UO) steady state (see Damjanovic et al. (2008) and Damjanovic et al. (2015)), i.e. we determine the steady state associated with the UO policy, which maximizes the unconditional expectation of (1) subject to constraints (39)-(46). Given the other steady-state parameters, the corresponding numerical optimization problem results in the optimal capital requirement  $\Gamma^* = 5.8\%$  and inflation rate  $\Pi^* - 1 = 0.02\%$ . Notably, the UO steady state features a mildly positive net rate of inflation. This is plausible as a mildly positive inflation rate alleviates the distortions arising from monopolistic competition to some extent. At this optimal steady-state capital requirement and inflation, the corresponding fraction of defaulting banks is  $\phi^{\Gamma^*} \approx 5.7\%$ .

## 4.2 Comparative Statics

In this section, we characterize and illustrate the properties of the steady state.

<sup>12</sup>See <https://fred.stlouisfed.org/series/CORALACBN> for the charge-off rate on loans for all commercial banks in the U.S. during 1985–2016. Another approach is to choose  $\alpha$  such that the fraction of non-performing loans to total loans, i.e.  $\phi^c$ , matches the ratio of non-performing loans to total loans for small enterprises in developed countries (see Beck et al. (2008)). Both approaches yield very similar value of  $\alpha$ .

<sup>13</sup>See Damodaran (2016) for a review of the equity premia across countries and over different periods.

<sup>14</sup>We take the U.S. data from Laeven and Valencia (2012).



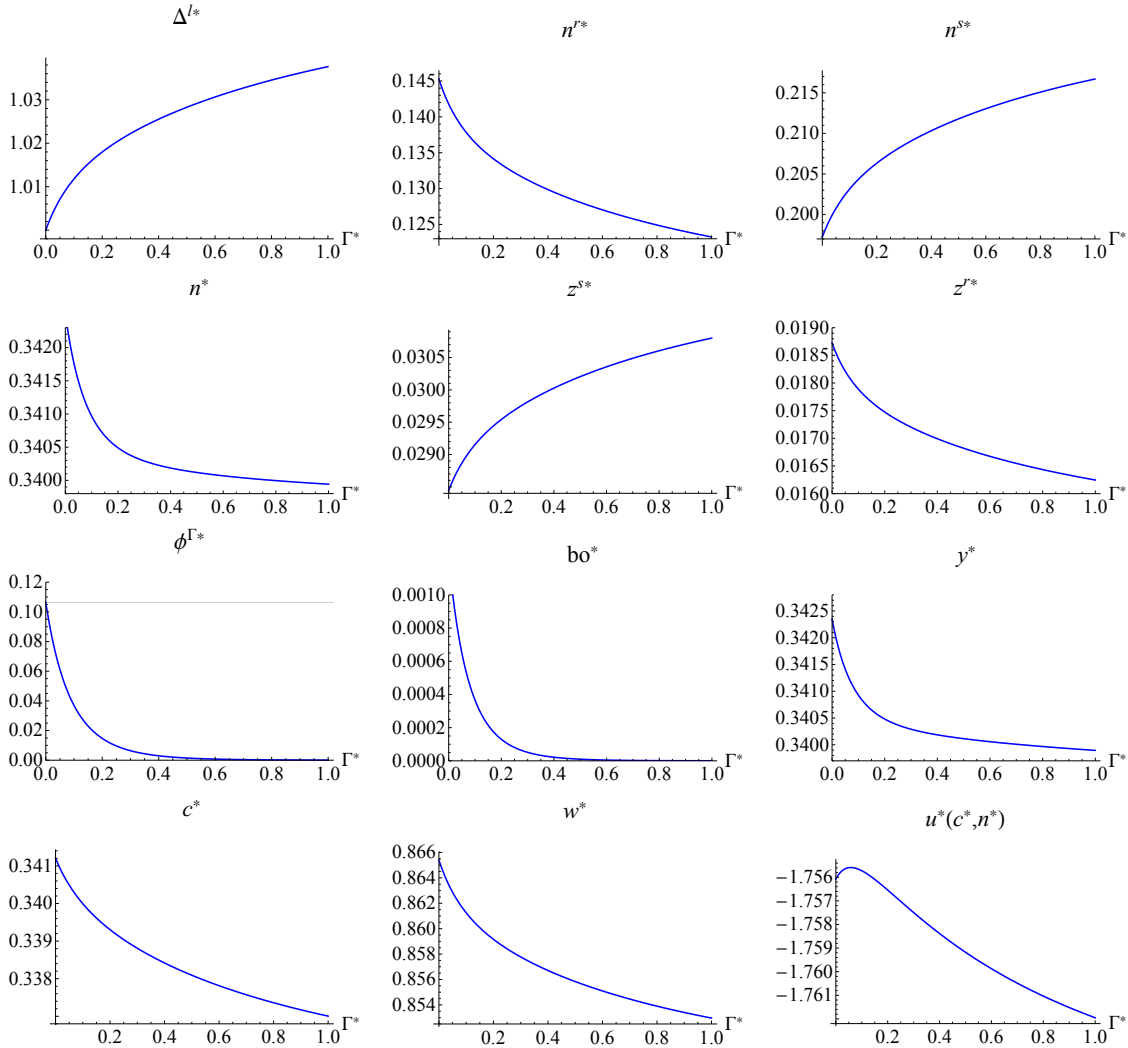


Figure 2: Steady-state variables as functions of the aggregate capital requirement.

Figure 2 shows the steady-state variables as a function of aggregate capital requirements. In the following, we interpret Figure 2 from left to right and from the top to the bottom.

- The first two graphs show the significant impact on the risky sector when aggregate capital requirements rise. The loan rate increases since banks face higher financing costs. As a consequence, loan demand by risky firms decreases and less labor is hired. The next graph indicates that labor is shifted to the safe sector.
- The sharp contraction in the risky sector dominates the reallocation to safe firms and aggregate labor used in production decline, mildly though, as displayed in Graph 4.

- As resources are shifted to safe firms, the safe firms' profit grows while the risky firms' profit shrinks, with the aggregate capital requirement.
- The contraction of the risky sector when aggregate capital requirements are raised entails less bank failure as indicated in Graph 7 (The horizontal dashed line represents  $\phi^c$ , the fraction of defaulting risky firms).
- The bailout fees decrease with aggregate capital requirement for two reasons. On the one hand, a higher  $\Gamma^*$  leads to fewer loans to risky firms, and thus fewer rescue funds are needed when banks default. On the other hand, a higher aggregate capital requirement results in a smaller fraction of defaulting banks.
- As aggregate labor decreases with  $\Gamma^*$ , the final output and consumption do the same.
- High aggregate capital requirements have only a moderately negative impact on wages.
- The last plot in Figure 2 displays the net impact of higher aggregate capital requirements on utility. Both consumption and labor supply decrease with  $\Gamma^*$ , i.e. both the utility from consumption and disutility from labor supply decrease. The last plot of Figure 2 shows that the utility increases with the aggregate capital requirements for low aggregate capital requirements and attains the maximum at  $\Gamma^* = 5.8\%$ . The reason is that there is significant overinvestment in risky firms with low aggregate capital requirements. Higher aggregate capital requirements reduce this inefficiency, thereby increasing the aggregate output per unit of labor input. However, too high aggregate capital requirements entail large costs of equity management, and excessively shift resources to safe firms.

### 4.3 Impulse Responses

In this section, we illustrate by some examples how the economy reacts to shocks when the aggregate capital requirement is fixed at its steady-state value, i.e.  $\Gamma_t = \Gamma^*$ , and the interest rate follows Taylor rule

$$\frac{I_t}{I^*} = \left( \frac{\Pi_t}{\Pi^*} \right)^{1.5} \left( \frac{y_t}{y^*} \right)^{0.5} e^{\epsilon_t^I}, \quad (55)$$

where  $\Pi_t := \frac{p_t}{p_{t-1}} = \frac{q_{t-1}}{q_t} \Pi_t^s$  represents the aggregate gross inflation and  $\epsilon_t^I$  is an independent and identically distributed shock. We first show the response of the economy in reaction to an interest rate shock. The set of equations used to compute the impulse responses is (39)-(46).

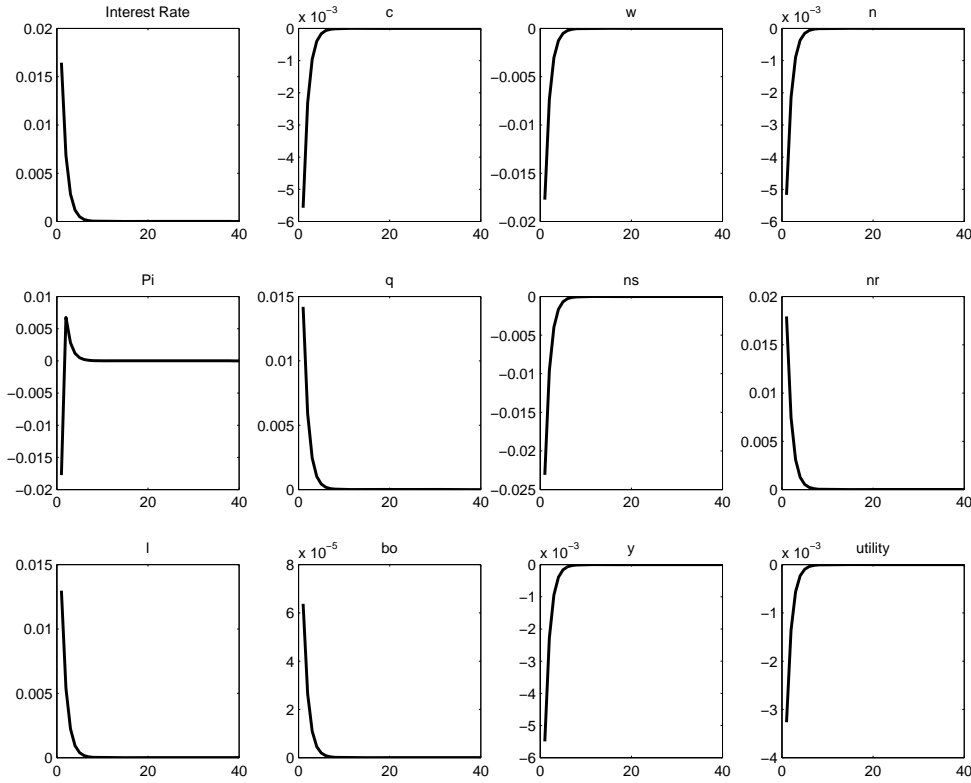


Figure 3: Impulse responses to a positive shock on interest rate.

