

Capital Requirements, Risk Choice, and Liquidity Provision in a Business Cycle Model

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Abstract

This paper develops a quantitative dynamic general equilibrium model in which households' preferences for safe and liquid assets constitute a violation of Modigliani and Miller. I show that the scarcity of these coveted assets created by increased bank capital requirements can reduce overall bank funding costs and increase bank lending. I quantify this mechanism in a two-sector business cycle model featuring a banking sector that provides liquidity and has excessive risk-taking incentives. Under reasonable parametrizations, the marginal benefit of higher capital requirements related to this channel significantly exceeds the marginal cost, indicating that US capital requirements have been sub-optimally low.

Keywords: Capital Requirements, Bank Regulation, Bank Lending, Demand for Safe Assets, Business Cycles

JEL codes: E44, G21, G28

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1 Introduction

A central policy question is how to set the capital requirements for banks. The conventional tradeoff considered by policy makers is one of financial stability versus credit and liquidity provision by banks. Using a quantitative general equilibrium model, this paper calls into question the cost of a higher capital requirement with regard to lending.

The main proposition is that higher capital requirements leading to a reduction in the supply of bank debt can in fact result in more lending. Key for this result is the assumption that the banking sector produces valuable safe and liquid assets in the form of government guaranteed bank liabilities. A safety and liquidity premium on the price of bank debt changes the standard intuition for the effect of capital requirements on bank lending. In general equilibrium interest rates on bank debt adjust downwards when the aggregate supply of bank debt is lowered. This can lead to a reduction in the funding costs of banks and to an expansion of credit. Calibrating the model to the U.S. aggregate banking sector, I find that the capital requirement should be 14% of banks' risky assets. This level trades off the reduced supply of safe and liquid assets against a lower output volatility and an increase in the loan supply.

Figure 1 provides suggestive evidence for the core assumption that bank debt is priced at a premium for its safety and liquidity. The figure presents the yield spread between Aaa-rated corporate bonds and the implied interest rate on bank debt against the bank debt-to-GDP ratio. A lower ratio of bank debt-to-GDP is related to a lower interest rate on bank debt relative to other safe assets, e.g. Aaa corporate bonds. This is akin to a demand function for money like assets in the form of bank debt.¹

The following numerical example illustrates the main mechanism of the model.² Suppose the banking sector funds loans with riskless debt and equity. Lending is subject to decreasing returns to scale. Households have a downward sloping demand for safe and liquid assets that are provided by the banking sector. This demand creates a violation of Modigliani and Miller. The funding costs of loans are a weighted average of debt and equity financing costs. Suppose the weight on equity financing (the capital requirement) is 10%, the annualized interest rate on bank debt is 1.5%, and the cost of equity is 10% per year. In this case, funding \$1 worth

¹For commercial banks, deposits are the main source of funding. Lucas and Nicolini (2015) provides evidence for a money demand for bank deposits. Krishnamurthy and Vissing-Jorgensen (2012) estimate a demand function for Treasuries. They find that Treasuries and bank deposits crowd out the net supply of privately issued short-term debt. This means that households prefer to hold liquid and safe assets provided by regulated banks and by the government over "safe" assets provided by non-regulated private institutions.

²In this example, I hold the return on equity constant in order to focus on the effect coming from the endogenous response of the bank debt rate. Generally, an increase in the capital requirement reduces the riskiness of equity and therefore the return on equity.

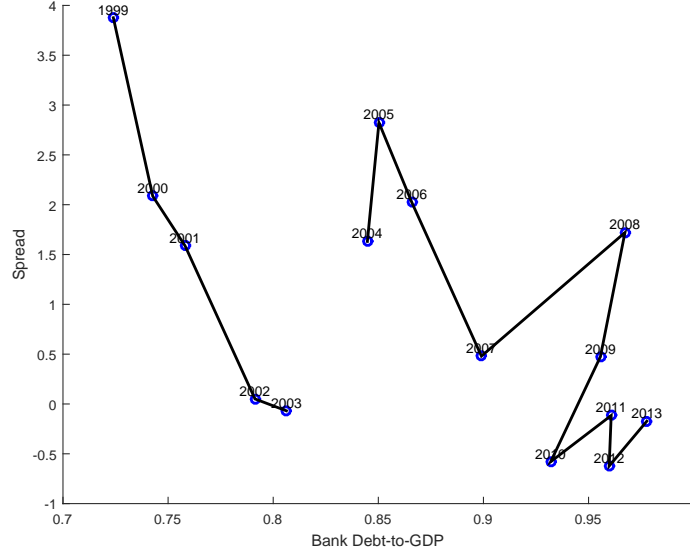


Figure 1: Corporate bond spread and bank debt. The figure plots the spread between the Aaa corporate bond rate and the implied interest rate on aggregate bank debt adjusted for the term spread between a twenty year and a one year zero-coupon treasury bond (y axis) against the bank debt-to-GDP ratio (x axis) on the basis of annual observations from 1999 to 2013. This period reflects a deregulated banking system that arguably started with the passing of the Gramm-Leach-Bliley Act in 1999. Note that the shift of the graph coincides with a tightening in monetary policy in 2004.

of loans costs the bank 2.35%. Now suppose the capital requirement increases to 14%. In partial equilibrium, the interest rate on bank debt does not change. Hence, loan funding costs increase by 14% because a larger share of loans has to be financed with relatively more expensive equity. With decreasing returns to scale in bank lending, banks reduce the loan supply to break even, the familiar result in the literature. At a binding requirement, banks also reduce their liabilities. In general equilibrium with a demand for safe and liquid assets, the contraction in the aggregate supply of bank debt represents an upward movement along the demand curve. In the calibrated model, the interest rate on bank debt falls to 0.9%,³ reducing loan funding costs to 2.17%. Lower funding costs motivate banks to increase lending by 2.12%.

At first glance, the positive effect on lending appears to be contrary to the evidence; see for instance the study by Peek and Rosengren (1995). A well identified estimated response in bank lending to a change in capital regulation can only be assessed in partial equilibrium.⁴ This is why it is useful to study the trade-offs of capital regulation in a quantitative general equilibrium framework.

³In the model, the reduction in the riskless rate is solely driven by the demand channel as bank debt is risk-free before and after the increase in the requirement because of implicit or explicit government guarantees.

⁴My model is consistent with studies that identify a negative response of lending to increases in the capital requirement when prices do not adjust.

In order to quantitatively evaluate the trade-off of higher bank capital requirements, I build upon a standard two-sector business cycle model in which households have a preference for bank debt. This is a simple way to introduce a demand for bank debt and is akin to a money-in-the-utility function specification. The model furthermore features a banking sector that makes risky and productive investments under decreasing returns to scale for a subset of production. This allows me to explicitly study banks' size and risk choice. Banks create safe assets by issuing debt.⁵ This implies a complementarity between lending activities and safe asset creation on banks' balance sheet. The banking sector benefits from a subsidy that is motivated by an implicit government guarantee, making bank debt safe but also encouraging banks to take excessive risks.⁶ Bank debt is priced at a premium because households value the safety and liquidity it provides. Hence, the Modigliani-Miller theorem does not hold even in the absence of government guarantees and banks choose as much leverage as allowed by regulation.

The downside of higher capital requirement is a reduction in the supply of safe and liquid assets by banks. On the positive side, higher capital requirements can boost lending and reduce the volatility in the economy. The latter effect is a result of the complementarity between banks' leverage and risk choice. More concretely, banks' risk choice weighs the benefit from the subsidy against a loss in lending efficiency that occurs with sufficiently high risk-taking. When banks decrease leverage, the subsidy is also decreased, lowering banks' incentives to choose too much risk. This reduces the volatility of output in the economy.

The model is matched to data from the National Income and Product Accounts (NIPA) and banks' regulatory filings from the Federal Deposit Insurance Corporation (FDIC) for 1999-2013. The welfare effect depends mainly on two parameters: the sensitivity of the subsidy to risk-taking and the elasticity of households' preference for bank debt relative to consumption. In the model, the elasticity determines how much households dislike supply shock driven variations in the bank debt-to-consumption ratio. The smaller the elasticity, the greater the response of the interest rate to a reduction in bank debt. I therefore choose this parameter by targeting the volatility of the ratio of total bank debt to NIPA consumption,

⁵Bank debt includes deposits and non-deposits bank liabilities. This captures the idea that apart from explicit guarantees such as deposit insurance, implicit government guarantees extend to formally uninsured bank liabilities as well. This is particularly true for large banks who benefit the most from implicit government guarantees. For example, money market and repo borrowing by banks is also relatively safe and liquid for corporate treasurers or asset managers to hold.

⁶The subsidy is derived from the inability of the government to commit to not bail out the banking sector. Government guarantees can be rationalized as a protection for small, dispersed, and unsophisticated debtholders of banks. For tractability reasons, I abstract from the benefits that households (e.g. guarantee on savings, reliable payment system, etc) obtain from these guarantees. Rather, I ask the question what should the capital requirement be in a world where government guarantees and their potential for moral hazard incentives exist.

attributing all variations to supply shocks. Consequently, I find an elasticity that is likely to be a lower bound. In the model, banks take on more risk when the subsidy (included in profits) is high. I infer the value for the sensitivity of the subsidy to risk-taking by targeting the volatility of banks' income-assets ratio conditional on past profits to the data.

The model matches balance sheet and income statement data from banks together with macroeconomic aggregates. Moreover, its dynamics are consistent with many business cycle moments in the data that have not been targeted. For example, it is consistent with the procyclicality and volatility of the banking sector balance sheet and income statement variables. It also captures the correlations between NIPA and balance sheet variables, which makes it particularly suitable for studying the effects of capital requirements on the economy.

Simulating the model, I derive the optimal Tier-1 capital requirement based on households' utility. Increasing the requirement to 14% from the current status quo leads to a reduction in bank debt, an increase in bank lending, and a reduction in the volatility of bank income.⁷ Total output and consumption increase by 0.10% on a quarterly basis. The volatility in the banking sector decreases by 3 percentage points, and bank debt decreases by 2%. The general equilibrium effect reduces banks' borrowing rate by 17 bps, leading to a 10 bps fall in total funding costs. Banking sector lending increases by roughly 0.6%, an amount that translates to \$1012 more bank credit per capita and year.

Related Literature

The recent financial crisis has sparked a discussion — motivated by theoretical models — of whether banks' capital requirements should be increased. This relates to the question of why banks are highly leveraged. One strand of the literature presents high leverage ratios as a solution to governance problems (for example Dewatripont and Tirole (1994)), or attributes high leverage ratios to banks' role as liquidity and safe asset providers (e.g. Gorton and Pennacchi (1990), Diamond and Rajan (2001), Gorton et al. (2012), and Hanson et al. (2014)). The present model incorporates the role of banks as providers of safe and liquid assets and thus captures the effects of higher capital regulation on liquidity creation.

In contrast to the previous strand of literature, Admati, DeMarzo, Hellwig, and Pfleiderer (2012) argue that equity is only costly because of government subsidies:⁸ higher capital requirements reduce incentives for excessive risk-taking and debt overhang problems. In the

⁷Note that the 14% can be interpreted to apply to large banks, because the parametrization uses aggregated data that is dominated by the largest banks. Indeed the four largest banks alone hold over 50% of the assets in the U.S. banking sector.

⁸Hanson, Stein, and Kashyap (2010) and Kashyap, Rajan, and Stein (2008) argue for higher capital requirements referring to the tax-advantage of debt and competitive pressure over cheap funding sources as the leading source for banks' high leverage.

present paper, I quantify the potential costs (a lower supply of safe and liquid assets) and benefits (less risk-taking by banks) of a higher requirement that have been identified in the theoretical literature.⁹

Macroeconomics models with financial frictions are rooted in Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). Bernanke, Gertler, and Gilchrist (1999) and Christiano, Motto, and Rostagno (2010) have incorporated credit market imperfections into New Keynesian models. This paper builds on this work and develops a tractable macroeconomic framework with a focus on the effects of capital requirements. It is more closely related to work that quantifies¹⁰ the effects of capital requirements and leverage constraints, for instance Christiano and Ikeda (2013), Martinez-Miera and Suarez (2014), Van Den Heuvel (2008), Nguyen (2014), De Nicolò et al. (2014), and Corbae and D’Erasmus (2012).

Van Den Heuvel (2008) is one of the first to use a quantitative general equilibrium growth model with liquidity demand of households to assess the effects of capital requirement on welfare. He finds that the main effect of the capital requirement was a reduction in deposits and therefore the current requirement was too high.

Recently, several papers study capital requirements in a quantitative environment; see for example Christiano and Ikeda (2013), Martinez-Miera and Suarez (2014), Corbae and D’Erasmus (2012), De Nicolò et al. (2014), Clerc et al. (2014), and Nguyen (2014). A common feature of these papers is that a tightening of the constraint reduces the riskiness of the banking system but¹¹ it also reduces the amount of lending, which results in a lower GDP. In the present model, the effects on risk-taking and lending activities from a change in the capital requirement are still present, but I also incorporate the consequences of a change in the supply of safe and liquid assets. With preferences for safe and liquid bank debt, the trade-off of a higher requirement with regard to banks’ lending activities (in general equilibrium) is reversed: when households value aggregate bank debt more because it is scarce, they are willing to accept an even higher discount on the interest rate on bank debt. This lowers the overall funding costs of bank assets, leading to more — not less — lending in the economy. The idea that the demand for safe and liquid assets drives down yields and can have important effects for the banking sector is at the center of Bernanke (2005) savings glut hypothesis and in other recent work (e.g. Caballero and Krishnamurthy (2009) and Gorton, Lewellen, and Metrick (2012)). The present paper embeds this idea and analyzes

⁹Harris, Opp, and Opp (2014) and Malherbe (2015) study effects of capital requirements in a stylized model.

¹⁰For example, Goodhart, Vardoulakis, Kashyap, and Tsomocos (2012) assess different regulatory tools in a rich illustrative model.