Figure 3 shows the dynamics of the economy after a temporary interest rate hike. High interest rates lead to more saving, less consumption, declining wage and lower

total labor supply. The declining demand results in prices falling down and a subsequent overshooting inflation. However, due to price stickiness, safe firms lower prices relatively slower than risky firms. Thus, the ratio between the price of the intermediate goods produced by safe firms with respect to the aggregate price, i.e.  $q_t$ , hikes. With relative high prices, safe firms get low demand of their goods, thus less labor is hired in safe firms and labor is shifted to risky firms. More loans are granted to risky firms, which leads to higher bailout fees. The aggregate output falls down due to the decreasing total labor supply and the utility decreases.

Next, we study two other types of shock on the economy: productivity shock ( $\hat{a}_t$ ) and financial shock ( $\hat{\chi}_t$ ), which follow

$$\hat{a}_t = \rho^a \hat{a}_{t-1} + \epsilon_t^a,$$

$$\hat{\chi}_t = \rho^\chi \hat{\chi}_{t-1} + \epsilon_t^\chi,$$

where  $\rho^a, \rho^\chi \in [0, 1)$  are coefficients of persistence and  $\epsilon_t^a, \epsilon_t^\chi$  are serially uncorrelated normally distributed error terms with zero mean.

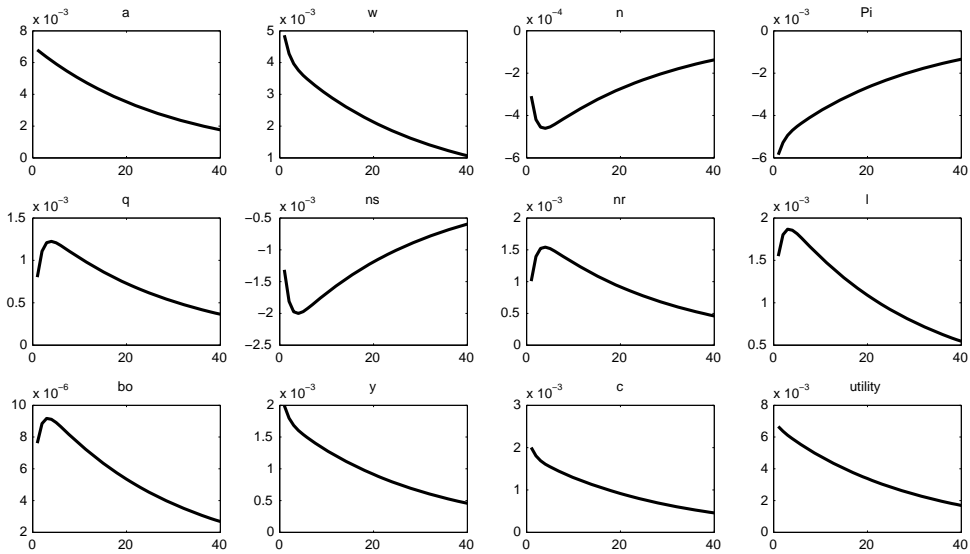


Figure 4: Impulse responses to a positive shock on technology.

We first examine the impact of productivity shocks in the absence of financial shock. Figure 4 shows the evolution of the economy in response to a temporary positive shock on technology. Higher marginal productivity raises wages. Higher wages decrease aggregate labor supply, since the income effect dominates the substitution effect. Lower marginal costs lead to deflation. However, due to the price rigidity, safe firms cannot lower the price as fast as the risky firms. Thus, the ratio between the price of the intermediate goods produced by safe firms with respect to the aggregate price, i.e.  $q_t$ , hikes with a humped shape. We observe a reallocation of resources between sectors: labor is shifted from safe firms to risky firms. Due to the price rigidity, the process of labor reallocation exhibits a humped shape. High wage rate and more labor employed in risky firms imply more bank loans granted to risky firms. Hence, more rescue funds are needed, as shown by the increase of bailout fees. That is, positive productivity shocks to firms increase the severity of bank failures. The remaining macroeconomic variables evolve as follows. The increase in productivity yields higher output, consumption and utility, which gradually decline to the steady level.

Figure 5 shows the evolution of the economy in response to a positive shock on equity management costs. The return on equity rises, as the opportunity costs of equity acquisition increase. This, in turn, implies that loan rates increase. Thus, the loan demand declines and labor is shifted from risky sector to safe sector. Furthermore, high loan rates lead to low bank failure rate and bailout fees. In addition, an increase of equity management costs leads to inflation, lower relative price of intermediate goods produced by safe firms (safe firms adjust price slower than risky firms) and declines of wage rate, aggregate labor, output (countercyclical equity premia), consumption and utility.

## 5 Optimal Policy Rules

The global financial crises 2007-2009 and its aftermath has cast doubt on the effectiveness of monetary policy, and has raised questions about how to include financial stability measures—proxied by, e.g. credit aggregates or non-performing loans—into macroeconomic policy-making. The crisis has also rekindled the debate how to govern

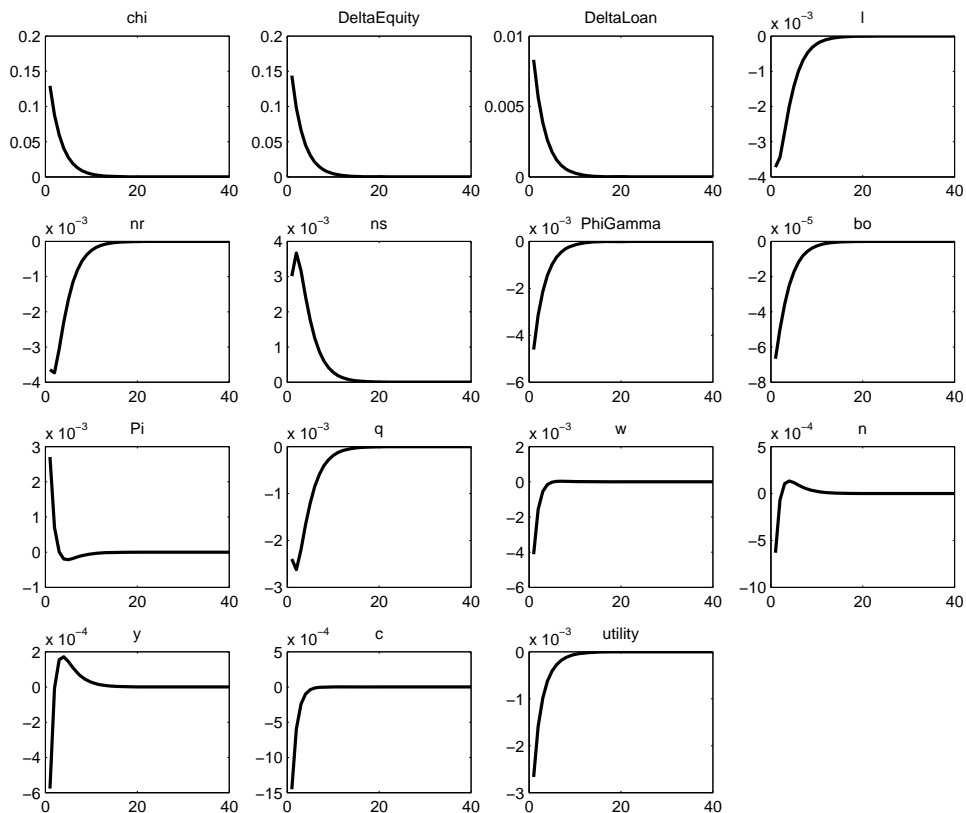


Figure 5: Impulse responses to a positive shock on equity management costs.

and coordinate monetary and macroprudential policies before, during and after financial crises. The last crisis has cast also considerable doubt on the consensus formed in “Great Moderation”, that stable inflation and output (the so-called divine coincidence) are generally sufficient for sound monetary policy decisions and sustained macroeconomic stability. The crisis has shown that with stable inflation and a near-zero output gap achieved by inflation-targeting Taylor Rules, unsustainable sectoral booms and gradual buildups of financial risks—e.g. excessive leverage of banks—may lead to a financial meltdown, causing strong output declines.

As a response, one strand of literature studies the modified Taylor Rules. Blanchard et al. (2013) and Woodford et al. (2014) point out that monetary policy should incorporate multiple targets and multiple instruments.<sup>15</sup> Woodford (2012) demonstrated

<sup>15</sup>As documented in Goodhart et al. (1988), the original purpose of establishing central banks in certain countries was to prevent financial instability. Several economists, such as King (1997),

that a temporary departure of monetary policy from inflation and output target path because of financial stability concerns can be socially optimal.

Another strand of literature studies the optimal proxy or indicator for financial instability. Bernanke and Gertler (2000) and Cecchetti et al. (2002) use asset prices; Agnor et al. (2011) and Christiano et al. (2010) use credit aggregates; and Carlstrom et al. (2010), Angelini et al. (2014), Curdia and Woodford (2009), Quint and Rabanal (2014) and Ueda and Valencia (2014) use credit spreads and leverage.

We contribute to this literature by studying the interplay of monetary policy and macroprudential policy and investigating optimal policy rules for central banks and the macroprudential policy-makers.

For our analysis, we use the simulated method of moments to find plausible values for the policy and financial shocks. This method involves matching the simulated model moments to the corresponding moments from the data. Kydland and Prescott (1982) were among the first to use this method. McFadden (1989), Duffie and Singleton (1993) and Lee and Ingram (1991) further developed the method. The empirical values used for the calibration of the persistences and standard deviations of the financial and policy shocks are as follows. The persistence of the financial shock is pinned down by the empirical value of the persistence of the return on bank equity (see Goddard et al. (2011) for the U.S. data). The standard deviation of the equity premium in the U.S. over 1900 – 2015 is 19.6% (see Damodaran (2016)). Using the data from the Federal Reserve Bank of St. Louis, we find that the standard deviation of U.S. inflation (1956 – 2016) is 2.8%. These two values allow us to pin down the standard deviations of the financial and policy shocks.