¹¹De Nicolò et al. (2014) find (table 5) that an unregulated bank increases its loan holdings when a small capital requirement is imposed but reduces its size of the loan book when the capital requirement is increased.

its importance for optimal bank capital regulation in a quantitative setting.

The paper proceeds as follows: Section 2 presents a two-sector business cycle model in which households have a preference for safe and liquid assets and banks benefit from government subsidies. Section 3 describes the mechanism and the trade-off of higher capital requirements in the steady-state. Section 4 explains how I take the model to the data and demonstrates how well the model captures moments that have not been targeted. Section 5 discusses the welfare implications.

2 Model

I first describe the model. Then I discuss my assumptions in section 2.6. The model incorporates a banking sector into a two-sector business cycle model with capital. One sector is owned by banks. That is, banks operate this sector's production technology by choosing its risk and scale of production. Banks are funded with equity and debt. The latter is valued by households for being safe and liquid. Banks receive a subsidy that depends positively on leverage, risk taking, and bank size. The following sections layout the model in detail.

2.1 Technology

Consider a single-good economy that produces good c in two different sectors. These two sectors are a bank-independent sector (sector f) and a bank-dependent sector (sector h). The firms in the bank-independent sector rent labor and capital from household to form output with a Cobb-Douglas technology

$$y_t^f = Z_t^f \left(k_{t-1}^f\right)^\alpha \left(N_t^f\right)^{1-\alpha}, \quad (1)$$

where Z_t^f is the productivity level at time t , k_{t-1}^f is the capital stock installed in $t-1$, α is the share of capital, and N_t^f is the quantity of labor input. Productivity is stochastic

$$\log Z_t^f = \rho^f \log Z_{t-1}^f + \sigma^f \epsilon_t^f, \quad (2)$$

where ϵ_t^f is drawn from a multivariate normal distribution.

The bank-dependent production sector is owned and run by banks. Using capital k_{t-1}^h , they produce output y_t^h with a decreasing returns to scale technology¹²

$$y_t^h = Z_t^h \left(k_{t-1}^h\right)^v. \quad (3)$$

¹²For a justification of the bank-dependent production section please refer to section 2.6.

The productivity level Z_t^h follows

$$\log Z_t^h = \rho^h \log Z_{t-1}^h + (\phi_1 - \phi_2 \sigma_{t-1}^h) \sigma_{t-1}^h + \sigma_{t-1}^h \epsilon_t^h, \quad (4)$$

where ϵ_t^h is drawn jointly with ϵ_t^f from $\sim \mathcal{N} \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \sigma^{fh} \\ \sigma^{fh} & 1 \end{bmatrix} \right)$, where σ^{fh} is the covariance between ϵ_t^f and ϵ_t^h .

I model log-productivity, $\log Z_t^h$, as a persistent process whose autocorrelation is ρ^h . The term $(\phi_1 - \phi_2 \sigma_{t-1}^h) \sigma_{t-1}^h$ affects the conditional mean. In period t , banks choose the amount of risk σ_t^h (i.e. exposure to the aggregate shock ϵ_t^h) at which they want to operate in $t+1$. The choice of σ_t^h also determines the expected productivity level in $t+1$. The parameters ϕ_1 and ϕ_2 govern the shape of the risk-productivity frontier.

Capital Accumulation

There is a common capital market for both capital types. Capital in sector $j \in \{f, h\}$ depreciates at the rate δ^j and accumulates according to

$$k_t^j = i_t^j + (1 - \delta^j) k_{t-1}^j.$$

Adjustments to the stock of capital are costly. When investment exceeds the replacement of depreciated capital, investors incur a proportional capital adjustment cost of

$$\varphi_j \left(\frac{i_t^j}{k_t^j} - \delta^j \right)^2 k_t^j,$$

where φ_j is the sector-specific adjustment cost parameter.

2.2 Banking Sector

Banks play two roles in this economy: First, they produce a good that households consume. Second, their debt is safe and liquid for households who value holding it. Banks are owned by households and maximize shareholder value by generating cash flow that is discounted with households' stochastic discount factor. Since all banks are identical and the shock to the bank-dependent sector is an aggregate shock, banks' risk choices are perfectly correlated and we can speak of a representative bank that takes prices as given. That is, we can think of the banks described here as the aggregate banking sector.

Banks enter the period with capital k_{t-1}^h , government security holdings b_{t-1} , bank debt s_{t-1} , equity e_{t-1} , and a risk level σ_{t-1}^h . The balance sheet equates risky assets k_{t-1}^h and

riskless assets b_{t-1} to bank debt s_{t-1} and equity e_{t-1} :

$$k_{t-1}^h + b_{t-1} = s_{t-1} + e_{t-1}.$$

At the beginning of the period t , the economy's states ϵ_t^h and ϵ_t^f are realized. Banks generate income from operating their production technology and investing in riskless assets. Their expenses are interest payments on bank debt. Therefore, profits are defined as

$$\pi_t = \underbrace{y_t^h - \delta^h k_{t-1}^h}_{\text{production income}} + \underbrace{r_{t-1}^B b_{t-1}}_{\text{interest inc.}} - \underbrace{r_{t-1} s_{t-1}}_{\text{interest exp.}}.$$

In period t , banks choose investment i_t^h as well as risk taking σ_t^h in the technology. Additionally, banks have a leverage and a portfolio choice. The leverage choice determines with how much debt s_t and with how much equity e_t ¹³ banks finance their assets. The portfolio choice determines the amount of risky assets k_t^h and the amount of riskless assets b_t . Finally, banks decide how much dividends d_t to distribute to households.

Market Imperfections in the Banking Sector

Banks face a regulatory constraint on the amount of debt that can be used to finance risky assets:

$$e_t \geq \xi k_t^h,$$

where ξ determines the amount of equity e_t needed to finance risky assets k_t^h . Banks receive a subsidy from the government.

$$TR \left(k_{t-1}^h, \frac{e_{t-1} + \pi_t}{k_{t-1}^h}, \sigma_t^h \right) = \omega_3 k_{t-1}^h \exp \left(-\omega_1 \left(\frac{e_{t-1} + \pi_t}{k_{t-1}^h} \right) + \omega_2 \sigma_t^h \right), \quad (5)$$

where ω_1 , ω_2 , and ω_3 are positive constants. The scalar ω_1 is the sensitivity of the transfer with respect to leverage after profits have been realized ($k_{t-1}^h / (e_{t-1} + \pi_t)$). The scalar ω_2 is the sensitivity of the transfer with respect to current risk taking σ_t^h , and ω_3 determines the average transfer per unit of physical capital. Moreover, since σ_t^h affects the conditional mean of banks' profits in $t + 1$, there is an additional benefit of risk taking when banks are highly leveraged. The rationale for the subsidy is explained in section 2.6.

The adjustment of dividends is costly: banks incur a cost if their dividend payout deviates from the target level \bar{d} . The dividend payout cost introduces intertemporal rigidities

¹³This is the book equity on banks' balance sheet.

into the balance sheet. Following Jermann and Quadrini (2012), the payout cost has the following form:

$$f(d_t) = \frac{\kappa}{2} (d_t - \bar{d})^2,$$

where κ governs the size of this cost.¹⁴

Problem of Banks

Banks use equity, profits, and the cash flow from government transfers $TR(\cdot)$ to finance next period's equity e_t , the capital adjustment costs, and the dividend payout to households. Due to the equity payout costs, the necessary cash flow to payout d_t is $d_t + f(d_t)$. Therefore, dividends are defined as:

$$d_t = e_{t-1} + \pi_t - f(d_t) + TR\left(k_{t-1}^h, \frac{e_{t-1} + \pi_t}{k_{t-1}^h}, \sigma_t^h\right) - e_t - \underbrace{\varphi_h \left(\frac{k_t^h - (1 - \delta^h) k_{t-1}^h}{k_t^h} - \delta^h \right)^2}_{\text{capital adjustment costs}} k_t^h.$$

The bank problem is written recursively. For the statement of the problem, it is useful to define $\tilde{e} = e + \pi$ as equity after profits. The state of the economy ε is determined by the realizations of the shocks ε^f and ε^h . Thus, the state variables of banks are the aggregate state vector X (to be described later), the state of the economy ε , equity after profits $\tilde{e}(\varepsilon, X)$, as well as k^h due to capital adjustment costs. Banks discount the future with the pricing kernel $M(X', \varepsilon')$ from households. They choose capital, government securities, bank debt, the amount of risk-taking, equity after profits (and therefore book equity), as well as dividends to solve

$$V^B(\tilde{e}, k^h, X, \varepsilon) = \max_{k^h, b', s', \sigma^h, \tilde{e}'(\varepsilon', X'), d} d + \mathbf{E}_{\varepsilon'|\varepsilon} [M(X', \varepsilon') V^B(\tilde{e}'(\varepsilon', X'), k^h, X', \varepsilon')] \quad (6)$$

subject to

¹⁴The introduction of dividend adjustment costs does not materially impact the results (neither qualitatively nor quantitatively) of the model. They do however improve the model's fit of second moments. Given log consumption volatility, second order moments do not play a large role for the welfare results. For a justification of dividend adjustment costs refer to section 2.6.

$$\begin{aligned}
d &= \tilde{e} - e' - f(d) + TR \left(k^h, \frac{\tilde{e}}{k^h}, \sigma^h \right) - \varphi_h \left(\frac{k'^h - (1 - \delta^h) k^h}{k'^h} - \delta \right)^2 k'^h \\
\tilde{e}'(\varepsilon', X') &= e' + \pi(k'^h, \sigma^h, b', s', X', \varepsilon') \\
k'^h + b' &= e' + s' \\
e' &\geq \xi k'^h.
\end{aligned}$$

Banks have unlimited liability: if $\tilde{e} < 0$ they set $d < 0$.

2.3 Households

Households are all identical and live indefinitely. They own capital k^f for firm production and supply labor N^f to firms inelastically. They are also the owners of banks and as such receive dividends d .

Households care about consumption c and holding safe and liquid assets in the form of bank debt s . Bank debt gives utility in the period it is acquired and pays interest in the following period. The felicity function is defined over consumption and bank debt (s') in a money-in-the-utility specification

$$U(c, s') = \log c + \theta \frac{s'^{1-\eta}}{1-\eta}, \quad (7)$$

where θ is the utility weight on bank debt and η governs the curvature of the bank-debt to consumption ratio in the utility¹⁵. This utility specification ensures that more consumption raises the marginal utility of liquidity. At the beginning of the period after the shocks have been realized (realizations of ε^h and ε^f are summarized in vector ε), the state variable of the household is net worth n

$$n(\varepsilon) = \text{Financial Wealth} + \text{Capital} - \text{Taxes}.$$

Financial wealth consists in dividends d and share value p from owning Θ shares of the banking sector and s bank debt.¹⁶

$$\text{Financial Wealth} = (d(X, \varepsilon) + p(X, \varepsilon)) \Theta + (1 + r(X)) s.$$

¹⁵This functional form is equivalent to Christiano, Motto, and Rostagno (2010).

¹⁶A consequence of a government guarantee is that depositors regard bank debt as risk free. Though not formally in the model, the model captures the effects of government guarantees.

That is, households do not hold bonds. Later, I will verify that in equilibrium they also do not want to hold bonds. Households own capital k^f which they rent out to firms

$$\text{Capital} = (r^f(X, \varepsilon) + 1 - \delta) k^f.$$

Lump sum taxes are denoted as T . Additionally, households receive labor income from supplying N_k hours inelastically to firms, earning wage w^f . Thus labor income is

$$\text{Labor Income} = w^f(X, \varepsilon) N^f.$$

Households' value function is determined by n , k^f , the aggregate state vector X , and the realization of shocks ε . They maximize their value function by choosing consumption c , new bank debt balance s' , capital k'^f , labor supply N^f , and bank shares¹⁷ Θ' subject to a budget constraint. Thus, their problem is to solve

$$V^H(n, k^f, X, \varepsilon) = \max_{\{c, s', k'^f, N^f, \Theta', n'(X', \varepsilon')\}} U(c, s') + E_{\varepsilon'|\varepsilon} [\beta V^H(n'(X', \varepsilon'), k'^f, X', \varepsilon')], \quad (8)$$

subject to the budget constraint

$$c + s' + \left(1 + \underbrace{\varphi_f \left(\frac{k'^f - (1 - \delta^f) k^f}{k'^f} - \delta \right)^2}_{\text{capital adjustment costs}} \right) k'^f + p(X, \varepsilon) \Theta' = n(\varepsilon) + w^f(X, \varepsilon) N^f, \quad (9)$$

and net worth tomorrow

$$n'(X', \varepsilon') = (d(X', \varepsilon') + p(X', \varepsilon')) \Theta' + (1 + r(X')) s' + (r^f(X', \varepsilon') + 1 - \delta^f) k'^f. \quad (10)$$

When installing new capital in excess of depreciation, the household incurs the cost $\varphi_f \left((k'^f - (1 - \delta^f) k^f) / k'^f - \delta \right)^2$ per unit of capital k'^f . The stochastic discount factor in the economy is given by

$$M(X', \varepsilon'|\varepsilon) = \beta \left(\frac{U_c(c(X', \varepsilon'), s')}{U_c(c(X, \varepsilon), s)} \right).$$

¹⁷Households own the banking sector, i.e. they hold Θ shares of the claim on banks' dividends and the market value.

2.4 Government

The government follows a balanced budget rule where it maintains debt levels at $B' = B$ so that:

$$TR(\cdot) + r^B B = T. \quad (11)$$

2.5 Recursive Competitive Equilibrium

Shocks occur first and decisions are made subsequently. Then a new period starts again. The state vector X contains the aggregate net worth of banks \tilde{E} , the aggregate net worth of households N , the aggregate capital stock of households K^f , the aggregate capital stock of banks K^h , and the productivity levels of firms and banks Z^f and Z^h respectively.

Definition. Given an exogenous¹⁸ government debt policy B , a recursive competitive equilibrium is defined by a pricing kernel $M(X, \varepsilon)$ and prices: $w^f(X, \varepsilon)$, $r^f(X, \varepsilon)$, $p(X, \varepsilon)$, $r(X)$, and $r^B(X)$, value functions for households V^H and banks V^B , and policy functions of households for consumption P_H^c , bank debt $P_H^{s'}$, capital $P_H^{k^f}$, bank equity shares $P_H^{\theta'}$, labor supply $P_H^{N^f}$, as well as policy functions of banks for their capital stock $P_B^{k^h}$, bonds $P_B^{b'}$, bank debt $P_B^{s'}$, equity $P_B^{e'}$, dividends P_B^d , and $P_B^{\sigma^h}$, and \mathcal{H} the function governing the law of motion for X such that

1. Given the price system and a law of motion for X :
 - (a) the policy function $P_B^{k^h}$, $P_B^{b'}$, $P_B^{s'}$, $P_B^{e'}$, P_B^d , $P_B^{\sigma^h}$, and the value function for banks V^B solve the Bellman equation, defined in equation 6.
 - (b) the policy function P_H^c , $P_H^{s'}$, $P_H^{k^f}$, $P_H^{\theta'}$, $P_H^{N^f}$, and the value function for households V^H solve the Bellman equation, defined in equation 8.
2. $w^f(X, \varepsilon)$ and $r^f(X, \varepsilon)$ satisfy the optimality conditions of firms.
3. For all realization of shocks, the policy functions imply
 - (a) market clearing for
 - i. government bonds: $P_B^{b'} = B$
 - ii. bank debt: $P_B^{s'} = P_H^{s'}$
 - iii. capital: $P_H^{k^f} + P_B^{k^h} = k^f + k^h$

¹⁸Government securities are not a choice variable in this model because otherwise the government could optimally set $B = \infty$, financed with non distortionary taxes. It would be optimal to do so, because households receive utility from bank debt which can be produced with government debt.

- iv. labor $P_H^{N^f} = N^f$
- v. bank shares: $\Theta = 1$
- vi. consumption:

$$c = y^h + y^f + (1 - \delta^f) k^f + (1 - \delta^h) k^h - \frac{\kappa}{2} (d - \bar{d})^2 - k'^f \left(1 + \varphi_f \left(\frac{i'^f}{k'^f} - \delta^f \right)^2 \right) - k'^h \left(1 + \varphi_h \left(\frac{i'^h}{k'^h} - \delta^h \right)^2 \right)$$

(b) consistency with aggregation: $n = N$, $\tilde{e} = \tilde{E}$, $k^f = K^f$ and $k^h = K^h$.

- 4. The government budget constraint in equation 11 is satisfied.
- 5. The law of motion for X is consistent with the policy functions, rational expectations, and $X' = \mathcal{H}(X)$.

The full set of equilibrium equations is listed in the web appendix section A.

2.6 Discussions of Assumptions

This section discusses the key assumptions of the model.

Household's Demand for Safe and Liquid Assets

Diamond and Dybvig (1983) were the first who explicitly analyzed the idea of households' liquidity demand and banks' role as liquidity providers. In this model, households value bank debt because it is liquid and safe. The idea to interpret bank debt as such goes back to Gorton and Pennacchi (1990) and is also present in Gorton et al. (2012). That the demand for safe and liquid assets can have important effects for the banking sector is at the center of Bernanke (2005) savings glut hypothesis and in other recent work (e.g. Caballero and Krishnamurthy (2009), Gorton, Lewellen, and Metrick (2012), and Krishnamurthy and Vissing-Jorgensen (2012)). In the model, all bank liabilities are considered safe and liquid. This is consistent with Gorton et al. (2012)'s definition for safe assets. For depository institutions, the lion share of funding comes from deposits of which many are insured. Large banks also use a small amount of Fed Funds and credit market borrowings. However, there is strong empirical evidence that large banks benefit from implicit government guarantees, e.g. Gandhi and Lustig (2013), making their liabilities safe. This interpretation is consistent with the fact that during the crisis liabilities of depository institutions increased, mainly through an inflow of deposits and credit market instruments.

I capture the demand for bank debt in a money-in-the-utility function specification. Since Sidrauski (1967) money-in-the-utility specifications have been used to capture the

benefits from money-like-securities for households in macroeconomic models.¹⁹ Feenstra (1986) showed the functional equivalence of models with money-in-the-utility and models with transaction or liquidity costs. The functional form is a version of Poterba and Rotemberg (1986) and Christiano, Motto, and Rostagno (2010).²⁰ It implies complementarity between consumption and liquidity. This is intuitive as higher consumption levels go hand in hand with higher transaction volumes and higher savings demand.²¹

Bank-Owned Production Sector

The final good is produced by two production sectors: bank-dependent and non-bank-dependent. This assumption assigns banks an important role in the provision of a good that households value. The idea that some agents need lenders (banks) to realize production projects underlies Bernanke and Gertler (1989) as well as Kiyotaki and Moore (1997). The bank-dependence of one production sector reflects the fact that banks generally provide funds to borrowers who have limited access to capital markets typically due to informational asymmetries (see e.g. Freixas and Rochet (1998)). That is, bank borrowers are by and large small businesses and households. To fix ideas, the bank dependent production sector can be thought of the construction sector that depends on households' access to mortgages.

Banks can emerge as a solution to the asymmetric information problem between borrowers and lenders by gathering information (e.g. Sharpe (1990)' long term relationships) and by screening and monitoring (as emphasized in Diamond (1984) and Tirole and Holmstrom (1997)). These practices allow banks to choose the riskiness and investment scale of their borrowers. The present model goes a step further: banks own the capital stock used in the bank dependent sector and operate the production technology. This idea has been used by Brunnermeier and Sannikov (2012).²² By allowing banks to own a production sector, I can study the behavior of banks in a tractable set-up. This abstraction serves the purpose to focus on the market imperfections that matter most for banks' investment, leverage, and risk choices.

Decreasing Returns to Scale in Bank Dependent Sector

The bank dependent sector operates a decreasing returns to scale technology in capital. This captures the idea that not all projects in the world are suitable to be carried out by the

¹⁹Other ways of eliciting liquidity demand of households include a shopping time technology.

²⁰Their money and deposit utility parameter relates to the bank debt-consumption elasticity η in the following way: $\sigma_q = 2 - \eta$.

²¹The effect of capital requirements on the economy does not qualitatively change when I specify utility as $U(c, s) = \log c + \theta \frac{s^{1-\eta}}{1-\eta}$.

²²It can be shown that this set up is isomorphic to a model in which bank borrowers have zero net worth and banks own a monitoring technology that allows them to effectively eliminate the asymmetric information.

banking sector. In other words, it is a stand-in for the degree to which banks can profitably eliminate the asymmetric information between them and their borrowers. This assumption also allows me to analyze the size of the banking sector in a meaningful way.

Intuitively, this assumption captures the following idea: banks can profitably lend because their monitoring and long term relationship building mitigates asymmetric information problems that hinder some borrowers to access capital markets. Since borrowers differ in their risk profiles and monitoring is costly, there exist top borrowers that banks find especially profitable to lend to. This is particularly true for capital intensive projects that are easier to monitor. When banks start lending to the bank-dependent sector they first lend to the profitable borrowers. After that only less profitable investments are left because the remaining borrower pool requires more monitoring, defaults more, or is less productive (see for instance Dell Ariccia, Igan, and Laeven (2012) for empirical evidence on the decreasing creditworthiness of the marginal borrower).

Bank's Risk and Return Menu

The stochastic productivity term, described in equation (4), depends on banks' risk choice σ^h . This choice is equivalent to picking a project from a risk-return menu (i.e. the particular combination of mean and risk exposure). This specification postulates a trade-off between mean and exposure. The menu of projects Z^h is set to have an interior maximum in σ^h . As a consequence, there exists a σ^h that is optimal in the sense of maximizing mean productivity Z^h . Marshall and Prescott (2006) derive such a reverse mean-variance trade-off for banks' investment choices in a stylized model.

The concavity of Z^h is meant to capture a decline in returns for high exposure to systematic risk. Generally, when investing in the stock market, mean returns can be increased with higher exposure to systematic risk. Regulators want to minimize the amount of systematic risk taken by banks and therefore limit their ability to invest in high risk/ high return projects.²³ If banks nevertheless want to increase their systematic risk exposure, they have to do this in ways that escape regulators. These evasive investment strategies can compromise mean returns since they involve the inefficient use of resources to avoid regulatory scrutiny.

Adjustment Costs to the Banking Capital Stock

Bank borrowers choose banks because they find it more difficult to obtain funds elsewhere. Banks build relationships with their customers to overcome the asymmetric information (as empirically shown by Berger and Udell (1995)). It is costly to build up these

²³They assess how diversified banks are and subject them to a more stringent capital requirement if they are insufficiently diversified. Also, regulators discourage banks from investing into the stock market.

customer relationships. This further implies that reducing the loan portfolio may be costly because other market participants lack the information that the selling bank has acquired over time.

Dividend Adjustment Costs

Corporations, including banks, smooth dividends (see Lintner (1956)). In the case of banks, Dickens, Casey, and Newman (2002) used Morningsart's Stocktools/Principia Pro data from 1998-2000 to show that past dividends strongly predict future dividends of banks. As in Jermann and Quadrini (2012), I introduce smoothness of dividends through a quadratic dividend adjustment costs function. Costs arise when the payout deviates from the steady state target level:

$$f(d) = \frac{\kappa}{2} (d - \bar{d})^2.$$

Thus, the model's qualitative results are not affected by dividend adjustment costs. Outside the steady state, dividend adjustment costs introduce intertemporal rigidities into the balance sheet that make banks' choices of equity dependent on the current level of equity. This is consistent with the observation of Adrian and Shin (2011), who found that bank equity is sticky.²⁴

The Subsidy Function

The government subsidy to banks in the model has the feature of a government put. These payments are increasing in (i) size, (ii) leverage, and (iii) risk taking of banks. I parametrize the subsidy function in the following way:

$$TR\left(k^h, \frac{\tilde{e}}{k^h}, \sigma'^h\right) = \omega_3 k^h \exp\left(-\omega_1 \frac{\tilde{e}}{k^h} + \omega_2 \sigma'^h\right),$$

where k^h are the risky assets that banks hold, $\tilde{e} = e + \pi$ represents equity after profits, and σ'^h denotes the risk choice of banks for the next period.

The main goal of the paper is to analyze how capital requirements impact banks' choice of lending scale and liquidity provision in the presence of aggregate risk and excessive risk-taking incentives. The reduced form transfer function allows me to carry out exactly this analysis without explicitly modeling endogenous default, i.e. keeping the model tractable. Alternative quantitative general equilibrium frameworks with endogenous default either require to abstract from aggregate risk (see Nguyen (2014) for an endogenous default model

²⁴The stickiness of equity can be derived from debt overhang problems (see discussion in Admati, DeMarzo, Hellwig, and Pfleiderer (2012)) and equity issuance costs. Paying out too much dividends can also be costly because of an increasing marginal tax rate on equity distributions (see Hennessy and Whited (2007)).

without aggregate risk), or from analyzing the efficient scale of bank lending.²⁵

In the data, banks have limited liability and benefit from explicit (FDIC insurance) or implicit government guarantees (i.e. bailout).²⁶ Without government protection, the risk of default is reflected in the cost of borrowing. If instead governments act as backstops to banks, debt holders do not require compensation for default risk, lowering the cost of debt financing.

In the model, banks have unlimited liability but receive a subsidy that depends on leverage and risk-taking. The subsidy in the form of the transfer function captures the effects of a banking system that is considered too-big-to-fail.²⁷ This has two consequences. First, default does not occur in equilibrium. Second, government guarantees act effectively as subsidies by lowering the debt financing costs for banks because default risks are not priced into the claims that banks issue.

Government guarantees can be rationalized as a protection for small, dispersed, and unsophisticated debtholders of banks. For tractability reasons, I abstract from the benefits that households (e.g. guarantee on savings, reliable payment system, etc) obtain from these guarantees. Rather, I ask the question what should the capital requirement be in a world where government guarantees and their potential for moral hazard incentives exist.

In the present model, banks' benefit from government guarantees is reflected in the subsidy function's positive dependence on leverage, risk-taking, and the size of the banking sector. The subsidy is increasing in σ^h because banks effectively save the risk premium which they would need to pay without a guarantee. The functional form of the subsidy captures the idea that risk taking incentives are particularly strong when banks are highly levered. Moreover, it captures the value of tax rules that benefit debt over equity financing.²⁸ The

²⁵Endogenous default can be modeled with a constant mass of banks whose problem is homogenous of degree 1 in their scale when they are hit by idiosyncratic iid valuation shocks. This leads a fraction of banks to default. In order to introduce default, Elenev, Landvoigt, and Van Nieuwerburgh (2015) use a similar trick using idiosyncratic shocks to agents' utility. That is, the problem needs to be independent in order to keep the analysis of endogenous default in a quantitative general equilibrium framework tractable.

²⁶During the financial crisis, bank regulators extended guarantees on bank liabilities. For example, they increased the insured amount of deposits and guaranteed 100% senior unsecured debt through the Temporary Liquidity Guarantee Program.

²⁷Bank owners have incentives to take on excessive risks when they have limited liability. In fact, equity claims are call-options on bank assets, an analogy that was first discussed by Black and Scholes (1973). More risk increases the value of the call option. Gollier, Koehl, and Rochet (1997) show that the risk exposure of firms with limited liability is always larger than that of firms with unlimited liability. Pennacchi (2006) presents a model in which deposit insurance subsidizes banks and that banks can increase the subsidy by concentrating their loan portfolio in systematic risk. Begeau, Piazzesi, and Schneider (2015) demonstrate empirically that commercial banks' use of derivatives increase the risk exposure of banks' balance sheet instead of hedging that exposure. One of the first papers to model the effect of bailout guarantees over the business cycle is by Schneider and Tornell (2004). Government subsidies are the core friction in Admati et al. (2012).

²⁸There is a subsidy on debt for all firms in the US. But the tax-advantage matters particularly for the

online appendix demonstrates how a model with an explicit default choice by banks and government bailout implies a subsidy function that is similar to the subsidy function considered here.