We then derive the unconditionally optimal (UO) policies as the welfare measure for different policy stances. As shown in Damjanovic et al. (2015), it is possible to derive a purely quadratic approximation to welfare around the UO steady state by using approximations to the social planner’s constraints up to second order to eliminate all linear terms in the approximation of the household’s utility function up to second order. This purely quadratic measure can be evaluated for constraints and policies that are

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Bernanke and Mishkin (1997) and Svensson (1999), for instance, proposed a more flexible inflation targeting. Käfer (2014) reviews the literature on Taylor Rules augmented with financial stability term.

correct up to the first order. For this purpose, one has to compute the variances and covariances of the log-deviations of the endogenous variables and exogenous shocks from the UO steady state. As the computation of the welfare measure requires the computation of second-order derivatives of the constraints and the utility function, which is quite cumbersome, we perform the respective calculations with the help of a computer algebra system.<sup>16</sup>

We next determine the optimal Taylor Rule for monetary policy-making. For this purpose, we set the aggregate capital requirement at the steady state value. This investigation breaks down to three questions:

- What are the optimal weights on inflation and output gap?
- Should the central bank take the concern of financial instability into account?
- If yes, which is the optimal indicator for financial instability, the financial risk represented by the fraction of defaulted banks  $\phi_t^\Gamma$  or the credit cycle represented by the change in the aggregate amount of bank loans  $l_t$ ?

To facilitate the analysis, we write down the central bank's augmented Taylor Rule

$$\frac{I_t}{I^*} = \left( \frac{\Pi_t}{\Pi^*} \right)^{v_{cb}^\pi} \left( \frac{y_t}{y^*} \right)^{v_{cb}^y} \left( \frac{l_t}{l^*} \right)^{v_{cb}^l} \left( \frac{\phi_t^\Gamma}{\phi^{\Gamma^*}} \right)^{v_{cb}^\phi}, \quad (56)$$

where  $(v_{cb}^\pi, v_{cb}^y, v_{cb}^l, v_{cb}^\phi)$  represents the Taylor-Rule coefficients. A priori, we allow that the Taylor Rule depends on inflation, the output gap, the aggregate amount of loans and the share of bank defaults—all variables are measured in relation to the steady state values.

We first shut down the financial instability terms, i.e.  $v_{cb}^l = v_{cb}^\phi = 0$ , and run the program for  $v_{cb}^\pi \in [1.1, 2.5]$  and  $v_{cb}^y \in [0, 1.5]$ . Figure 6a shows the UO social losses under different coefficient constellations  $(v_{cb}^\pi, v_{cb}^y, 0, 0)$ . We observe that social losses are minimal for  $v_{cb}^y = 0$ . Thus, given that the capital requirement is fixed at its steady-state level and the monetary policy maker does not react to financial instability, the central bank should focus solely on price stability.

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<sup>16</sup>Details are available upon request.



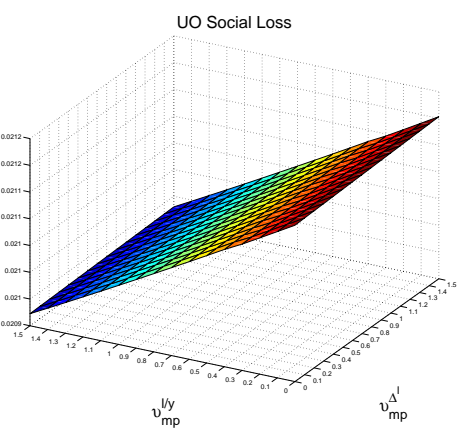
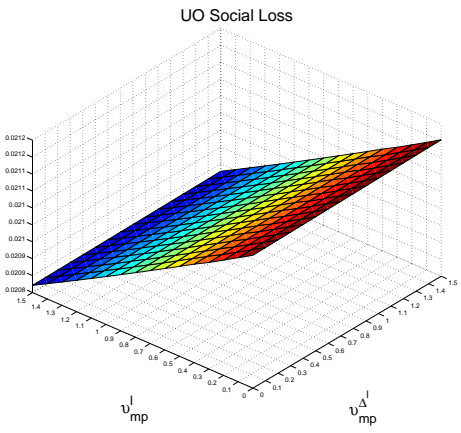
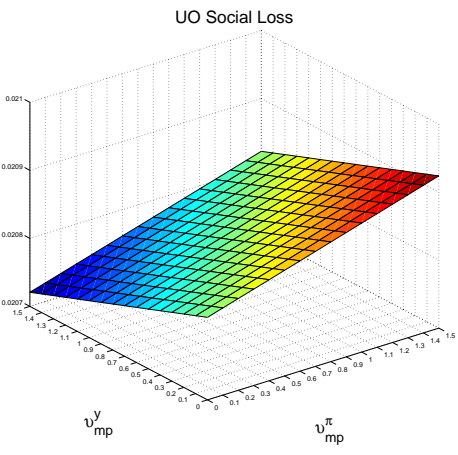
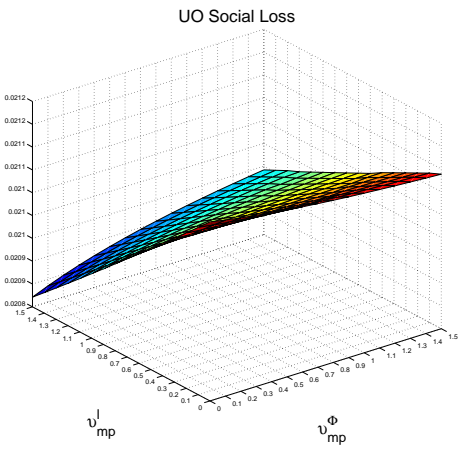
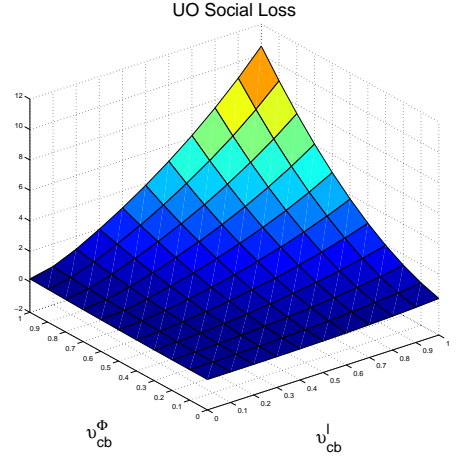
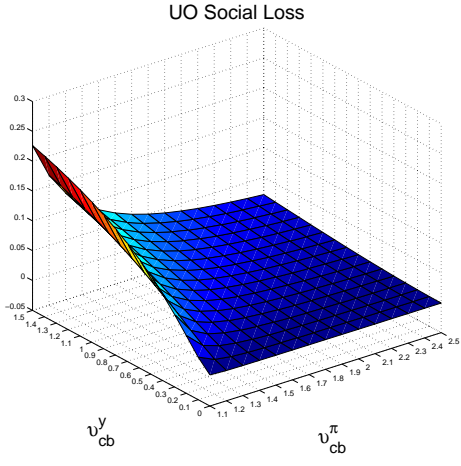


Figure 6: UO Social Losses under different policy rules.

We next study whether the central bank should take into account the financial instability and if yes, which one serves better as the indicator of financial instability, the fraction of defaulted bank or the total credit supply? We run the program for  $v_{cb}^l \in [0, 1]$  and  $v_{cb}^\phi \in [0, 1]$ .<sup>17</sup> Figure 6b shows the UO social losses under different coefficient constellations  $(2.5, 0, v_{cb}^l, v_{cb}^\phi)$ . Thus, the optimal Taylor Rule does not involve any financial instability concern. This finding backs the prevailing view that monetary policy cannot serve as an effective tool to safeguard financial stability, as it primarily affects the aggregate amount of lending through the banking system and capital market.

To tame excessive risk-taking behavior, policy maker has to use the tool that has direct impact on the composition of credit<sup>18</sup>. For this purpose, we now turn to macroprudential policy making. Similar to the central bank's augmented Taylor Rule (56), we write down the macroprudential policy maker's rule

$$\frac{\Gamma_t}{\Gamma^*} = \left( \frac{\Pi_t}{\Pi^*} \right)^{v_{mp}^\pi} \left( \frac{y_t}{y^*} \right)^{v_{mp}^y} \left( \frac{l_t}{l^*} \right)^{v_{mp}^l} \left( \frac{\phi_t^\Gamma}{\phi^{\Gamma^*}} \right)^{v_{mp}^\phi}, \quad (57)$$

where  $(v_{mp}^\pi, v_{mp}^y, v_{mp}^l, v_{mp}^\phi)$  represents the macroprudential-policy-rule coefficient constellation.

We study the optimal macroprudential rule for a given central bank's Taylor Rule (56), with coefficients  $(1.5, 0.5, 0, 0)$ . We first consider the scenario when the macroprudential policy maker focuses only on financial instability. We investigate which financial indicator should be given more weight, i.e. we study the optimal constellation of coefficients  $(0, 0, v_{mp}^l, v_{mp}^\phi)$ . Figure 6c shows that the use of time-varying capital requirements should be based on the credit cycles, as suggested in Basel III.<sup>19</sup> We next examine whether the macroprudential policy maker should also react to the price and output variations beyond credit fluctuations. Figure 6d shows that the macroprudential policy maker should also take into account output stability but not inflation. In

<sup>17</sup>For the determinacy of the equilibrium, see Bullard and Mitra (2002) and Blanchard and Kahn (1980).

<sup>18</sup>On this point see also Borio and Zhu (2012).

<sup>19</sup>The event analysis of credit booms by Mendoza and Terrones (2012) shows that credit booms occur with a frequency of only 2.8 percent in a sample of 61 industrial and emerging economies for the 1960-2010 period, but conditional on a credit boom, the probability of banking or currency crises is one-third. For the connection between the abnormal credit expansion and financial instability, see Borio and Drehmann (2009) and Rogoff and Reinhart (2008).

addition, we study whether the credit-to-GDP ratio ( $l_t/y_t$ ) or the spread between loan rate and deposit rate ( $\Delta_t^l$ ) are other suitable indicators for financial instability. Figures 6e and 6f show that the credit-to-GDP ratio could significantly improve the UO social welfare, while the spread between loan rate and deposit rate has a negligible impact.

Finally, by running  $v_{cb}^y$ ,  $v_{mp}^y$  and  $v_{mp}^l$  from 0 to 1.5 and  $v_{cb}^\pi$  from 1.1 to 2.5, we find that the UO social loss is minimized when  $v_{cb}^y = 0$ ,  $v_{cb}^\pi = 2.5$ ,  $v_{mp}^y = 1.5$  and  $v_{mp}^l = 1.5$ .<sup>20</sup> That is, the UO social welfare attains the maximum when the monetary authority exclusively focuses on price stability and when the macroprudential authority reacts to both the output variation and the credit cycles.<sup>21</sup>

## 6 Conclusion

We have integrated banks and the coexistence of banks and bond financing into an otherwise standard New Keynesian Model. While interest rate policies stabilize shocks that affect aggregate variables, they are less suitable to stabilize macroeconomic events that are driven by sectoral shocks. Such shocks, if they affect firms primarily financed by banks, are best dealt with by time-varying aggregate capital requirements.

While we have pursued a small number of applications, numerous extensions of the basic framework and further applications can and should be pursued. Regarding applications, a variety of alternative shocks could be investigated. For instance, markup shocks and demand shocks originating from preference shocks or government spending shocks are obvious candidates for an in-depth analysis how monetary policy and aggregate bank-equity policies can jointly stabilize such shocks.

Regarding extensions, one could introduce aggregate shocks occurring after households have acquired equity, which would introduce risk premia to equity returns. Moreover, the banking sector could be modeled in more sophisticated ways, e.g. by introducing monitoring costs or a more complex funding and asset structure, to provide extensions in this area.

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<sup>20</sup>Our results are robust for larger range of coefficients ( $v_{cb}^y$ ,  $v_{mp}^y$  and  $v_{mp}^l$  from 0 to 10 and  $v_{cb}^\pi$  from 1.5 to 10.5), see Figure 8 in Appendix F.

<sup>21</sup>It provides a weak argument for the separation of monetary and macroprudential policy makers since the optimal policy requires the two policy makers focusing on different targets.

## A Optimal Behavior of Safe Intermediate Firms

**Stage 2: Price setting** In line with (15), (20), and  $s_t(i) = w_t n_t^s(i) = \frac{w_t y_t^s(i)}{a_t}$ , the real profits of a safe intermediate firm  $i$  in period  $t$  are given by

$$z_t^s(i) = \left( (1 - \tau_t) \frac{p_t^s(i)}{p_t} - \frac{w_t}{a_t} \right) \left( \frac{p_t^s(i)}{p_t} \right)^{-\theta} y_t - \frac{\gamma^p}{2} \left( \frac{p_t^s(i)}{p_{t-1}^s(i)} - 1 \right)^2 y_t. \quad (58)$$

Consequently, the present value of discounted profits can be written as

$$\mathbb{E}_0 \sum_{t=0}^{\infty} Q_t \left\{ \left( (1 - \tau_t) \frac{p_t^s(i)}{p_t} - \frac{w_t}{a_t} \right) \left( \frac{p_t^s(i)}{p_t} \right)^{-\theta} y_t - \frac{\gamma^p}{2} \left( \frac{p_t^s(i)}{p_{t-1}^s(i)} - 1 \right)^2 y_t \right\}. \quad (59)$$

The first-order condition with respect to  $p_t^s(i)$  yields safe firms' optimal price dynamics

$$0 = \left( \frac{p_t^s(i)}{p_t} \right)^{-\theta} \frac{y_t}{p_t} \left[ (1 - \tau_t)(1 - \theta) + \theta \frac{w_t}{a_t} \frac{p_t}{p_t^s(i)} \right] - \frac{\gamma^p y_t}{p_{t-1}^s(i)} \left( \frac{p_t^s(i)}{p_{t-1}^s(i)} - 1 \right) + \mathbb{E}_t \left[ \beta \frac{c_t^\sigma}{c_{t+1}^\sigma} \frac{\gamma^p p_{t+1}^s(i) y_{t+1}}{(p_t^s(i))^2} \left( \frac{p_{t+1}^s(i)}{p_t^s(i)} - 1 \right) \right]. \quad (60)$$

□

## B Optimal Behavior of Risky Intermediate Firms

**Stage 2: Price setting** In stage 2, after the realization of the idiosyncratic shock  $\phi(i)$ , production is determined in line with (23). Each risky firm's revenues are maximized by selecting the maximum price for which it can sell its output. Rewriting (15), we obtain the optimal price set by risky firms

$$p_t^r(i) = \left( \frac{y_t}{y_t^r(i)} \right)^{\frac{1}{\theta}} p_t. \quad (61)$$

It will be convenient to introduce the premium on bank financing:

$$\Delta_t^l := \frac{R_t^l}{R_t^s}. \quad (62)$$

Combining (25) and (61) yields the real profit, conditional on the firm's being able to repay the loan:

$$z_t^r(i) = (1 - \tau_t) y_t^{\frac{1}{\theta}} y_t^r(i)^{\frac{\theta-1}{\theta}} - \Delta_t^l l_t(i) \geq 0. \quad (63)$$

Let  $\phi^c$  be the level of  $\phi(i)$  below which risky intermediate firms default and hence cannot fully repay the loan. We can solve the critical value  $\phi^c$  from  $l_t(i) = R_t^s \tilde{l}_t(i)$ ,  $w_t = R_t^s \tilde{w}_t$ , (23), (24) and (63):

$$\phi^c = \left( \frac{1}{Aa_t n_t^r(i)} \left( \frac{\Delta_t^l l_t(i)}{(1-\tau_t)y_t^{\frac{1}{\theta}}} \right)^{\frac{\theta}{\theta-1}} \right)^{\frac{1}{\alpha}} = \left( \frac{w_t}{Aa_t} \left( \frac{l_t(i)}{y_t} \right)^{\frac{1}{\theta-1}} \left( \frac{\Delta_t^l}{1-\tau_t} \right)^{\frac{\theta}{\theta-1}} \right)^{\frac{1}{\alpha}}. \quad (64)$$

For risky intermediate firms with  $\phi(i) \in [0, \phi^c)$ , i.e. firms that cannot repay the loan in full, profit is zero

$$z_t^r(i) = 0, \quad (65)$$

and all the revenue goes to the bank. Thus, provided that the firm defaults, the gross return on the bank loan is

$$R_t^r(i) = (1-\tau_t) \frac{y_t^{\frac{1}{\theta}} y_t^r(i)^{\frac{\theta-1}{\theta}}}{l_t(i)} R_t^s \in [0, R_t^l). \quad (66)$$

□

**Stage 1: Attraction of loans** Given the price (61) set in stage 2, firms determine the optimal amount of loan  $\tilde{l}_t(i)$ .

The risky firms' expected real profit is

$$\int_0^1 z_t^r(i) d\phi(i) = \int_{\phi^c}^1 \left[ (1-\tau_t) y_t^{\frac{1}{\theta}} y_t^r(i)^{\frac{\theta-1}{\theta}} - \Delta_t^l l_t(i) \right] d\phi(i), \quad (67)$$

where we have taken into account that profits are zero if  $\phi(i) < \phi^c$ .

Equation (64) reveals that we have to restrict the choice of  $l_t(i)$  to values that involve  $\phi^c \leq 1$ , i.e.

$$l_t(i) \leq \left( \frac{Aa_t}{w_t} \right)^{\theta-1} \frac{y_t(1-\tau_t)^\theta}{(\Delta_t^l)^\theta} =: \bar{l}. \quad (68)$$

Using (23), (24), (64) and (67), we can state the firm's profit maximization problem in the following way:

$$\max_{l_t(i)} \left( \frac{\theta}{\theta + \alpha(\theta-1)} \bar{l}^{\frac{1}{\theta}} l_t(i)^{\frac{\theta-1}{\theta}} + \frac{\alpha(\theta-1)}{\theta + \alpha(\theta-1)} \frac{l_t(i)^{\frac{1+\alpha(\theta-1)}{\alpha(\theta-1)}}}{\bar{l}^{\frac{1}{\alpha(\theta-1)}}} - l_t(i) \right) \Delta_t^l \quad (69)$$

*s.t.*  $l_t(i) \leq \bar{l}$ .

Obviously, the condition  $\phi^c \leq 1$  will be slack at the optimal choice of  $l_t(i)$  because profits are zero when  $\phi^c = 1$ , which means that the firm defaults with probability one.

An optimal choice of  $l_t(i)$  implies

$$(\theta - 1) \left( \frac{\bar{l}}{l_t(i)} \right)^{\frac{1}{\theta}} + (1 + \alpha(\theta - 1)) \left( \frac{l_t(i)}{\bar{l}} \right)^{\frac{1}{\alpha(\theta-1)}} - (\theta + \alpha(\theta - 1)) = 0. \quad (70)$$

Consequently, the optimal value of  $l_t(i)$  can be written as

$$l_t(i) = \bar{l}L^* = \left( \frac{Aa_t}{w_t} \right)^{\theta-1} \frac{(1 - \tau_t)^\theta}{(\Delta_t^l)^\theta} y_t L^*, \quad (71)$$

where  $L^*$  is the root of

$$g(L) := (\theta - 1)L^{-\frac{1}{\theta}} + (1 + \alpha(\theta - 1))L^{\frac{1}{\alpha(\theta-1)}} - (\theta + \alpha(\theta - 1)) \quad (72)$$

that satisfies  $0 < L^* < 1$ .<sup>22</sup>

For arbitrary  $\theta > 1$ , the existence of such a solution can be readily established. Function  $g(L)$  has at least one root on  $(0, 1)$  because (i)  $\lim_{L \rightarrow 0} g(L) = \infty$ , (ii)  $g(1) = 0$ , and (iii)  $g'(1) > 0$ . The uniqueness of the solution follows from the additional observation that  $g(L)$  has a single minimum on  $(0, 1)$ , which is straightforward to verify. To sum up, the risky firms' expected profit is maximized when the real loan is given by  $l_t(i) = L^*\bar{l}$ , where  $L^*$  is the solution to (72).