Bank Capital Requirements

Banks are subject to a Basel-II type of capital requirement. The Basel-II accords stipulate that banks must hold a certain percentage of risk-weighted assets in terms of equity. Under these rules, assets that are considered safe such as government securities receive a 0% risk weight. In the model banks have to hold ξ dollars of equity e for each dollar of risky assets k^h .

3 Mechanism and Trade-off

This section illustrates the mechanism that works against the standard intuition of how higher capital requirements affect bank lending in a simplified social planner world. Key for this results is the complementarity between valuable liquidity creation on banks' liability side and lending on banks' asset side. Subsection 3.2 describes the trade-offs of higher capital requirements in the non-stochastic steady state.

3.1 Mechanism in a Simplified Social Planner World

Consider a simplified version of the previously described model. The technology is described by equations (1)-(4) and the standard accumulation of capital without adjustment costs. Preferences are as described in equation (7). The social planner chooses the optimal amount of capital in both sectors and consumption to maximize the present value of households' lifetime utility, taking into account the resource constraint and the fact that bank debt must be produced with k^h . The problem is:

$$\begin{aligned}
 V^{FB}(X, \varepsilon) &= \max_{k^h, k'^f, c} \log c + \theta \frac{\left(\frac{k^h}{c}\right)^{1-\eta}}{1-\eta} + \beta E_{\varepsilon'|\varepsilon} [V^{FB}(X', \varepsilon')], & (12) \\
 \text{s.t.} & \\
 c + k'^f + k'^h &= y^f + y^h + (1-\delta)(k^h + k^f),
 \end{aligned}$$

using $s = k^h$. The state vector X contains the aggregate capital stock $k = k^h + k^f$, and the productivity levels Z^h and Z^k . In the non-stochastic steady state, the first order conditions

financial sector because they compete on small interest margins (e.g. Hanson, Stein, and Kashyap (2010)).

are

$$\begin{aligned} \frac{c}{k} &= \frac{y^h + y^f}{k} + (1 - \delta) \\ \frac{\partial y^f}{\partial k^f} - \delta &= \frac{1}{\beta} - 1 \end{aligned} \quad (13)$$

$$\underbrace{\frac{\partial y^h}{\partial k^h}}_{\text{MP}k_h} + \frac{1}{\beta} \underbrace{\frac{\theta \left(\frac{k_h}{c}\right)^{-\eta}}{1 - \theta \left(\frac{k_h}{c}\right)^{1-\eta}}}_{\text{liquidity premium}} - \delta = \frac{1}{\beta} - 1. \quad (14)$$

The right hand side of equation (14) represents the opportunity cost of investing one unit of the final good in the bank dependent sector instead of in the non-banking sector and the left hand side describes its benefit. The benefit has two components: the marginal product on bank investment and the marginal utility stream through liquidity provision. Equations (13) and (14) show that the marginal product of capital in the firm sector is higher than the marginal product in the bank dependent sector, where a higher capital-output ratio is needed to satisfy the demand for safe and liquid assets. In other words, the marginal product of capital across these two sectors does not equalize because capital in the banking sector produces liquidity and a part of the final good.²⁹

Imposing a Capital Requirement

In order to illustrate the mechanism, I analyze what happens when the social planner makes her choice under the restriction that the bank dependent sector faces a capital requirement. This changes the amount of bank debt produced to $s = (1 - \xi) k^h$. Substituting this expression into the objective of problem (12) the first order conditions change to:

$$\frac{\partial y^h}{\partial k^h} + \frac{1}{\beta} \frac{\theta (1 - \xi)^{1-\eta} \left(\frac{k^h}{c}\right)^{-\eta}}{1 - \theta (1 - \xi)^{1-\eta} \left(\frac{k^h}{c}\right)^{1-\eta}} - \delta = \frac{1}{\beta} - 1. \quad (15)$$

That is, the marginal rate of substitution between consumption and bank debt depends on η . In the first best, welfare is always maximized by choosing a capital requirement of $\xi = 0$ since any $\xi > 0$ reduces the amount of bank debt.

The question is how does the capital stock in the economy with $\xi > 0$ compare to the first best? The answer to this question provides the intuition for the effect of the capital requirement on bank lending in the full model. Parameter η (an elasticity) governs how the

²⁹With preference for liquidity, the capital stock is thus higher than the modified golden rule level (also discussed in Van Den Heuvel (2008)).

demand for safe and liquid assets s relative to consumption (marginal rate of substitution (MRS)) depends on its amount and therefore, on the capital requirement. When the demand for bank debt is not too elastic ($\eta > 1$), equation (15) implies that the social planner chooses more k^h compared to the first best to prevent bank debt holdings from falling too much. In this case the MRS is increasing in ξ . In contrast when $\eta < 1$, the social planner chooses a smaller level of k^h compared to the first best because utility can be increased by substituting consumption for bank debt (MRS is decreasing in ξ).³⁰ When $\eta = 1$ the income and substitution effect cancel. The term $(1 - \xi)$ drops out of the utility and we are back to the first best.³¹

3.2 Trade-Off

I characterize the trade-off that occurs when the capital requirement is increased. The non-stochastic steady state equilibrium is the equilibrium in which Z^h and Z^f are constants.

Definition. Given an exogenous government debt policy B , a steady state equilibrium is defined by a constant level of Z^h and Z^f , a pricing kernel $M(X)$ and prices: $w^f(X)$, $r^f(X)$, $r^h(X)$, $p(X)$, $r(X)$, and $r^B(X)$, value functions for households V^H and banks V^B , and policy functions of households for consumption P_H^c , bank debt $P_H^{s'}$, capital $P_H^{k^f}$, bank equity shares $P_H^{e'}$, labor supply $P_H^{N^f}$, as well as policy functions of banks for their capital stock $P_B^{k^h}$, bonds $P_B^{b'}$, bank debt $P_B^{s'}$, equity $P_B^{e'}$, dividends P_B^d , and $P_B^{\sigma^h}$ and a law of motion for X such that the equilibrium definition in section 2.5 is satisfied.

Households' Higher Demand for Safe Assets Lowers their Yield

Households value bank debt because it is safe and liquid. This implies a discount on its interest rate. Hence, it is optimal for banks to lever up aside of government subsidies. DeAngelo and Stulz (2013) show this mechanism in a stylized model. The discount equals the marginal increase in utility from increasing the holdings of bank debt by one dollar keeping the marginal utility of consumption constant. Households' first order condition for bank debt in the non-stochastic steady state is:

$$\frac{\partial U(c, s)}{\partial s} \times \left(1 / \frac{\partial U(c, s)}{\partial c} \right) = \left(\frac{r^e - r}{1 + r^e} \right), \quad (16)$$

³⁰This effect has also been discussed by an earlier version (2005) of Van Den Heuvel (2008). Therein, he shows in a static model how the interest rate elasticity determines whether the capital requirement has a positive or negative effect on the capital stock in the economy.

³¹The threshold value of η that delivers a positive lending effect depends on the amount of government debt B since banks can issue deposits against B . In the example shown here, $B = 0$ and banks' capital stock increases whenever $\eta > 1$. When B is set to its empirical value on banks' balance sheet, the value for $\eta > 1.39$.

where $\partial U(c, s) / \partial s' = \theta s^{-\eta} c^{\eta-1}$ is the marginal utility of bank debt holdings and $\partial U(c, s) / \partial c = 1/c - \theta s^{1-\eta} c^{\eta-2}$ is the marginal utility of consumption, which are both positive. As long as households are not satiated with liquidity (the left hand side (LHS) of equation (16) is positive), the spread between banks' equity and debt financing will be positive (RHS of equation (16)).

The marginal benefit of safe assets s depends on its amount. When $\eta > 1$, a reduction in s makes safe and liquid assets more valuable to households, which is expressed by an increased marginal utility of s relative to consumption. Higher demand drives down the yield on bank debt as in Bernanke (2005)'s saving glut hypothesis. That is, the MRS (LHS of equation (16)) increases, leading to an increase in the interest rate discount (the spread³² between r^e and r) and therefore a reduction in the interest rate on bank debt r .³³

Banks' Capital Constraint

In the non-stochastic steady state and for every combination of parameters, the capital constraint of banks is binding if either households have preference for bank debt or banks receive transfers from the government that imply a debt benefit. The first order condition of banks with respect to equity in the non-stochastic steady state is

$$\mu = \frac{r^e - r}{1 + r^e} + \omega_1 TR \left(1, \frac{\tilde{e}}{k^h}, \sigma^h \right) \left(\frac{1 + r}{1 + r^e} \right), \quad (17)$$

where μ is the Lagrange multiplier on the capital constraint in (6). The capital constraint is binding for any parametrization ($\mu > 0$) because financing with debt is cheaper than with equity. By increasing equity, banks give up the interest rate discount on debt³⁴ and the marginal subsidy.

Optimal Size of the Banking Sector

³² In the steady state $r^e = r^f - \delta$ (the interest rate on capital employed in the non-bank dependent sector) because households first order condition with respect to capital k^f in the steady state is $1/M = (1 + r^f - \delta)$. This means that bank equity holders must be paid the same return as they would obtain from investing one dollar into the firm sector and receiving the return $(1 + r^f - \delta)$.

³³ In the model, households cannot invest in government bonds. But even if given the opportunity, households would not want to hold government bonds because they have the same risk characteristics as bank liabilities without providing utility. Moreover, government bonds earn the same interest rate because government bonds are risk free and receive a risk weight of zero in the capital constraints of banks ($e \geq \xi k^h + 0 \times b$). If returns were not equated, there would be an arbitrage opportunity: banks could issue more debt to buy bonds driving down the interest rate. Or if bonds are more expensive than bank debt (low interest rate), banks would not want to hold bonds.

³⁴ Without households' preference for liquidity or a subsidy for banks, the rate on bank debt equals the interest rate on capital (Friedman rule) in the non-stochastic steady state, $r = r^e$. In this case (and without the subsidy), the capital requirement would have no effect on the equilibrium.

Decreasing returns to scale in the bank dependent production technology implies an optimal size of the banking sector. It is determined by banks' first order condition for equity (see equation (17)) and risky assets:

$$\underbrace{\frac{TR}{k^h} \left(1 + \omega_1 (1 - v) \frac{y^h}{k^h} \right)}_{:= \frac{\partial TR}{\partial k^h} > 0} + (1 + r^h - \delta^h) = \underbrace{\xi (1 + r^e) + (1 - \xi) (1 + r)}_{\text{Funding cost of } k^h}, \quad (18)$$

where $r^h \equiv vy^h/k^h$. Equation (18) tells us what an additional unit of capital is worth, keeping leverage constant. Given the interest rates on debt and equity, the optimal size of the banking sector trades off the benefits (LHS) and costs of risky assets (RHS). The funding cost of k^h is a weighted average between the interest rate paid to shareholders ($1 + r^e$) and the interest rate paid to debt holders ($1 + r$). The subsidy drives a wedge between the funding costs and the return on risky assets. Given a level of funding costs, the higher the value of the subsidy the lower the marginal product of risky assets. This implies that banks are larger in a world with subsidies than in a world without, consistent with the finding of Gandhi and Lustig (2013).

Risk-Taking Incentives

The risk-return trade-off embedded in the technology of banks allows me to analyze banks' risk choice even in the steady state. The variable σ^h determines not only the exposure to the aggregate shock (which is not defined in the non-stochastic steady state) but also the mean productivity in banks' technology and the flow payment from the government subsidy. The first order condition of banks with respect to the amount of the risk-taking variable σ^h yields the optimal risk choice:

$$\sigma^h = \underbrace{\frac{\phi_1}{2\phi_2}}_{\max Z^h} + \underbrace{\frac{(1 + r^e) k^h}{2\phi_2} \frac{\omega_2 TR/k^h}{y^h (1 - \omega_1 TR/k^h)}}_{\text{Subsidy}}. \quad (19)$$

Without the transfer, the optimal risk choice is equal to the first term of equation (19) that maximizes the productivity level of banks' production technology in the steady state. When banks receive a subsidy that is sensitive to risk taking ($\omega_2 > 0$) banks choose higher risk levels than the amount that maximizes the productivity of banks' technology. The scalar ω_2 governs how much more risk banks want to choose over the level that maximizes productivity.

Effect of an Increase in the Capital Requirement

Banks can respond in three ways to comply with a higher requirement. They can increase equity holding assets constant. They can decrease assets holding equity constant. Or they can increase equity and assets which may or may not hold bank debt constant.

Holding interest rates constant, a higher capital requirement increases the funding costs of risky assets in equation (18) because a larger share of assets has to be financed with relatively more expensive equity. Indeed, this is a familiar result from partial equilibrium models. The decreasing returns to risky assets in the bank dependent production technology implies that a reduction in risky assets increases its return. Thus to increase the return on assets to match higher funding costs, banks achieve the reduction in leverage through a reduction in assets and, consequently, bank debt.

In general equilibrium, however, the interest rates on bank debt change with an increase in the capital requirement, affecting banks' funding costs. Equation (16) determines the response of banks' debt financing costs to a change in the amount of bank debt. With households valuing safe and liquid assets more the scarcer they are ($\eta > 1$), a reduction in the supply of bank debt holdings drives down its yield. This can lead to a fall in banks' overall funding costs.

A reduction in leverage lowers the marginal subsidy from risk-taking in equation (19), causing banks to choose lower levels of σ^h . This is due to the complementarity between banks' risk choice and leverage. A reduction in σ^h leads to an increase in the mean productivity level of banks' investment technology. This raises the marginal product of risky assets. Outside the steady state, lower levels of σ^h imply a lower variance of bank dependent output and thus total output.³⁵

Both the reduction in funding costs and the increase in the marginal product make risky assets more desirable. For this reason banks want to increase their risky asset holdings. Higher productivity and a higher stock of risky assets increase the capital stock of the economy and the output from the bank dependent part of production. As a consequence, overall output and consumption increase. The optimal capital requirement trades off the fall in liquidity in the form of bank debt against the rise in consumption. When shocks are included in the analysis, the optimal capital requirement also takes into account the reduction in output volatility.