We observe that (71) also allows to use a particularly simple expression for  $\phi^c$ . Inserting (71) into (64) results in

$$\phi^c = (L^*)^{\frac{1}{\alpha(\theta-1)}}. \quad (73)$$

Hence,  $\phi^c$  will be constant in equilibrium and will not depend on the central bank's policy rate  $I_t$  or the capital requirement  $\Gamma_t$ .

Using (23), (24), and (71), we can write the output of risky firms as

$$y_t^r(i) = (\phi(i))^\alpha \left( \frac{Aa_t(1 - \tau_t)}{w_t \Delta_t^l} \right)^\theta L^* y_t. \quad (74)$$

The aggregate profits of all risky firms can be computed with the help of (67), (71), (72), (73), and (74) as

$$z_t^r = (1 - \nu)(1 - \tau_t)^\theta \left( \frac{Aa_t}{w_t \Delta_t^l} \right)^{\theta-1} \frac{L^*}{\theta - 1} \left( 1 - (L^*)^{\frac{1}{\alpha(\theta-1)}} \right) y_t. \quad (75)$$

□

---

<sup>22</sup>For  $\theta = 2$  and  $\alpha = 1$ , for example, the unique solution is  $L = \frac{1}{4}(\sqrt{3} - 1)^2$ .

## C Optimal Behavior of Banks

We examine the problem of a representative bank in three steps.

### Step 1: Loan provision for given capital structure

In the first step, we examine loan provision of a representative bank if it has a capital structure equal to the aggregate capital requirement and can provide a loan to one risky firm. For convenience, we denote the risky firm by  $i$  and use the same index  $i$  for the representative bank that lends to firm  $i$ . On a bank's balance sheet, the asset (loan to a risky firm) is equal to the sum of liabilities (deposits and equity). Thus, we have

$$\tilde{l}_t(i) = \tilde{d}_t(i) + \tilde{e}_t(i) = (1 + \Gamma_t)\tilde{d}_t(i). \quad (76)$$

We define  $R_t^\Gamma$  as the smallest gross return on bank loans  $R_t^r(i)$ , such that the corresponding bank does not default. At this rate, the following condition must hold:

$$\tilde{d}_t(i)R_t^s = \tilde{l}_t(i)R_t^\Gamma, \quad (77)$$

which has the interpretation that the total repayment to depositors just equals the funds received from the risky firm. Combining (76) and (77) yields

$$\Delta_t^\Gamma := \frac{R_t^\Gamma}{R_t^s} = \frac{1}{1 + \Gamma_t}. \quad (78)$$

As a next step, we compute  $\phi^\Gamma$ , the value of  $\phi(i)$  below which the bank defaults. According to (23) and (66),  $\Delta_t^\Gamma$  has to satisfy

$$\Delta_t^\Gamma = \frac{(1 - \tau_t)y_t^{\frac{1}{\theta}} [(\phi^\Gamma)^\alpha Aa_t n_t^r(i)]^{\frac{\theta-1}{\theta}}}{l_t(i)}. \quad (79)$$

Equating (78) and (79) and solving for  $\phi^\Gamma$  results in

$$\phi^\Gamma = \left( \frac{1}{Aa_t n_t^r(i)} \left( \frac{l_t(i)}{(1 + \Gamma_t)(1 - \tau_t)y_t^{\frac{1}{\theta}}} \right)^{\frac{\theta}{\theta-1}} \right)^{\frac{1}{\alpha}}. \quad (80)$$

Using (64) and (80) entails

$$\phi^\Gamma = \frac{1}{(\Delta_t^l(1 + \Gamma_t))^{\frac{\theta}{\alpha(\theta-1)}}} \phi^c = \left( \frac{L^*}{(\Delta_t^l)^\theta(1 + \Gamma_t)^\theta} \right)^{\frac{1}{\alpha(\theta-1)}}. \quad (81)$$

Note that  $\phi^\Gamma$  decreases with  $\Gamma_t$ , which indicates that a high equity-to-debt ratio reduces the fraction of banks that fail. When  $\Gamma_t \rightarrow \infty$ , i.e. banks are fully financed by equity, we obtain  $\phi^\Gamma \rightarrow 0$ , i.e. banks never default.

We note that the above equation implies

$$\phi^\Gamma \leq \phi^c. \quad (82)$$

Hence, we have to distinguish between three ranges of  $\phi(i)$ . For  $\phi(i) \geq \phi^c$ , the firm can fully repay the loan and thus the bank does not default. For an intermediate range of  $\phi(i)$ ,  $\phi(i) \in [\phi^\Gamma, \phi^c)$ , the firm cannot fully repay the loan. However, the bank does not default because it can simply reduce dividends. For  $\phi(i) < \phi^\Gamma$ , the repayment on the loan is not sufficient to repay depositors. In this case, the government has to bail out the bank and equity holders receive nothing.

The expected return on equity

$$R_t^e = \int_0^{\phi^\Gamma} 0 d\phi(i) + \int_{\phi^\Gamma}^{\phi^c} R_t^e(i) d\phi(i) + \int_{\phi^c}^1 \bar{R}_t^e d\phi(i),$$

where

$$R_t^e(i) = \frac{R_t^r(i)\tilde{l}_t(i) - R_t^d\tilde{d}_t(i)}{\tilde{e}_t(i)} = \frac{(1 + \Gamma_t)R_t^r(i) - R_t^d}{\Gamma_t},$$

$$\bar{R}_t^e = \frac{R_t^l\tilde{l}_t(i) - R_t^d\tilde{d}_t(i)}{\tilde{e}_t(i)} = \frac{(1 + \Gamma_t)R_t^l - R_t^d}{\Gamma_t}.$$

We can rewrite the expected return on equity as

$$R_t^e = \int_{\phi^\Gamma}^{\phi^c} \frac{(1 + \Gamma_t)R_t^r(i) - R_t^d}{\Gamma_t} d\phi(i) + \int_{\phi^c}^1 \frac{(1 + \Gamma_t)R_t^l - R_t^d}{\Gamma_t} d\phi(i). \quad (83)$$

We observe that (66) can be combined with (23), (24), (71) and (73) to yield

$$R_t^r(i) = \left( \frac{\phi(i)}{\phi^c} \right)^{\frac{\alpha(\theta-1)}{\theta}} R_t^l. \quad (84)$$

Inserting (84) into (83) yields the following relationship between  $\Delta_t^e$  and  $\delta_t^l$ , where  $\delta_t^l := (1 + \Gamma_t)\Delta_t^l$ :

$$\Gamma_t \Delta_t^e = h(\delta_t^l) := \frac{\alpha(\theta-1)}{\theta + \alpha(\theta-1)} \left( \frac{1}{(\delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}}} - \delta_t^l \right) \phi^c + \delta_t^l - 1. \quad (85)$$



## Step 2: Uniqueness of loan rate

For  $\Gamma_t \rightarrow 0$ , which implies that banks would be entirely financed by deposits, (85) becomes

$$0 = \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left( \frac{1}{(\Delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}}} - \Delta_t^l \right) \phi^c + \Delta_t^l - 1. \quad (86)$$

The solution is  $\Delta_t^l = 1$  in this case. In the case of  $\Gamma_t \rightarrow \infty$ , i.e. with very strict capital requirements that lead to banks being financed entirely through equity, we obtain

$$\Delta_t^l = \frac{1}{1 - \frac{\alpha(\theta-1)}{\theta+\alpha(\theta-1)}\phi^c} \Delta_t^e > \Delta_t^e. \quad (87)$$

For general values of  $\Gamma_t$ , (85) is more difficult to analyze. Recall that  $(1+\Gamma_t)\Delta_t^l \geq 1$  and therefore  $\delta_t^l \geq 1$ . It can be easily verified that  $h(1) = 0$  and that  $\lim_{\delta_t^l \rightarrow \infty} h(\delta_t^l) = \infty$ . Moreover,  $h'(\delta_t^l) > 0$ ,  $\forall \delta_t^l \in [1, \infty)$ . As a consequence, for all combinations of  $\Gamma_t$  with  $\Gamma_t \geq 0$  and  $\Delta_t^e$  with  $\Delta_t^e \geq 1$ , there is a unique solution for  $\Delta_t^l$ , which is given by  $\Gamma_t \Delta_t^e = h((1+\Gamma_t)\Delta_t^l)$  or  $\Delta_t^l = \frac{1}{1+\Gamma_t} h^{-1}(\Gamma_t \Delta_t^e)$ . For fixed  $\Gamma_t$ ,  $\Delta_t^l$  is an increasing function of  $\Delta_t^e$ .