Key Parameters

³⁵If the government could credibly commit to not bail out the banks, the incentives for excessive risk-taking would be void and the model's optimal capital requirement would be zero. The paper is silent on why these government bailout guarantees exist. The literature makes the case for both inefficient and efficient bailouts (e.g. Chari and Kehoe (2013)). The present paper focuses on the capital requirement as the only policy tool because it is arguably more time-consistent.

The magnitude of the fall in r depends on the curvature parameter η in the utility function of the households. In addition to η , the curvature parameter in the banking sector technology v matters for how much banks increase their assets in response to tighter requirements. The larger v is, the easier assets are transformed into bank dependent output and therefore the larger the effect on consumption will be. The other two parameters that matter are ω_2 and ϕ_2 which together affect the optimal risk choice of banks. A high value for ω_2 implies a larger sensitivity of the subsidy with respect to risk-taking. A high value of ϕ_2 means that the productivity level Z^h decreases faster in risk taking. In the next section, I present how the model is matched to the data.

4 Mapping the Model to the Data

The model is calibrated for the United States at quarterly frequency from the first quarter of 1999 to the last quarter of 2013. This period reflects a deregulated banking system which arguably started with the passing of the Gramm-Leach-Bliley Act.³⁶ The firm parameters are calibrated using NIPA data while bank parameters are calibrated using data from commercial banks and savings institutions. This data stems from aggregated regulatory filings, so called call reports, which comprise balance sheet and income statement data.³⁷ The dollar quantities are converted to trillion of dollars and normalized by the St. Louis Fed population numbers measured in billions.

4.1 Choosing Parameters

The calibrated parameters can be divided into three groups. The parameters in the first group (Table 2) are directly set to their data counterpart. The parameters of the second group (Table 1) use moments in the data together with the steady state conditions of the model. The remaining parameters determine second moments of the model (Table 4) which are jointly calibrated with the other parameters in Table 1. This leaves several other second moments which can be used to check the model. For example, I can check the model against business cycle moments and cross-correlations of balance sheet and income statement variables that have not been targeted. I will now explain in more detail how each parameter is calibrated.³⁸

It is not straightforward to find the data counterpart of bank output. GDP can be measured with the value added, expenditure, or income approach. Bank income is thus

³⁶In 1996, the Federal Reserve reinterpreted the Glass-Steagall Act several times, eventually allowing bank holding companies to earn up to 25 percent of their revenues in investment banking. But it was not until 1999 that the Glass-Steagall Act was completely repealed with the Gramm-Leach-Bliley Act.

³⁷<http://www.fdic.gov/bank/statistical/guide/index.html>

³⁸The web appendix describes the calibration strategy in great detail.

Table 1: PARAMETERS SELECTED USING STEADY STATE CONDITION

Parameter	Function	Target Moment
$\alpha = 0.3323$	firm production	firm labor share in firm GDP
$\beta = 0.9770$	discount rate	capital output ratio in firm sector
$\delta^h = 0.0214$	firm depreciation rate	bank investment
$E^f = 18.354$	effective hours	matches Cobb Douglas y^f
$v = 0.2994$	bank production	income-asset
$\xi = 10.88$	capital constraint	averages Tier-1 capital over risk-based assets
$\theta = 0.016$	deposit utility weight	interest rate spread on bank debt
$\omega_1 = 5.097$	transfer parameter	bank profits
$\phi_1 = 0.1336$	Z_h productivity process	normalizes mean productivity level = 1
$\phi_2 = 0.8949$		std(HP filtered $\log(y^h/k^h)$) = 0.131
This table contains the parameter values that have been selected to satisfy steady state conditions of the model together with the target moments in the right column.		

Table 2: PARAMETERS SELECTED WITHOUT STEADY STATE CONDITIONS

	Parameter Function	Target Moment
$\Gamma = 1.0076$	average growth rate p.c.	p.c. quarterly GDP growth
$\delta = 0.0213$	capital depreciation	NIPA capital consumption
$\delta^f = 0.0213$	bank depreciation rate	δ is weighted average of δ^f and δ^h
$\rho^f = 0.95$	z^f productivity process	firm TFP persistence - from literature
$\sigma^f = 0.0071$		firm TFP volatility
$N^f = 1.43$	average hours (1/1000)	hours: Simona Cociuba
$B = 15.571$	riskless securities	bank balance sheet riskless assets
$\rho^h = 0.75$	persistence of Z^h	persistence of HP-filtered $\log(y^h/k^h)$
$\sigma^{fh} = 0.3927$	corr: ϵ^h and ϵ^f	corr: TFP and HP-filtered $\log(y^h/k^h)$
$\omega_3 = 0.0043$	transfer parameter	tax benefit of debt 4.3 % - Graham (2000)
This table present the parameter values that have been selected to match the moments in the right column.		

Table 3: MAPPING THE MODEL TO THE DATA

Model	NIPA and FDIC balance sheet & income statement
y^h : bank output	income – securities interest income
k^h : bank capital	assets – sec – cash – fixed assets
y^f : firm output	NIPA total GDP – bank output
k^f : firm capital	NIPA $K - k^h$
c : consumption	NIPA consumption
s : bank debt	bank liabilities
π : profits	net income + non interest expense
r : rate on bank debt	interest expenses / bank liabilities
σ^h : risk choice	STD of HP-filtered $\log(y^h/k^h)$
e : equity	Tier-1 equity
This table presents the model objects in the left and their data analogue in the right column.	

part of GDP and can be viewed as the value added from the banking sector. In the model, bank dependent output is produced with capital and banks are able to extract all rents. Thus, rents to capital in the bank dependent part of production equal the income of banks. The calibration uses this analogy and measures bank dependent production output as the sum over interest and non-interest income net of interest income from securities using the aggregated income statements of commercial banks and savings institutions. The value added by firms is measured as the difference between total GDP from NIPA tables and banks' value added. According to this measure banks account for roughly 5% of GDP. This number is consistent with Philippon (2008).³⁹ An overview on how model objects are mapped to the data is given in table 3.

For capital used in bank production, I use banks' risky assets from the balance sheet: total assets net of government securities, fixed assets, and cash. This capital measure of banks implies a capital-output ratio of roughly 12. Using the data on risky assets of banks as well as interest and non-interest income, the decreasing return to scale parameter $v = 0.3$ matches the income-risky asset ratio in the data. This parameter governs how much bank dependent output can be generated with one unit of risky assets. In the model, the amount of government debt B is exogenous. I set B to the average level of riskless assets on banks' balance sheets which consist mainly in government securities and cash. The average of

³⁹The assumption that banks can extract all the rents from bank dependent production results in a conservative estimate for how important banks are for the economy. The bank independent sector value added is computed as the residual of total GDP and bank sector value added. Suppose that banks cannot capture all the rents from bank dependent production. In this case, I assign too much value added to the non-bank dependent sector. The benefits from capital requirements regulation with regard to lending are consequently understated as they affect a relatively smaller part of the economy.

riskless assets amounts to \$15.571.

The depreciation rate in the bank dependent sector δ^h is set such that the economy's resource constraint is satisfied. I use the economy wide (average) depreciation rate, using gross investment data and data on capital consumption from the NIPA, to back out the depreciation rate in the firm sector. The capital-output ratio of firms is 7. The firm Cobb-Douglas function parameter α is chosen to match the share of salaries and wages in GDP, which gives $\alpha = 0.33$. The growth rate Γ is computed using real GDP which results in an annualized growth rate of 3%. The time preference rate ($\beta = 0.977$) is picked such that it is consistent with the steady state investment optimality condition as well as the marginal product of firm capital. In the model, households supply labor inelastically. I use this fact to normalize hours worked to a constant, using the hours series constructed and kept updated by Cociuba, Ueberfeldt, and Prescott (2012)⁴⁰. The number of average hours worked in the firm sector is around 1433 hours (at an annual rate), so $N^f = 1.43$. For the parameters and firm sector size to match the restriction of the Cobb-Douglas function, I convert hours into effective hours. In the model, I call this parameter E^f , which is roughly 18. In order to parametrize the productivity process Z^f of firms, I decompose GDP into its factor components. Then I apply the HP filter to the series and calculate its standard deviation which gives $\sigma^f = 0.0071$. I take the persistence parameter from the literature which typically sets a value of $\rho^f = 0.95$.

The parameter ξ denotes the Tier-1 capital requirement in the model. According to the FDIC rules, banks are deemed well capitalized if they hold a 6 percent Tier-1 capital (common stock, noncumulative perpetual preferred stock, and minority interests in consolidated subsidiaries) to risk-weighted asset ratio. On average, banks hold 10.88% of risky assets (measured here as assets net of fixed assets, government securities, and cash) in terms of Tier-1 equity (common stock, noncumulative perpetual preferred stock, and minority interests in consolidated subsidiaries), so that $\xi = 10.88\%$.

Now I describe the parameters that are essential for the behavior of banks and specific to this model. The scalar ω_3 in the subsidy function is calibrated so that the subsidy without the benefit for leverage and risk-taking equals the tax-benefit on debt per unit of risky assets:

$$\text{Tax Advantage} = TR \left(1, \frac{\tilde{e}}{k^h}, \sigma^h \mid \omega_1 = 0, \omega_2 = 0 \right) = \omega_3 \exp \left(-0 \times \frac{\tilde{e}}{k^h} + 0 \times \sigma^h \right)$$

Graham (2000) estimated the tax benefit of debt to be 4.3% (net of personal taxes) of firm market value. The ratio of banks' market value to risky assets is approximately 0.10. Thus

⁴⁰The data can be downloaded from Simona Cociuba's website: <https://sites.google.com/site/simonacociuba/research>.

the tax benefit of debt per dollar of risky assets is on the magnitude of 0.43 cents, giving $\omega_3 = 0.0043$.

I obtain an estimate for $TR(1, \frac{\bar{e}}{k^h}, \sigma^h)$ from the model by finding $TR(1, \frac{\bar{e}}{k^h}, \sigma^h)$ as the difference from profits in the model to profits in the data which results in $TR(1, \frac{\bar{e}}{k^h}, \sigma^h) = 27$ basis point. I find the sensitivity of the transfer function with respect to ω_1 by targeting bank profits in the steady state. The scalar ω_1 takes on large values when banks operate at a low marginal product and high capital intensity levels, and when they are highly leveraged.

The parameters ω_2 and ϕ_2 determine the risks choice of banks. The parameter ω_2 governs how much risk banks want to take because of the subsidy, whereas the parameter ϕ_2 governs how much risk reduces the productivity of banks. The steady state optimality condition with regard to banks' risk choice pins down only one of the two parameters. I identify ϕ_2 using the steady state condition, while I choose ω_2 such that the conditional variance of the HP filtered income-asset ratio given past profits is matched. In the data, the subsidy to banks is included in profits. I infer a high value for ω_2 if the income-asset volatility is high conditional on the profit-asset ratio being high a period ago. That is, I regress the demeaned business cycle component of the income-asset ratio on the lagged profit-asset ratio

$$\left(\log \left(\frac{y^h}{k^h} \right) \right)^2 = \text{const} + \text{coefficient}(\pi/k^h) + \text{error},$$

in the data and obtain an estimate for the coefficient on π/k^h . Then I solve the model given ω_2 and simulate data to find the model implied regression coefficient. I find ω_2 such that the distance between the data target and the model counterpart is minimized.

The scalar ϕ_1 matches the unconditional mean of the stationary process in Z^h . To calculate this process, I use the HP filtered business cycle component of $\log(y^h/k^h)$. The parameter ρ^h equals the autocorrelation of this series. Given an observed volatility of banks, ϕ_2 controls where the unconditional mean Z^h reaches its maximum. This parameter is chosen to satisfy the first order condition of banks with respect to risk taking σ^h while at the same time satisfying the restriction of the unconditional mean of Z^h . A higher value for ϕ_2 implies a lower productivity maximizing amount of risk as $\sigma^{*h} = \phi_1/2\phi_2$. For the calibration, σ^h is set to the volatility of the income to risky assets ratio.

Households have log utility with respect to consumption for simplicity. The preferences for bank liabilities are governed by parameters η and θ . The parameter θ determines the interest rate discount on bank liabilities. I select θ to match the interest rate discount using the first order conditions of the model. More concretely given η , the scalar θ is identified by the first order condition of households with respect to bank debt holdings in steady state (see equation 16). The interest rate on bank debt is on average 0.39% (annualized). The

Table 4: 2ND MOMENT PARAMETERS

Parameter	Function	Target Moment
$\eta = 3.15$	s/c elasticity	$\frac{Std(s/c)}{Std(GDP)} = 1.49$
$\omega_2 = 2.92$	transfer parameter	conditional variance of income-asset ratio
$\varphi_f = 0.14$	Adjustment cost of k^f	
$\varphi_h = 0.0774$	Adjustment cost of k^h	$\frac{Std(I_h)}{Std(GDP)} = 43.3$
$\kappa = 0.0001$	Dividend payout costs	$\frac{Std(d)}{Std(GDP)} = 25.8$

This table contains parameter values that govern second moments in the model. They have been selected to match the target moments in the right column.

Table 5: SECOND MOMENT CALIBRATION

1999q1 - 2011q4	Rel. STD - D	Rel. STD - M
Dividend	25.80	18
Investment	4.42	4.40
Investment Bank	43.30	79.23
Deposit/Consumption	1.49	1.49
<p>This table contains the standard and the targeted relative standard deviations of the data (D) and compares those to the model (M). Variables: HP-Cycle component of logged variable expressed in percent †Variables: HP-Cycle component of variable</p>		

return on equity in the steady state is $1 + r^e = 1/\beta\Gamma^{-1}$, implying a θ value of 0.0203.

The parameter η determines the curvature in the utility of the bank debt holdings to consumption ratio. As such, it determines how much this ratio varies. Naturally, the target moment in the data to calibrate η is the volatility of the bank debt holdings to consumption ratio. I choose η jointly with the other second moment parameters (government subsidy sensitivity to risk-taking ω_2 and the adjustment costs parameters φ_f , φ_h , and κ) to minimize the average distance (relative to GDP) between the volatility of bank investment as well as aggregate investment, the volatility of dividend, the volatility of the bank debt holdings to consumption ratio, and the conditional income-asset ratio volatility and their data counterparts. Table 5 presents the targeted relative standard deviations in the model and contrasts them with the data.

Discussion of Calibrated Values

The value of κ is very low compared to the value used in Jermann and Quadrini (2012) where $\kappa = 0.146$. Dividend adjustment costs thus have virtually no effect on banks' decision

Table 6: VOLATILITIES

1999q1 - 2013q4	STD - D	STD - M	Rel. STD - D	Rel. STD - M
GDP	1.28	1.10	1	1
Bank GDP	6.91	16.71	5.66	15.37
Assets	1.67	1.84	1.31	1.69
Bank Debt	1.91	1.79	1.48	1.64
Risky Assets	3.06	2.49	2.39	2.29
Consumption	1.04	0.41	0.81	0.37
Profits	12.37	24.92	9.65	22.92

This table contains the standard and the relative standard deviations of the model (M) and compares those to the data (D).
Variables: HP-Cycle component of logged variable expressed in percent
†Variables: HP-Cycle component of variable

in the full dynamic model. Note also that dividend adjustment costs have no effect in the steady state because dividends equal their target.

The value of η is critical for the sign and size of the expansionary effect of capital requirements. In the model capital requirements are expansionary as long as $\eta > 1$. By targeting the volatility of the ratio of total bank debt to consumption, the calibrated value of η attributes all variations to supply shocks. Consequently, I find an elasticity that is likely to be a lower bound. This value is also consistent with other calibrations (see e.g. Christiano, Motto, and Rostagno (2010)) and estimates for the money demand elasticity (see e.g. Lucas and Nicolini (2015)). Finally, the complementarity between bank debt and consumption implied by the value of η is also consistent with the procyclicality of banks' balance sheet variables in the data (see section 4.2), which the model captures.

4.2 Business Cycle Statistics

In this section, I discuss the business cycle implications of the model. The model is solved using local perturbation methods (see Tommaso Mancini Griffoli's Dynare user guide) with the benchmark calibration where $\xi = 10.88\%$. I simulate the model 1500 times for twice as many periods as are in my sample (roughly 120). Half of the observations are discarded. Then I apply the HP filter with a smoothing parameter of 1600 to the remaining simulated data points. I use this data to compute volatilities and correlations that are reported in tables 6 and 7. The online appendix explains in detail the intuition behind the numbers. Below, I focus only on selected business cycle dynamics.

Table 6 reports the volatilities of key variables in the model. While it captures the

Table 7: BUSINESS CYCLE CORRELATIONS (D=DATA, M=MODEL) 1999Q1 - 2013Q4

	GDP		Bank Output		Investment		Assets		Bank Debt	
	D	M	D	M	D	M	D	M	D	M
GDP	1	1								
y^h Bank Output	0.66	0.64	1	1						
Investment	0.97	0.98	0.60	0.70	1	1				
Assets	0.37	0.52	0.34	0.85	0.34	0.30	1	1		
Bank Debt	0.31	0.52	0.28	0.85	0.29	0.30	0.99	1	1	1
k^h (Bank Risky Assets)	0.57	0.52	0.59	0.85	0.52	0.30	0.91	1	0.89	1
\tilde{e} Equity	0.33	0.63	0.31	0.99	0.30	0.68	-0.07 †	0.89	-0.21 †	0.89
d Dividend	0.40	0.63	0.28	0.99	0.37	0.69	-0.19 †	0.83	-0.22 †	0.83
†† r	0.68	0.55	0.95	0.86	0.65	0.63	0.38	0.88	0.33	0.88
c Consumption	0.94	0.88	0.71	0.44	0.90	0.77	0.31	0.52	0.25	0.52
π Profit	0.34	0.62	0.33	0.98	0.35	0.68	-0.48	0.77	-0.54	0.77
i^h Bank Investment	0.46	0.44	0.33	0.64	0.50	0.63	0.21 †	0.29	0.18 †	0.29

This table displays the business cycle correlations of model object (M) and compares those to their data counterpart (D).

Variables: HP-Cycle component of logged variable / GDP trend, HP smoothing = 1600

†: p-value > .05 ; †† Variables: HP-Cycle component variable / GDP trend

volatility of GDP, assets, bank debt, and bank profits, it overstates the volatility of bank income. The shocks follow a essentially a one-factor model that is calibrated to match the volatility of the ratio y^h/k^h . For this reason the model cannot jointly match the volatility of k^h and y^h . This fact is of no consequence for the results, however, since agents care about the volatility of consumption and the volatility of s , which is matched by the model. The low consumption volatility is a common feature of standard business cycle models.

Table 7 summarizes the business cycle – and cross-correlations of the model and compares it to the data. Overall, it produces reasonable correlations, in particular with regard to the business cycle correlations (first column of Table 7). Banking output and balance sheet variables are procyclical as in the data. The curvature on the bank debt-consumption ratio in the utility η and the adjustment costs of capital in both sectors are important for producing the procyclicality of banking sector variables. In a boom, agents want to consume more and with $\eta > 1$, they also demand more liquidity from banks, leading to an expansion of banks' balance sheet. The co-movement between bank investment and aggregate investment stems from the complementarity between consumption and liquidity.

The model generates realistic business cycle correlations of bank output, investment, assets, bank debt, bank risky assets, equity, dividends, interest on bank liabilities, consumption, bank profits, and bank investment. Bank output and profits are governed by the marginal product of risky assets and therefore procyclical. Dividends are essentially a

Table 8: BUSINESS CYCLE CORRELATIONS 1999Q1-2013Q4

	k^h		\tilde{e}		d		r		c		π	
	D	M	D	M	D	M	D	M	D	M	D	M
k^h	1	1										
\tilde{e}	0.03†	0.89	1	1								
d	-0.03 †	0.83	0.20 †	0.98	1	1						
†† r	0.63	0.88	0.24†	0.87	0.31	0.85	1	1				
c	0.54	0.53	0.37	0.47	0.48	0.44	0.72	0.47	1	1		
π	-0.32	0.77	0.53	0.96	0.40	0.99	0.16†	0.81	0.42	0.41	1	1
i^h	0.25†	0.29	0.24 †	0.60	0.07†	0.65	0.33	0.37	0.39	0.16	0.40	0.69

This table displays the business cycle correlations of model object (M) and compares those to their data counterpart (D).

Variables: HP-Cycle component of logged variable / GDP trend, HP smoothing = 1600

†: p-value > .05 ; †† Variables: HP-Cycle component variable / GDP trend

function of profits and thus pro-cyclical.

The model generates the correct signs of the correlations besides the following exceptions. The correlations of equity with balance sheet variables appear more procyclical compared to the data for the calibration sample (1999-2014).⁴¹ In the model, risky assets and book equity are strongly correlated as the capital requirement is binding. This is consistent with the data where the ratio of equity to assets is acyclical, implying that equity expands along with assets during booms. The model fails to capture however the negative correlation between profits and assets (bank debt) as well as dividends and assets (bank debt).

5 Welfare

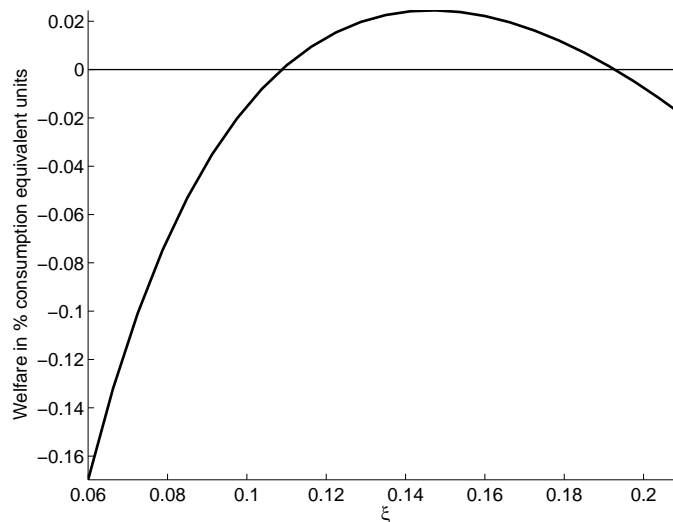
In this section, I discuss how a regulator should optimally set the capital requirement of banks. To solve the model, I use local perturbation methods (see Tommaso Mancini Grifoli's Dynare user guide).

Optimal Capital Requirement

I solve for the equilibrium presented in section 2.5 for different levels of capital require-

⁴¹ When computing the correlation between equity and assets in the data for the longer period from 1984 to 2013 (see the web appendix section C.1), the correlation is significantly positive.

Figure 2: OPTIMAL LEVEL OF RISK-BASED CAPITAL RATIO



ment and obtain its decision rules. Next, I simulate the model under the benchmark capital requirement of $\xi = 10.88\%$. In order to find the optimal requirement taking into account the transition effects, I use the decision rules for each value of ξ to simulate time paths for consumption and bank debt, starting at a random point on the time path of the benchmark capital requirement. This procedure is repeated over the number of simulations, starting the new regime each time at a different point on the old regime's time path. Then - for each ξ - I evaluate the realized utility and compute the value function for the period before the new regime is introduced by discounting the time path of utility with households' pricing kernel. Finally, I average across simulations.

Figure 2 depicts the result expressed in consumption equivalent percentage units, that is, the percentage permanent change in consumption if the economy moves from the current regime ($\xi = 10.88\%$) to any capital requirement on the x-axis. The value function reaches its maximum at about $\xi = 14\%$, which is above the level that commercial banks and savings institutions currently hold on their balance sheet. Note that the 14% can be interpreted to apply mostly for large banks, as the model is calibrated with aggregated data that are dominated by the largest banks. Indeed the four largest banks alone hold over 50% of the assets in the U.S. banking sector.

When the capital requirement is increased, banks reduce the supply of bank debt and increase equity (see the online appendix for figures on the transition path from the old to the new capital requirement). As discussed in section 3.2, banks' response to an increase in the requirement can be divided into two steps. First, keeping the interest rate on bank debt constant a higher capital requirement requires banks to finance a larger share of assets

Table 9: PERCENTAGE CHANGE IN COMPARISON TO OLD STEADY STATE

% Change	Output	Cons.	Bank Output	Assets
Levels	0.09	0.09	2.30	0.40
Std	-3.87	-2.95	-11.98	-9.87
	π/k^h	Subsidy	Risk Taking	z^h
Levels	6.71	-23.15	-11.20	1.71
Std	-18.15	-11.77	-21.97	-15.46
	Equity	k^h	Bank Debt	r
Levels	25.80	0.56	-2.70	-22.50
Std	-19.17	-10.03	-10.79	43.42

with relatively more expensive equity. Even though the return on equity decreases with an increase in ξ because equity becomes less risky, banks' funding costs increase as long as the return on equity does not fall by more than 30%, which is quantitatively implausible for an 3 percentage point increase in ξ . Thus, the increase in ξ leads to an increase in the total cost of assets to which banks respond by deleveraging. Second, the reduction in the supply of bank debt leads to a fall in the interest rate on bank debt, driving down the overall funding costs. Banks then find it optimal to increase their assets financed with more equity. The increase in size works against the reduction in bank debt.

The increase in equity occurs relatively quickly because the adjustment costs to dividends are quite low. However, it takes time to expand the balance sheet because capital (necessary for the balance sheet expansion) accumulates slowly over time.⁴² As described in section 3.2, banks not only increase their assets, they also invest more efficiently, through a reduction in risk-taking. The choice of σ^h implies a trade-off between the benefit from the subsidy and the loss in efficiency (reduction in the expected mean Z^h). The capital requirement lowers the benefit from the subsidy, encouraging banks to choose more efficient levels of risk.

The expansion in bank investment leads to an increase in overall output and consumption. The optimal capital requirement trades off the fall in utility due to the reduction in bank debt against the rise in utility through a reduction in economic volatility and higher consumption levels.

How does the Economy behave under the Optimal Capital Requirement

⁴²Figure 6 in the online appendix shows the time path of capital in the banking sector (left panel) and non-banking sector (right panel). Only for a high value of the capital requirement, say $\xi = 22\%$, banks need to initially lower their assets.

Table 9 shows how the benchmark economy (averaged over simulations and time paths) under $\xi = 10.88\%$ differs from the economy under $\xi = 14\%$. The first row of each block in Table 9 presents the percentage difference in average levels between the new and the old regime. The second row presents the average difference in the standard deviations.

Households prefer the higher capital requirement regime over the current one because it leads to higher consumption (+0.09%) and lower volatility (-3.87%) in consumption. To reach this new level of capital requirement, they accept a 2.70% reduction in the holding of bank debt. Banks also profit from an increase in the capital requirement. The fall in the funding costs, driven by a 22.5% reduction in the rate on bank debt, increases profits per unit of capital by 6.71%. Table 9 shows that higher capital requirements do not necessarily imply a fall in output, bank activity, or bank profits. The reason for this is the general equilibrium effect that changes the funding costs of assets. If the capital requirement is not increased by too much, the increase in the capital requirement leads to a reduction in the funding costs of banks.

The reduction in banks' risk-taking by 11% translates to 1 percentage point lower σ^h . This drives the fall in the standard deviation of output. It also increases the productivity of banks by 1.71%. Banks' output increases because they are more productive and employ more capital in the production process. To comply with the higher requirement, banks need to increase equity by about 26%.