## Step 3: Optimal capital structure

We finally show that it is optimal for banks to choose a capital structure that is equal to the aggregate capital requirement  $\Gamma_t$  in each period. Suppose that all banks, except one deviating bank, choose  $\Gamma_t$  in period  $t$ . Then, the market loan rate  $\Delta_t^l$  is given by (85) and illustrated in Graph 1 in Figure 2, since the deviating bank has no impact on equilibrium interest rates. Suppose that the deviating bank chooses a capital structure  $\frac{\tilde{e}_t(i)}{\tilde{d}_t(i)} > \Gamma_t$  and finances a loan to the risky firm  $\tilde{l}_t(i) = \tilde{d}_t(i) + \tilde{e}_t(i)$ . It is profitable for this bank to do so if the deviation strictly increases the return on equity. Hence, we have to verify whether for a given  $\Delta_t^l$ ,  $\Delta_t^e$  is increasing in the bank-specific capital structure which we denote by  $\Gamma_t(i)$ . Such a deviation cannot be profitable. For a given loan size and market loan rate  $\Delta_t^l$ , choosing  $\Gamma_t(i) > \Gamma_t$  implies that expected transfers from the government in case of default and bailout is lower than for  $\Gamma_t(i) = \Gamma_t$ . The reason is that both the likelihood of default and the bailout transfer in case of default are lower. Since bank revenues are unaffected by different choices of capital structure and since return on equity is higher than deposit rates, the preceding observation implies

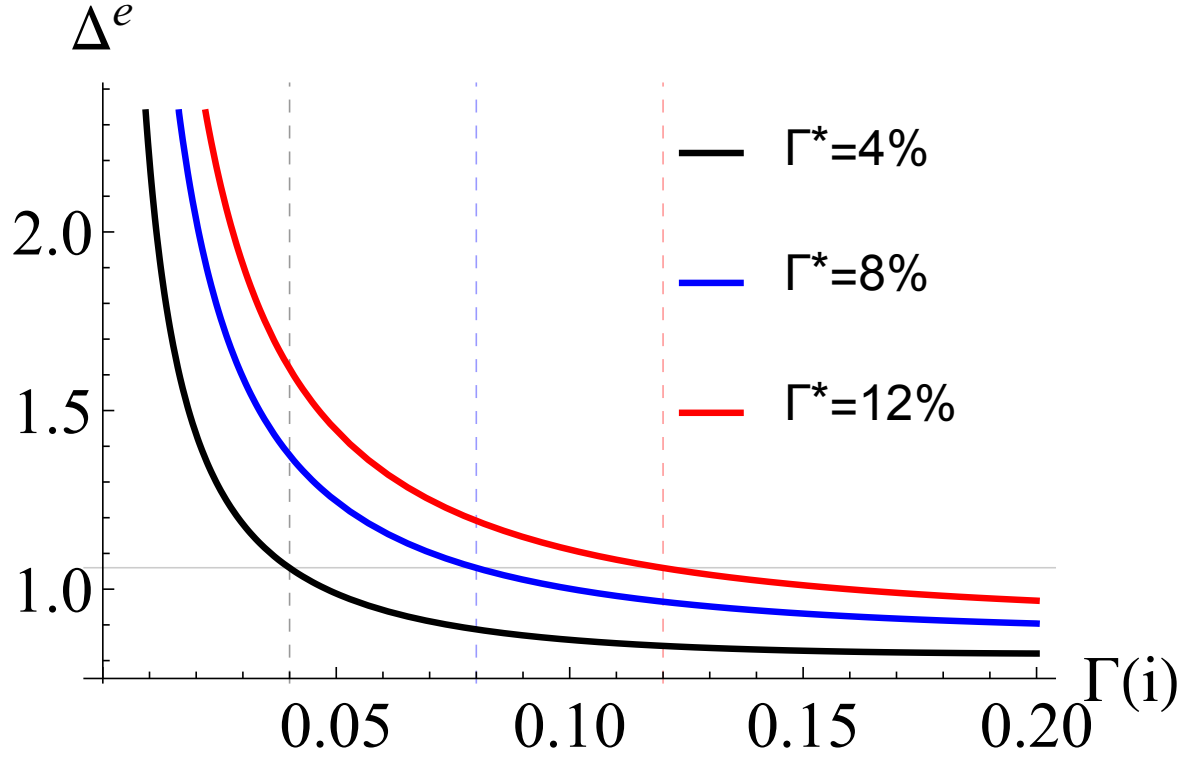


Figure 7: Expected returns on equity for different aggregate capital requirement ratios.

necessarily that expected return on equity is lower with the choice  $\Gamma_t(i) > \Gamma_t$  than with  $\Gamma_t(i) = \Gamma_t$ . This is illustrated in Figure 7, which displays expected returns on equity for aggregate capital requirement ratios of 4%, 8% and 12%, respectively. For instance, the solid black line represents the expected return on equity when the aggregate capital requirement ratio  $\Gamma_t$  is 4% (represented by the vertical dashed black line). The expected return on equity decreases with the equity-to-deposit ratio  $\Gamma_t(i)$ . Thus, the individual bank would select the lowest possible  $\Gamma_t(i)$ , i.e.  $\Gamma_t(i) = \Gamma_t$ . The realized return on equity is represented by the horizontal gray line at the value  $\Delta^{e*} = \frac{1}{1-\chi^*} = 1.055$ .

□

## D The Government

The sales taxes revenues amount to

$$st_t = \tau_t \int_0^\nu \frac{p_t^s(i)}{p_t} y_t^s(i) di + \tau_t \int_\nu^1 \int_0^1 \frac{p_t^r(i)}{p_t} y_t^r(i) d\phi(i) di.$$

Using (15), (17) and (23), we can restate this expression as

$$st_t = \tau_t \frac{p_t^s(i)}{p_t} a_t n_t^s + \frac{\theta}{\alpha(\theta - 1) + \theta} \tau_t (1 - \nu)^{\frac{1}{\theta}} y_t^{\frac{1}{\theta}} (Aa_t n_t^r)^{\frac{\theta-1}{\theta}}. \quad (88)$$

The real bail-out fees amount to

$$bo_t = (1 - \nu) \int_0^{\phi^\Gamma} (d_t(i) - R_t^r(i) \tilde{l}_t(i)) d\phi(i).$$

With the help of  $\phi^c / \phi^\Gamma = (\Delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}} (1 + \Gamma_t)^{\frac{\theta}{\alpha(\theta-1)}}$ ,  $\phi^c = (L^*)^{\frac{1}{\alpha(\theta-1)}}$ ,  $l_t(i) = w_t n_t^r(i)$ , and (84), this expression can be stated as

$$bo_t = \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \frac{(1 - \nu) w_t n_t^r(i) (L^*)^{\frac{1}{\alpha(\theta-1)}}}{(\Delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}} (1 + \Gamma_t)^{\frac{\theta + \alpha(\theta-1)}{\alpha(\theta-1)}}}. \quad (89)$$

## E Linearized Dynamics

All variables with an asterisk denote steady-state values. Variables with a “hat” stand for the relative deviation from steady-state values. We explicitly allow non-zero inflation in the steady state.

### Equation (39)

$$w_t n_t^r(i) = \left( \frac{Aa_t}{w_t} \right)^{\theta-1} \frac{(1 - \tau_t)^\theta}{(\Delta_t^l)^\theta} L^* y_t. \quad (90)$$

Steady state:

$$w^* n^{r*}(i) = \left( \frac{Aa^*}{w^*} \right)^{\theta-1} \frac{(1 - \tau^*)^\theta}{(\Delta^{l*})^\theta} L^* y^*. \quad (91)$$

Log-linearization:

$$w^*(1 + \hat{w}_t) n^{r*}(i) (1 + \hat{n}_t^r(i)) = \left( \frac{Aa^*(1 + \hat{a}_t)}{w^*(1 + \hat{w}_t)} \right)^{\theta-1} \frac{(1 - \tau^*(1 + \hat{\tau}_t))^\theta}{(\Delta^{l*}(1 + \hat{\Delta}_t^l))^\theta} L^* y^*(1 + \hat{y}_t). \quad (92)$$

Using (91) to simplify the equation above yields

$$\hat{w}_t + \hat{n}_t^r(i) = (\theta - 1)(\hat{a}_t - \hat{w}_t) - \theta \left( \frac{\tau^*}{1 - \tau^*} \hat{\tau}_t + \hat{\Delta}_t^l \right) + \hat{y}_t. \quad (93)$$

### Equation (40)

We can write (40) as

$$0 = q_t^{1-\theta} y_t \left[ (1 - \tau_t)(1 - \theta) + \frac{\theta w_t}{a_t q_t} \right] - \gamma^p y_t \frac{q_t}{q_{t-1}} \Pi_t \left( \frac{q_t}{q_{t-1}} \Pi_t - 1 \right) + \beta \mathbb{E}_t \left[ \frac{c_t^\sigma}{c_{t+1}^\sigma} \gamma^p y_{t+1} \frac{q_{t+1}}{q_t} \Pi_{t+1} \left( \frac{q_{t+1}}{q_t} \Pi_{t+1} - 1 \right) \right]. \quad (94)$$

Steady state:

$$(1 - \beta) \gamma^p \Pi^* (\Pi^* - 1) = (q^*)^{1-\theta} \left[ (1 - \tau^*)(1 - \theta) + \frac{\theta w^*}{a^* q^*} \right]. \quad (95)$$

Log-linear approximation around steady state:

$$0 = (q^*)^{1-\theta} y^* \left[ (1 - \theta)(1 - \tau^*) + \frac{\theta w^*}{a^* q^*} \right] (\hat{y}_t - (\theta - 1) \hat{q}_t) + (q^*)^{1-\theta} y^* \frac{\theta w^*}{a^* q^*} (\hat{w}_t - \hat{a}_t - \hat{q}_t) - (q^*)^{1-\theta} y^* (1 - \theta) \tau^* \hat{\tau}_t - \gamma^p y^* \Pi^* (\Pi^* - 1) (\hat{q}_t - \hat{q}_{t-1} + \pi_t + \hat{y}_t) - \gamma^p y^* (\Pi^*)^2 (\hat{q}_t - \hat{q}_{t-1} + \pi_t) + \gamma^p \beta y^* \Pi^* (\Pi^* - 1) \mathbb{E}_t \left[ \sigma \hat{c}_t - \sigma \hat{c}_{t+1} + \hat{y}_{t+1} + \hat{q}_{t+1} - \hat{q}_t + \pi_{t+1} \right] + \gamma^p \beta y^* (\Pi^*)^2 \mathbb{E}_t \left[ \hat{q}_{t+1} - \hat{q}_t + \pi_{t+1} \right], \quad (96)$$

where  $\pi_t := \hat{\Pi}_t$  is the relative deviation of inflation from its steady-state value. Note that  $\pi_t + \hat{q}_t - \hat{q}_{t-1} = \hat{p}_t^s - \hat{p}_{t-1}^s = \pi_t^s$  represents the relative deviation of the growth rate of the price of goods produced by safe firms from the corresponding steady-state inflation rate.