Welfare Gain of Optimal Capital Requirement

In the spirit of Lucas (2000), I compute the welfare cost of current capital requirement as the percentage change in consumption needed to make households indifferent between the current regime and the optimal regime in case of an immediate implementation. That is, I find the scalar λ_0 that keeps households indifferent between

$$E_0 \left(\sum_{t=0}^{\infty} \beta^t U((c_t, s_t) | \xi = 10.88\%) \right) = E_0 \left(\sum_{t=0}^{\infty} \beta^t U((\lambda_0 c_t, s_t) | \xi = 14\%) \right),$$

starting from their respective steady states. The λ_0 that makes households indifferent between the two regimes is 0.99975. In other words, households are indifferent between the old regime and the new regime, if they accept a permanent reduction of 0.025% in quarterly consumption. This is a small improvement in welfare that is common in the literature (see Lucas (2000) and Van Den Heuvel (2008)).

6 Conclusion

This paper has developed a quantitative dynamic general equilibrium model to study the effects of capital requirements on the economy and to determine the optimal level. Key to the model is the assumption that government guarantees allow the banking sector to produce valuable safe and liquid assets. The safety and liquidity premium on the price of bank debt changes the standard intuition for the effect on bank lending of capital requirements.

Higher capital requirements increase banks' ratio of equity to risky assets. In general equilibrium, this increases the aggregate scarcity of safe and liquid assets in the form of bank debt in the economy, driving down their yield and therefore reducing the funding costs of banks.

An important avenue for future research is to model a financial system that captures the demand for safe assets and their production by both regulated and unregulated financial institutions. The intuition of this paper suggests that the change in funding costs for regulated banks depends on the ability of the unregulated banking sector to produce substitutes in terms of safe and liquid assets. In order to assess the effectiveness of new regulatory proposals, we essentially need to know the degree to which this substitution can take place.

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A For Online Publication

A.1 Equilibrium Conditions

This section presents the equilibrium conditions for the detrended model. Original variables, e.g. Y_t , are decomposed into the part that is purely driven by the deterministic balanced growth path trend Γ and into the part that is the stochastic variation around that trend. That is, one can write $Y_t = \bar{Y} X_t \exp(\hat{y}_t)$ where \hat{y}_t is the log deviation from that trend. Eventually, I want to express the model in terms of the log deviation from its steady state. As a first step, I need to transform the original model by taking out the trend X_t . Also, I want to express the model in per capita terms by dividing all variables by N_t total economy hours. Since labor is measured in efficiency units N_k generally represent effective hours per worker of non-bankers and bankers respectively. The lower case y denotes the trend stationary equivalent of Y (except for T , taxes).

The household utility is

$$U(c_t, s_t) = \log(c_t) + \theta \frac{(s_t/c_t)^{1-\eta}}{1-\eta}$$

and the resource constraint:

$$c_t + \Gamma k_t^f \left(1 + \varphi_f \left(\frac{i_t^f}{k_t^f} - \delta^*\right)^2\right) + \Gamma k_t^h \left(1 + \varphi_h \left(\frac{i_t^h}{k_t^h} - \delta^*\right)^2\right) = y_t^h + y_t^f + (1-\delta) k_{t-1}^f + (1-\delta) k_{t-1}^h - \frac{\kappa}{2} (d_t - \bar{d})^2$$

where $\delta^* = (\Gamma - 1 + \delta)$. The equilibrium conditions are

$$\begin{aligned} M_{t+1} &= \beta \Gamma^{-1} \left(\frac{\frac{1}{c_{t+1}} - \theta (s_{t+1})^{1-\eta} (c_{t+1})^{\eta-2}}{\frac{1}{c_t} - \theta (s_t)^{1-\eta} c_t^{\eta-2}} \right) \\ n_t &= (d_t + p_t) \Theta_{t-1} + (1 + r_{t-1}) s_{t-1} + \dots \\ &\quad \dots w_t^f N^f + (r_t^f + 1 - \delta) k_{t-1}^f - T_t \\ n_t &= c_t + \Gamma s_t + \left(1 + \varphi_f \left(\frac{i_t^f}{k_t^f} - \delta^*\right)^2\right) \Gamma k_t^f + p_t \Theta_t \\ i_t^f &= \Gamma k_t^f - (1 - \delta) k_{t-1}^f \\ E_t(M_{t+1})(1 + r_t) &= \left(1 - \frac{\theta}{\Gamma} s_t^{-\eta} c_t^{\eta-1} \left(\frac{1}{c_t} - \theta (s_t)^{1-\eta} c_t^{\eta-2}\right)\right) \\ 1 + \varphi_f \Gamma \left(\frac{i_t^f}{k_t^f} - \delta^*\right)^2 + 2\varphi_f \Gamma \left(\frac{i_t^f}{k_t^f} - \delta^*\right) (1 - \delta) \frac{k_{t-1}^f}{k_t^f} &= E_t \left[M_{t+1} \left(r_{t+1}^f + \left(1 + 2\varphi_f \Gamma \left(\frac{i_{t+1}^f}{k_{t+1}^f} - \delta^*\right)\right) (1 - \delta) \right) \right] \\ 1 &= E_t \left[M_{t+1} \frac{(d_{t+1} + p_{t+1})}{p_t} \right] \end{aligned}$$

$$\begin{aligned}
w_t^f &= (1 - \alpha) Z_t^f (k_{t-1}^f)^\alpha (N^f)^\alpha \\
r_t^f &= \alpha Z_t^f (k_{t-1}^f)^{\alpha-1} (N^f)^{1-\alpha} \\
y_t^f &= Z_t^f (k_{t-1}^f)^\alpha (N^f)^{1-\alpha} \\
y_t^h &= Z_t^h (k_{t-1}^h)^v \\
\log Z_t^f &= \rho^f \log Z_{t-1}^f + \sigma^f \epsilon_t^f, \\
\log Z_t^h &= \rho^h \log Z_{t-1}^h + (\phi_1 - \phi_2 \sigma_{t-1}^h) \sigma_{t-1}^h + \sigma_{t-1}^h \epsilon_t^h \\
\pi_t &= y_t^h - \delta k_{t-1}^h + r_{t-1}^B b_{t-1} - r_{t-1} s_{t-1} \\
r_t^h &= v \frac{y_t^h}{k_{t-1}^h} \\
d_t &= \tilde{e}_t - \frac{\kappa}{2} (d_t - \bar{d})^2 + TR \left(k_{t-1}^h, \frac{e_{t-1} + \pi_t}{k_{t-1}^h}, \sigma_t^h \right) \dots \\
&\quad - \varphi_h \left(\frac{i_t^h}{k_t^h} - \delta \right)^2 \Gamma k_t^h - \Gamma e_t \\
\tilde{e}_t &= \pi_t + e_{t-1} \\
e_t &= k_t^h + b_t - s_t \\
e_t &= \xi k_t^h \\
A_t &= s_t + e_t \\
TR \left(k_{t-1}^h, \frac{e_{t-1} + \pi_t}{k_{t-1}^h}, \sigma_t^h \right) &= \omega_3 k_{t-1}^h \exp \left(-\omega_1 \left(\frac{e_{t-1} + \pi_t}{k_{t-1}^h} \right) + \omega_2 \sigma_t^h \right) \\
TR \left(k_{t-1}^h, \frac{e_{t-1} + \pi_t}{k_{t-1}^h}, \sigma_t^h \right) + (1 + r_{t-1}^b) b_{t-1} &= \Gamma b_t + T_t
\end{aligned}$$

$$\begin{aligned}
1 &= \Lambda_t (1 + \kappa (d_t - \bar{d})) \\
i_t^h &= \Gamma k_t^h - (1 - \delta) k_{t-1}^h
\end{aligned}$$

$$0 = \mathbf{E}_t [M_{t+1} \Lambda_{t+1} (r_t^B - r_t)]$$

$$\mu_t = \Lambda_t \Gamma - \mathbf{E}_t \left[M_{t+1} \Lambda_{t+1} (1 + r_t) \left(1 - \omega_1 TR \left(1, \frac{\tilde{e}_t}{k_t^h}, \sigma_{t+1}^h \right) \right) \right]$$

$$\begin{aligned}
\mu_t \xi &= -\Lambda_t \left(\varphi_h \Gamma \left(\frac{i_t^h}{k_t^h} - \delta^* \right)^2 + 2\varphi_h \left(\frac{i_t^h}{k_t^h} - \delta^* \right) \Gamma(1-\delta) \frac{k_{t-1}^h}{k_t^h} \right) \dots \\
&+ \mathbf{E}_t \left\{ M_{t+1} \Lambda_{t+1} \left(\left(v \frac{y_{t+1}^h}{k_t^h} - r_t - \delta \right) \left(1 - \omega_1 TR \left(1, \frac{e_{t+1}^{\tilde{}}}{k_t^h}, \sigma_{t+1}^h \right) \right) \right) \right. \\
&+ 2\Gamma \varphi_h \left(\frac{i_{t+1}^h}{k_{t+1}^h} - \delta^* \right) (1-\delta) \\
&\left. + TR \left(1, \frac{e_{t+1}^{\tilde{}}}{k_t^h}, \sigma_{t+1}^h \right) \left(1 + \omega_1 \frac{e_{t+1}^{\tilde{}}}{k_t^h} \right) \right\}
\end{aligned}$$

$$\begin{aligned}
0 &= \mathbf{E}_t \left\{ M_{t+1} \Lambda_{t+1} \left(\frac{y_{t+1}^h}{k_t^h} (\phi_1 - 2\phi_2 \sigma_{t+1}^h + \epsilon_{t+1}^h) \right) \right. \\
&\left. \times \left(1 - \omega_1 TR \left(1, \frac{e_{t+1}^{\tilde{}}}{k_t^h}, \sigma_{t+1}^h \right) \right) \right\} + \frac{1}{k_t^h} \Lambda_t TR \left(1, \frac{e_t^{\tilde{}}}{k_{t-1}^h}, \sigma_t^h \right) \omega_2
\end{aligned}$$

A.2 Calibration

This section provides additional detail on the calibration.

I obtain an estimate for $TR(1, \frac{\tilde{e}}{k^h}, \sigma^h)$ from the model by finding $TR(1, \frac{\tilde{e}}{k^h}, \sigma^h)$ as the difference from profits in the model to profits in the data which results in $TR(1, \frac{\tilde{e}}{k^h}, \sigma^h) = 27$ basis point. As a robustness check I use an bailout estimate from Veronesi and Zingales (2009) that gives me a slightly higher value for $TR(1, \frac{\tilde{e}}{k^h}, \sigma^h)$. To this end, I translate the bailout amount into a stream of income:

$$\text{Bailout stream} = \frac{\text{Bailout Amount}}{k^h} \frac{r^{FDIC}(1+r^{FDIC})^{N^B}}{(1+r^{FDIC})^{N^B} - 1},$$

where r^{FDIC} is the interest rate at which the bailout is translated into quarterly payments and N^B is the number of quarters between bailouts. I set $N^B = 58$ corresponding to two bailouts between 1984 and 2012 (the 1987 savings and loan crisis and 2008)⁴³. I set r^{FDIC} to the average quarterly assessment rates of the FDIC⁴⁴ which is around 25 basis point on each dollar of the assessment base (assets-equity), that is around 31 basis point for each dollar of k^h . Veronesi and Zingales (2008)'s estimate the bailout value to be \$130 billion which amounts to 1.52% per dollar of risky assets or around 0.9% of GDP in 2008. Scaling the bailout stream value to the size of banks' risky assets implies that the bailout benefit amounts to approximately 7 basis point in terms of GDP per year. The transfer value is approximated as:

$$TR\left(1, \frac{\tilde{e}}{k^h}, \sigma^h\right) = \text{Tax-Advantage of Debt} + \text{bailout -stream},$$

which is 46 basis point. If instead I use the bailout number of 175 billion dollars of the New York Times for the bank TARP recipients, the quarterly transfer is 47 basis point. I show results for $TR(1, \frac{\tilde{e}}{k^h}, \sigma^h) = 27$ basis point, though I have found the results to be robust to using the Veronesi and Zingales (2009) implied value for $TR(1, \frac{\tilde{e}}{k^h}, \sigma^h)$.

The scalar ϕ_1 matches the unconditional mean of the stationary process in Z^h . To calculate this process, I use the HP filtered business cycle component of $\log(y^h/k^h)$. The parameter ρ^h equals the autocorrelation of this series. The unconditional mean of a demeaned and stationary process is

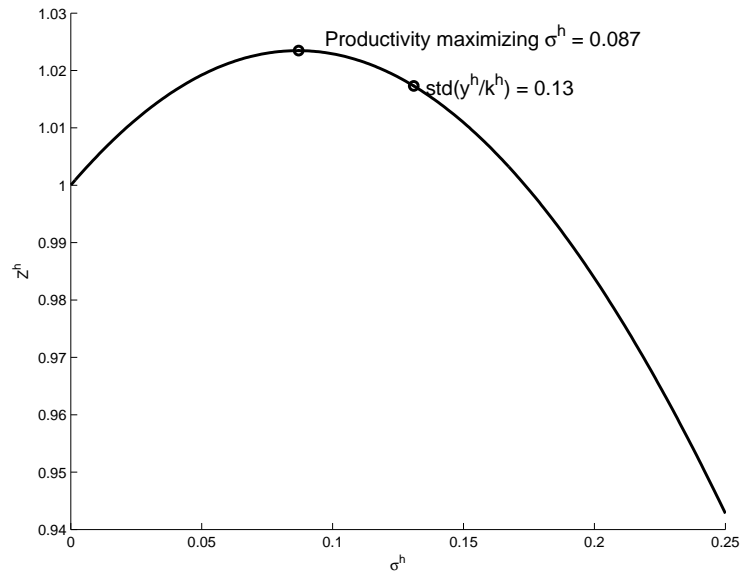
$$E(Z^h) = 0 = \exp\left(\frac{\phi_1\sigma^h - \phi_2(\sigma^h)^2}{1 - \rho^h} + \frac{(\sigma^h)^2}{2}\right). \quad (20)$$

Given an observed volatility of banks, ϕ_2 controls where the unconditional mean Z^h reaches its maximum. This parameter is chosen to satisfy the first order condition of banks with respect to risk taking σ^h while at the same time satisfying the restriction of the unconditional mean of Z^h . A higher value for ϕ_2 implies a lower productivity maximizing amount of risk as $\sigma^{*h} = \phi_1/2\phi_2$. For

⁴³Using only the number of bailouts of the sample period N^B can be alternatively set to 56, which is without consequences for the results.