Combining (95) and (96) yields

$$\begin{aligned}
0 = & (1 - \beta)\gamma^p\Pi^* (\Pi^* - 1) (\hat{y}_t - (\theta - 1)\hat{q}_t) \\
& + [(1 - \beta)\gamma^p\Pi^* (\Pi^* - 1) + (q^*)^{1-\theta}(1 - \tau^*)(\theta - 1)] (\hat{w}_t - \hat{a}_t - \hat{q}_t) \\
& + (q^*)^{1-\theta}(\theta - 1)\tau^*\hat{\tau}_t \\
& - \gamma^p\Pi^* \left( \Pi^* - 1 \right) (\hat{q}_t - \hat{q}_{t-1} + \pi_t + \hat{y}_t) - \gamma^p(\Pi^*)^2(\hat{q}_t - \hat{q}_{t-1} + \pi_t) \\
& + \gamma^p\beta\Pi^*(\Pi^* - 1)\mathbb{E}_t \left[ \sigma\hat{c}_t - \sigma\hat{c}_{t+1} + \hat{y}_{t+1} + \hat{q}_{t+1} - \hat{q}_t + \pi_{t+1} \right] \\
& + \gamma^p\beta(\Pi^*)^2\mathbb{E}_t \left[ \hat{q}_{t+1} - \hat{q}_t + \pi_{t+1} \right],
\end{aligned} \tag{97}$$

which can be re-arranged to

$$\begin{aligned}
0 = & (1 - \beta)\gamma^p\Pi^* (\Pi^* - 1) (\hat{y}_t - \theta\hat{q}_t + \hat{w}_t - \hat{a}_t) \\
& + (q^*)^{1-\theta}(1 - \tau^*)(\theta - 1) \left( \hat{w}_t - \hat{a}_t - \hat{q}_t + \frac{\tau^*}{1 - \tau^*}\hat{\tau}_t \right) \\
& + \gamma^p(\Pi^*)^2\mathbb{E}_t \left[ \beta(\sigma\hat{c}_t - \sigma\hat{c}_{t+1} + \hat{y}_{t+1} + 2\pi_{t+1}^s) - 2\pi_t^s - \hat{y}_t \right] \\
& + \gamma^p\Pi^*\mathbb{E}_t \left[ \pi_t^s + \hat{y}_t - \beta(\sigma\hat{c}_t - \sigma\hat{c}_{t+1} + \hat{y}_{t+1} + \pi_{t+1}^s) \right].
\end{aligned} \tag{98}$$

For a steady-state gross inflation rate of  $\Pi^* = 1$ , (98) simplifies to

$$\pi_t^s = \frac{(1 - \tau^*)(\theta - 1)}{\gamma^p(q^*)^{\theta-1}} \left( \hat{w}_t - \hat{a}_t - \hat{q}_t + \frac{\tau^*}{1 - \tau^*}\hat{\tau}_t \right) + \beta\mathbb{E}_t[\pi_{t+1}^s]. \tag{99}$$

### Equation (41)

$$a_t n_t^s(i) = q_t^{-\theta} y_t. \tag{100}$$

Steady state:

$$a^* n^{s*}(i) = (q^*)^{-\theta} y^*. \tag{101}$$

Log-linearization yields

$$\hat{a}_t + \hat{n}_t^s(i) = -\theta\hat{q}_t + \hat{y}_t. \tag{102}$$

### Equation (42)

$$y_t = \left( \nu(n_t^s(i))^{\frac{\theta-1}{\theta}} + (1 - \nu) \frac{\theta}{\theta + \alpha(\theta - 1)} (A n_t^r(i))^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} a_t. \tag{103}$$

Steady state:

$$y^* = \left( \nu(n^{s*}(i))^{\frac{\theta-1}{\theta}} + (1-\nu)\frac{\theta}{\theta+\alpha(\theta-1)}(An^{r*}(i))^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} a^*. \quad (104)$$

Log-linearization:

$$\begin{aligned} & (1 + \hat{y}_t)^{\frac{\theta-1}{\theta}} (y^*)^{\frac{\theta-1}{\theta}} \\ &= \left( \nu(1 + \hat{n}_t^s(i))^{\frac{\theta-1}{\theta}} (n^{s*}(i))^{\frac{\theta-1}{\theta}} \right. \\ & \quad \left. + (1-\nu)\frac{\theta}{\theta+\alpha(\theta-1)}(1 + \hat{n}_t^r(i))^{\frac{\theta-1}{\theta}} (An^{r*}(i))^{\frac{\theta-1}{\theta}} \right) (1 + \hat{a}_t)^{\frac{\theta-1}{\theta}} (a^*)^{\frac{\theta-1}{\theta}}. \end{aligned} \quad (105)$$

An approximation that disregards all terms of order two and higher is

$$\begin{aligned} \hat{y}_t(y^*)^{\frac{\theta-1}{\theta}} &= \left( \nu(n^{s*}(i))^{\frac{\theta-1}{\theta}} \hat{n}_t^s(i) + (1-\nu)\frac{\theta}{\theta+\alpha(\theta-1)}(An^{r*}(i))^{\frac{\theta-1}{\theta}} \hat{n}_t^r(i) \right) (a^*)^{\frac{\theta-1}{\theta}} \\ & \quad + \left( \nu(n^{s*}(i))^{\frac{\theta-1}{\theta}} + (1-\nu)\frac{\theta}{\theta+\alpha(\theta-1)}(An^{r*}(i))^{\frac{\theta-1}{\theta}} \right) \hat{a}_t (a^*)^{\frac{\theta-1}{\theta}}. \end{aligned} \quad (106)$$

Simplifying yields

$$\hat{y}_t = \hat{a}_t + \kappa_1 \hat{n}_t^s(i) + (1 - \kappa_1) \hat{n}_t^r(i), \quad (107)$$

where  $\kappa_1 = \frac{\nu(n^{s*}(i))^{\frac{\theta-1}{\theta}}}{\nu(n^{s*}(i))^{\frac{\theta-1}{\theta}} + (1-\nu)\frac{\theta}{\theta+\alpha(\theta-1)}(An^{r*}(i))^{\frac{\theta-1}{\theta}}} \in (0, 1)$ .

**Equation (43)**

$$\frac{\Gamma_t}{1 - \chi_t} = h((1 + \Gamma_t)\Delta_t^l), \quad (108)$$

where  $(1 + \Gamma_t)\Delta_t^l = \delta_t^l$ . With steady-state identity  $\delta^{l*} = (1 + \Gamma^*)\Delta^{l*}$ , the log-linearized version of  $(1 + \Gamma_t)\Delta_t^l = \delta_t^l$  can be written as

$$\hat{\delta}_t^l = \frac{\Gamma^* \hat{\Gamma}_t}{1 + \Gamma^*} + \hat{\Delta}_t^l. \quad (109)$$

Equation (33):

$$\frac{\Gamma_t}{1 - \chi_t} = h(\delta_t^l) = \frac{\alpha(\theta-1)}{\theta + \alpha(\theta-1)} \left( \frac{1}{(\delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}}} - \delta_t^l \right) \phi^c + \delta_t^l - 1. \quad (110)$$

with steady state:

$$\frac{\Gamma^*}{1 - \chi^*} = \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left( \frac{1}{(\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} - \delta^{l*} \right) \phi^c + \delta^{l*} - 1. \quad (111)$$

Log-linearization:

$$\frac{\Gamma^*(1 + \hat{\Gamma}_t)}{1 - \chi^*(1 + \hat{\chi}_t)} = \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left[ \frac{1}{(1 + \hat{\delta}_t^l)^{\frac{\theta}{\alpha(\theta-1)}} (\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} - (1 + \hat{\delta}_t^l) \delta^{l*} \right] (L^*(\theta))^{\frac{1}{\alpha(\theta-1)}} + (1 + \hat{\delta}_t^l) \delta^{l*} - 1. \quad (112)$$

Using the following equation:

$$\frac{1}{(1 + \hat{\delta}_t^l)^{\frac{\theta}{\alpha(\theta-1)}} (\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} - (1 + \hat{\delta}_t^l) \delta^{l*} = \frac{1}{(\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} - \delta^{l*} - \frac{\theta}{\alpha(\theta - 1)} \frac{1}{(\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} \hat{\delta}_t^l - \delta^{l*} \hat{\delta}_t^l \quad (113)$$

yields

$$\begin{aligned} \frac{\Gamma^*(1 + \hat{\Gamma}_t)}{(1 - \chi^*)(1 - \frac{\chi^*}{1 - \chi^*} \hat{\chi}_t)} &= \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left( \frac{1}{(\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} - \delta^{l*} \right) (L^*(\theta))^{\frac{1}{\alpha(\theta-1)}} + \delta^{l*} - 1 \\ &\quad - \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left( \frac{\theta}{\alpha(\theta - 1)} \frac{1}{(\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} + \delta^{l*} \right) (L^*(\theta))^{\frac{1}{\alpha(\theta-1)}} \hat{\delta}_t^l + \delta^{l*} \hat{\delta}_t^l. \end{aligned} \quad (114)$$

Dividing by the steady-state equation yields

$$\hat{\Gamma}_t + \frac{\chi^*}{1 - \chi^*} \hat{\chi}_t = \kappa_2 \hat{\delta}_t^l, \quad (115)$$

$$\text{where } \kappa_2 = \frac{1 - \chi^*}{\Gamma^*} \left( \delta^{l*} - \frac{\alpha(\theta - 1)}{\theta + \alpha(\theta - 1)} \left( \frac{\theta}{\alpha(\theta - 1)} \frac{1}{(\delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}}} + \delta^{l*} \right) (L^*(\theta))^{\frac{1}{\alpha(\theta-1)}} \right).$$

With the help of (109), (115) can be restated as

$$\frac{\chi^*}{1 - \chi^*} \hat{\chi}_t = \frac{(\kappa_2 - 1)\Gamma^* - 1}{1 + \Gamma^*} \hat{\Gamma}_t + \kappa_2 \hat{\delta}_t^l. \quad (116)$$

### Equation (44)

$$\frac{1}{I_t p_t} c_t^{-\sigma} = \mathbb{E}_t \left[ \beta \frac{c_{t+1}^{-\sigma}}{p_{t+1}} \right] \quad (117)$$

is equivalent to

$$1 = I_t \beta \mathbb{E}_t \left[ \frac{c_t^\sigma}{c_{t+1}^\sigma} \frac{1}{\Pi_{t+1}} \right]. \quad (118)$$

Steady state:

$$I^* = \frac{\Pi^*}{\beta}. \quad (119)$$

Log-linearization:

$$\hat{c}_t = -\sigma^{-1} \left( \hat{I}_t - \mathbb{E}_t[\pi_{t+1}] \right) + \mathbb{E}_t[\hat{c}_{t+1}]. \quad (120)$$

**Equation (45)**

$$\psi(\nu n_t^s(i) + (1-\nu)n_t^r(i))^\varphi = c_t^{-\sigma} w_t. \quad (121)$$

Steady state:

$$\psi(\nu n^{s*}(i) + (1-\nu)n^{r*}(i))^\varphi = (c^*)^{-\sigma} w^*. \quad (122)$$

$$\hat{w}_t - \sigma \hat{c}_t = \varphi \kappa_3 \hat{n}_t^s(i) + \varphi(1-\kappa_3) \hat{n}_t^r(i), \quad (123)$$

where  $\kappa_3 = \frac{\nu n^{s*}(i)}{\nu n^{s*}(i) + (1-\nu)n^{r*}(i)} \in (0, 1)$ .

**Equation (46)**

$$\begin{aligned} y_t = c_t + \frac{1}{2} \gamma^p \nu \left( \Pi_t \frac{q_t}{q_{t-1}} - 1 \right)^2 y_t + \frac{\chi_t}{1-\chi_t} \frac{\Gamma_t}{1+\Gamma_t} (1-\nu) w_t n_t^r(i) \\ + \mu \frac{\alpha(\theta-1)}{\theta+\alpha(\theta-1)} \frac{(1-\nu) w_t n_t^r(i) (L^*)^{\frac{1}{\alpha(\theta-1)}}}{(\Delta_t^l)^{\frac{\theta}{\alpha(\theta-1)}} (1+\Gamma_t)^{\frac{\theta+\alpha(\theta-1)}{\alpha(\theta-1)}}}, \end{aligned} \quad (124)$$

Steady state:

$$\begin{aligned} y^* = c^* + \frac{1}{2} \gamma^p \nu (\Pi^* - 1)^2 y^* + \frac{\chi^*}{1-\chi^*} \frac{\Gamma^*}{1+\Gamma^*} (1-\nu) w^* n^{r*}(i) \\ + \mu \frac{\alpha(\theta-1)}{\theta+\alpha(\theta-1)} \frac{(1-\nu) w^* n^{r*}(i) (L^*)^{\frac{1}{\alpha(\theta-1)}}}{(\Delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}} (1+\Gamma^*)^{\frac{\theta+\alpha(\theta-1)}{\alpha(\theta-1)}}}, \end{aligned} \quad (125)$$

Log-linearization:

$$\begin{aligned} y^* \hat{y}_t = c^* \hat{c}_t + \nu y^* \frac{\gamma^p}{2} (\Pi^* - 1)^2 \hat{y}_t + \nu y^* \gamma^p \Pi^* (\Pi^* - 1) (\pi_t + \hat{q}_t - \hat{q}_{t-1}) \\ + \frac{\chi^*}{1-\chi^*} \frac{\Gamma^*}{1+\Gamma^*} (1-\nu) w^* n^{r*}(i) (\hat{w}_t + \hat{n}_t^r(i) + \frac{\hat{\chi}_t}{1-\chi^*} + \frac{\hat{\Gamma}_t}{1+\Gamma^*}) \\ + \mu \frac{\alpha(\theta-1)}{\theta+\alpha(\theta-1)} \frac{(1-\nu) w^* n^{r*}(i) (L^*)^{\frac{1}{\alpha(\theta-1)}}}{(\Delta^{l*})^{\frac{\theta}{\alpha(\theta-1)}} (1+\Gamma^*)^{\frac{\theta+\alpha(\theta-1)}{\alpha(\theta-1)}}} \left( \hat{w}_t + \hat{n}_t^r(i) - \frac{\theta}{\alpha(\theta-1)} \hat{\Delta}_t^l - \frac{\theta+\alpha(\theta-1)}{\alpha(\theta-1)} \frac{\Gamma^*}{1+\Gamma^*} \hat{\Gamma}_t \right). \end{aligned} \quad (126)$$



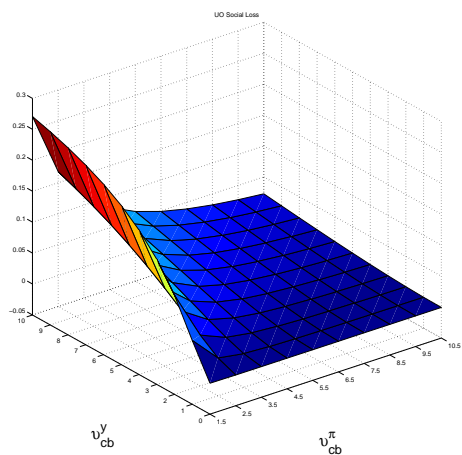
Further simplification yields

$$\begin{aligned}
\hat{y}_t = & \frac{c^*}{y^*(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{c}_t + \frac{\nu \gamma^p \Pi^* (\Pi^* - 1)}{1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2} \pi_t^s + \frac{y^* - c^* - \frac{1}{2} \gamma^p \nu (\Pi^* - 1)^2 y^*}{y^*(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} (\hat{w}_t + \hat{n}_t^r(i)) \\
& + \frac{\kappa_4}{(1 - \chi^*)(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{\chi}_t - \frac{\kappa_5 \theta}{\alpha(\theta - 1)(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{\Delta}_t^l \\
& + \frac{\kappa_4 \alpha(\theta - 1) - \kappa_5(\theta + \alpha(\theta - 1)) \Gamma^*}{\alpha(\theta - 1)(1 + \Gamma^*)(1 - \nu \frac{\gamma^p}{2} (\Pi^* - 1)^2)} \hat{\Gamma}_t,
\end{aligned} \tag{127}$$

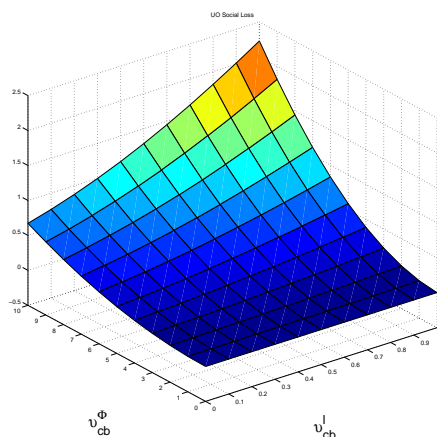
where  $\kappa_4 = \frac{(1-\nu)\chi^*}{1-\chi^*} \frac{\Gamma^*}{1+\Gamma^*} \frac{w^* n^{r^*}(i)}{y^*}$  and  $\kappa_5 = \mu \frac{\alpha(\theta-1)}{\theta+\alpha(\theta-1)} \frac{(1-\nu)(L^*)^{\frac{1}{\alpha(\theta-1)}} w^* n^{r^*}(i)}{y^*(\Delta^{l^*})^{\frac{\theta}{\alpha(\theta-1)}} (1+\Gamma^*)^{\frac{\theta+\alpha(\theta-1)}{\alpha(\theta-1)}}$ .

□

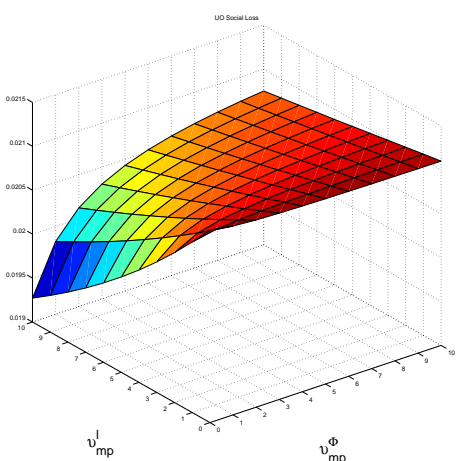
## F UO Social Losses under Different Policy Rules



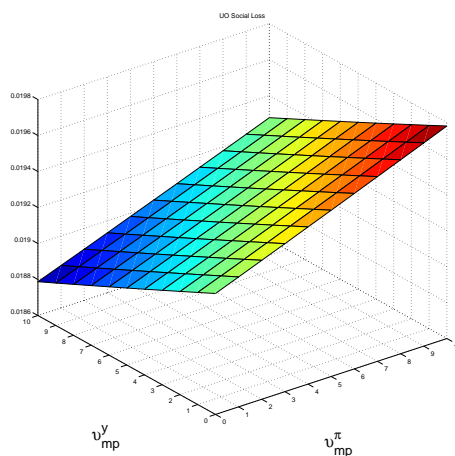
(a)



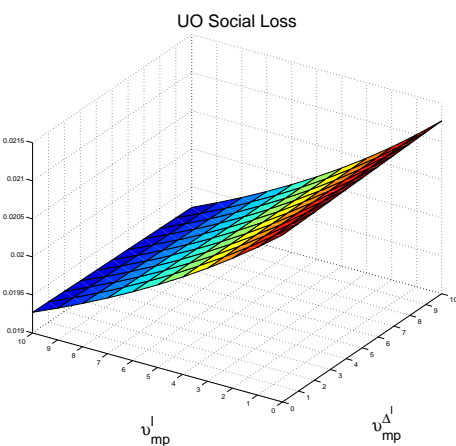
(b)



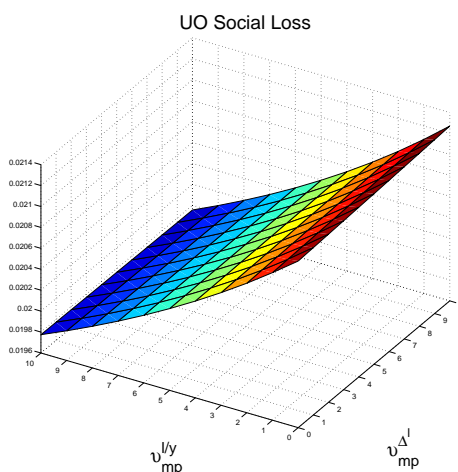
(c)



(d)



(e)



(f)

Figure 8: UO social losses under different policy rules for larger ranges of coefficients.

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