⁴⁴<http://www.fdic.gov/deposit/insurance/assessments/proposed.html>

Figure 3: Productivity in Steady State



the calibration, σ^h is set to the volatility of the income to risky assets ratio. Figure 3 depicts the conditional mean of Z^h with the calibrated parameters $\phi_1 = 0.1336$ and $\phi_2 = 0.895$.

A.3 Business Cycle Statistics

In this section, I discuss the business cycle implications of the model in further detail.

A.3.1 Intuition for business cycle facts

Table 6 in the main text reports the volatilities of key variables in the model. In the model, GDP is almost as volatile as in the data which is largely driven by the volatility of the banking sector. The model captures the volatility of assets, bank debt, and bank profits. It overstates the volatility of bank income and understates the volatility of consumption. This model is in essence a one factor model that is calibrated to match the volatility of the ratio y^h/k^h . This makes it difficult for the model to match the volatility of both, the level of k^h and the level of y^h . This does not matter for the results, as households care about the volatility of consumption and the volatility of bank liabilities to consumption, which is matched by the model. The low consumption volatility is a familiar feature of many business cycle models.

Table 7 in the main text contains the business cycle – and cross-correlations of the model and compares it to the data. The model captures the correlation between bank debt holdings and consumption in the data. Consumption and total investment co-move with GDP because the marginal product on capital is higher during booms, leading to better investment opportunities and higher output during booms. Banking output and balance sheet variables are procyclical as in the data. The curvature on the bank debt-consumption ratio in the utility η and the adjustment costs of capital in both sectors are important for producing the procyclicality of banking sector variables. The positive correlation between banking and firm sector productivity plays a minor role for generating the procyclicality of banking sector variables. The business cycle statistics for the case when $\rho_{hk} = 0$ are essentially identical to the baseline calibration where $\rho_{hk} > 0$.

When η takes on a large value, households are less flexible with regard to changes in the bank debt holdings-consumption ratio. When only the firm sector is hit by a positive shock, the marginal product of firm capital k^f is higher. This raises the opportunity costs for k^h and the rate at which shareholders want to be compensated. Without adjustment costs to capital or relatively strong curvature in the preferences for the bank debt holdings to consumption ratio, risky assets of banks flow immediately to firms at times when the productivity of capital in the firm sector is higher than in the banking sectors, producing a negative correlation between balance sheet variables and total GDP. Adjustment costs make it expensive to change the current stock of capital in either sector and therefore slow down the response to shocks.

Since banks are at the capital constraint, movements in bank capital stock k^h are perfectly correlated with movements in bank debt s . Relatively inelastic preferences for the bank debt holdings to consumption ratio therefore represent another reason for a slow response of k^h to shocks. In a boom, agents want to consume more and with $\eta > 1$, they also demand more liquidity from banks. As a result, the model is able to generate a positive correlation between bank investment and aggregate investment.

Since bank debt holdings are procyclical, the interest rate on bank debt is procyclical, too. The model captures these procyclicalities. Movements in the interest rate come from movements in the ratio of marginal utilities of bank debt and consumption. Since bank debt is procyclical the marginal utility of bank debt is countercyclical, inducing co-movement of the interest rate on bank debt rates with GDP.

The model generates similar business cycle correlations of bank output, investment, assets, bank debt, dividends, return over risky assets, and bank investment as in the data. Good times increase profits for banks because the marginal product of risky assets increases. The higher profitability of banks during booms implies lower payoffs of the government subsidy whose value is higher during bad times. When the payments from the subsidy are lower, banks have less incentive to take on excessive risks so that they choose less risky and more efficient projects, which increases profits and lowers the subsidy further. The return over risky assets is governed by the marginal product of risky assets and therefore procyclical. Dividends are essentially a function of profits and thus pro-cyclical.

Overall, the model is able to produce the correct signs of the correlations besides the following exceptions. The correlations of equity with balance sheet variables appear more procyclical in the model than in the data for the calibration sample (1999-2014).⁴⁵ In the model, risky assets and book equity are perfectly correlated because banks are constrained by the capital requirement. This is consistent with the data where the ratio of equity to assets is acyclical, implying that equity expands along with assets during booms. The model fails to capture the negative correlation between profits and assets (as well as bank debt and risky assets). The model produces excessive co-movement of profits with GDP. Since assets and profits move together along the business cycle, they also exhibit a positive cross-correlation.

A.3.2 Correlations for 1984-2013

Table 10 presents the business cycle correlations for the longer sample from the first quarter in 1984 to last quarter in 2013. The main text noted that the model had difficulties to replicate the correlations of dividends, profits, return over risky assets, and equity with balance sheet variables. Those are the variables for which the correlation behavior changes most over the 1984-2013 period. For instance, book equity covaries more with GDP, bank income, and investment over the period 1999-2013 than compared to the longer horizon. Book equity appears to be uncorrelated with balance sheet variables over the shorter horizon. Over the long horizon book equity covaries positively with balance sheet variables in a significant way. Return over risky assets (as measured

⁴⁵ When computing the correlation between equity and assets in the data for the longer period from 1984 to 2013 (see the web appendix section C.1), the correlation is significantly positive.

Table 10: BUSINESS CYCLE CORRELATIONS (D=DATA, M=MODEL) 1984Q1 - 2013Q4

	GDP	Bank Inc.	Investment	Assets	Bank Debt	Risky As	Tier 1 E	Equity	Dividend	Deposit	Consp.	Assets/Equity	Income	Profit
GDP	1													
Bank Income	0.62	1												
Investment	0.93	0.53	1											
Assets	0.46	0.39	0.34	1										
Bank Debt	0.44	0.38	0.29	0.99	1									
Risky Assets	0.54	0.64	0.52	0.88	0.88	1								
Tier 1 Equity	-0.04†	-0.12†	0.00†	-0.27	-0.31	-0.22	1							
Equity	0.28	0.12†	0.26	0.24	0.14 †	0.19	0.40	1						
Dividend	0.33	0.25	0.34	-0.07†	0.04 †	0.07†	-0.08†	0.11†	1					
Deposit rate ††	0.55	0.94	0.50	0.23	0.24	0.55	-0.12†	-0.03†	0.22	1				
Consumption	0.89	0.54	0.80	0.49	0.46	0.51	0.03†	0.36	0.35	0.43	1			
Assets/Equity	0.09†	0.18†	0.06	0.51	0.60	0.48	-0.55	-0.71	-0.05†	0.20	0.04†	1		
Income/Risky A	0.53	0.65	0.53	-0.12†	-0.16 †	0.08 †	0.20	0.29	0.39	0.60	0.51	-0.34	1	
Profit	0.23	0.09†	0.23	-0.20	-0.25	-0.20	0.41	0.46	0.24†	-0.04†	0.30	-0.55	0.72	1
Bank Investment	0.33	0.07†	0.34	0.23	0.21	0.18†	-0.04†	0.23	0.01†	0.01†	0.36	-0.04†	0.20	0.26

This table displays the business cycle correlations of model object (M) and compares those to their data counterpart (D).
 Variables: HP-Cycle component of logged variable / GDP trend, HP smoothing = 1600 †: p-value > .05
 ††Variables: HP-Cycle component variable / GDP trend

Table 11: Business Cycle Correlations

1999q1 - 2013q4	Relative STD - D	Relative STD - M $\rho_{hk} = 0$	Rel. STD - M $\rho_{hk} > 0$
GDP	1	1	1
Bank GDP	5.66	15.11	16.85
Assets	1.31	1.49	1.87
Bank Debt	1.48	1.45	1.81
Risky Assets	2.39	2.04	2.55
Consumption	0.81	0.35	0.39
Profits	9.65	23.49	28.31
This table contains the standard and the relative STD of the model (M) and compares those to the data (D). Variables: HP-Cycle component of logged variable expressed in percent. †Variables: HP-Cycle component of variable			

by income relative to risky assets) is negatively correlated in the shorter sample with balance sheet variables but acyclical in the longer sample. Profits have a lower negative correlation with balance sheet variables in the longer sample. Dividends correlation coefficient becomes even zero and turns insignificant. The correlation coefficients of those variables that are reasonably well matched by the model are also more stable across sample periods.

A.3.3 Correlation: Data Model Comparison when $\rho_{hk} = 0$

The baseline calibration of the model sets the autocorrelation between bank and bank independent sector shocks to $\rho_{hk} > 0$. But even with $\rho_{hk} = 0$, the model generates very similar correlations and relative standard deviations as in the case of $\rho_{hk} > 0$.

The relative standard deviations are a bit lower compared to the $\rho_{hk} > 0$ calibration but essentially unchanged. One reason for this is that bank debt and consumption are complements when $\eta > 1$. That is, the marginal utility of bank debt is increasing with consumption. Households demand more bank debt the more they consume. A positive shock in the bank independent sector increases consumption and therefore also the demand for bank debt. When banks want to increase bank debt they need to increase equity because they are at the capital requirement constraint. The increase in available funds allows banks to increase their stock of risky assets which leads to an increase in bank output and thus a positive (and almost identical) correlation between bank output and GDP as in the $\rho_{hk} > 0$ case.

The second reason for the observed correlations is the following: abstracting from adjustment costs of capital, capital can flow from one sector to the other without frictions. A (e.g.) positive shock in the bank independent sector increases the marginal product of capital in that sector. Without adjustment costs, risky assets would flow to the bank independent sector causing a negative correlation between GDP and assets and GDP and bank output. With adjustment costs, it is relatively costly to move risky assets from the balance sheet to the bank independent sector. This

prevents the model to generate a negative correlation of risky assets and GDP.

	GDP		Bank Output		Investment		Assets		Bank Debt	
	D	M	D	M	D	M	D	M	D	M
GDP	1	1								
y^h Bank Output	0.66	0.63	1	1						
Investment	0.97	0.98	0.60	0.70	1	1				
Assets	0.37	0.32	0.34	0.54	0.34	0.29	1	1		
Bank Debt	0.31	0.32	0.28	0.54	0.29	0.28	0.99	1	1	1
k^h (Bank Risky Assets)	0.57	0.32	0.59	0.54	0.52	0.28	0.91	0.99	0.89	0.99
\tilde{e} Equity	0.33	0.62	0.31	0.98	0.30	0.67	-0.07 †	0.65	-0.21 †	0.65
d Dividend	0.40	0.62	0.28	0.99	0.37	0.68	-0.19 †	0.51	-0.22 †	0.51
†† r	0.68	0.64	0.95	0.40	0.65	0.62	0.38	0.70	0.33	0.70
c Consumption	0.94	0.87	0.71	0.37	0.90	0.77	0.31	0.34	0.25	0.34
$ROK_h = y^h/k^h$	0.61	0.62	0.68	0.98	0.61	0.69	-0.24 †	0.40	-0.31	0.40
π Profit	0.34	0.61	0.33	0.99	0.35	0.68	-0.48	0.48	-0.54	0.48
i^h Bank Investment	0.46	0.55	0.33	0.89	0.50	0.62	0.21 †	0.25	0.18 †	0.25

This table displays the business cycle correlations of model object (M) and compares those to their data counterpart (D).

Variables: HP-Cycle component of logged variable / GDP trend, HP smoothing = 1600

†: p-value > .05 ; †† Variables: HP-Cycle component variable / GDP trend

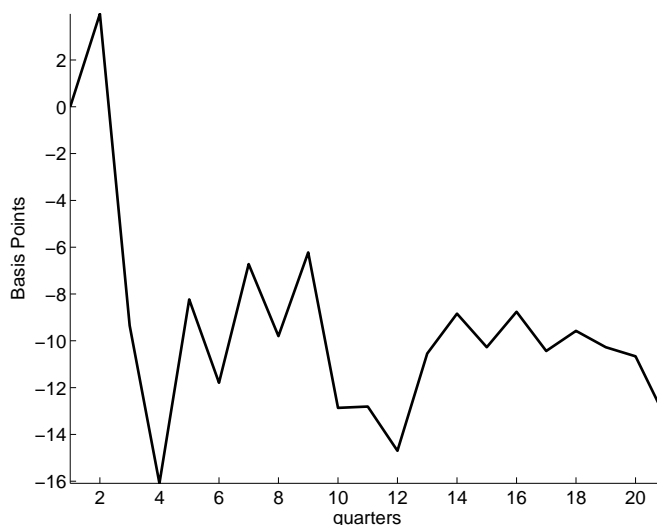
	k^h		\tilde{e}		d		r		c		ROK_h		π	
	D	M	D	M	D	M	D	M	D	M	D	M	D	M
k^h	1	1												
\tilde{e}	0.03 †	0.65	1	1										
d	-0.03 †	0.51	0.20 †	0.98	1	1								
†† r	0.63	0.70	0.24 †	0.45	0.31	0.37	1	1						
c	0.54	0.34	0.37	0.37	0.48	0.35	0.72	0.58	1	1				
ROK_h	0.01 †	0.40	0.51	0.95	0.50	0.99	0.60	0.28	0.70	0.32	1	1		
π	-0.32	0.48	0.53	0.96	0.40	0.99	0.16 †	0.34	0.42	0.33	0.88	0.99	1	1
i^h	0.25 †	0.25	0.24 †	0.84	0.07 †	0.91	0.33	0.15	0.39	0.26	0.48	0.94	0.40	0.92

This table displays the business cycle correlations of model object (M) and compares those to their data counterpart (D).

Variables: HP-Cycle component of logged variable / GDP trend, HP smoothing = 1600

†: p-value > .05 ; †† Variables: HP-Cycle component variable / GDP trend

Figure 4: FUNDING COST DIFFERENTIAL BETWEEN OLD AND NEW POLICY AFTER INTRODUCTION



A.4 Additional Results

A.4.1 Funding Cost Differential

Figure (4) presents the cost differential for funding banks' risky assets between the old and new capital requirement policy after introducing the policy at the end of period 1.

A.4.2 Optimal Capital Requirement without transition dynamics

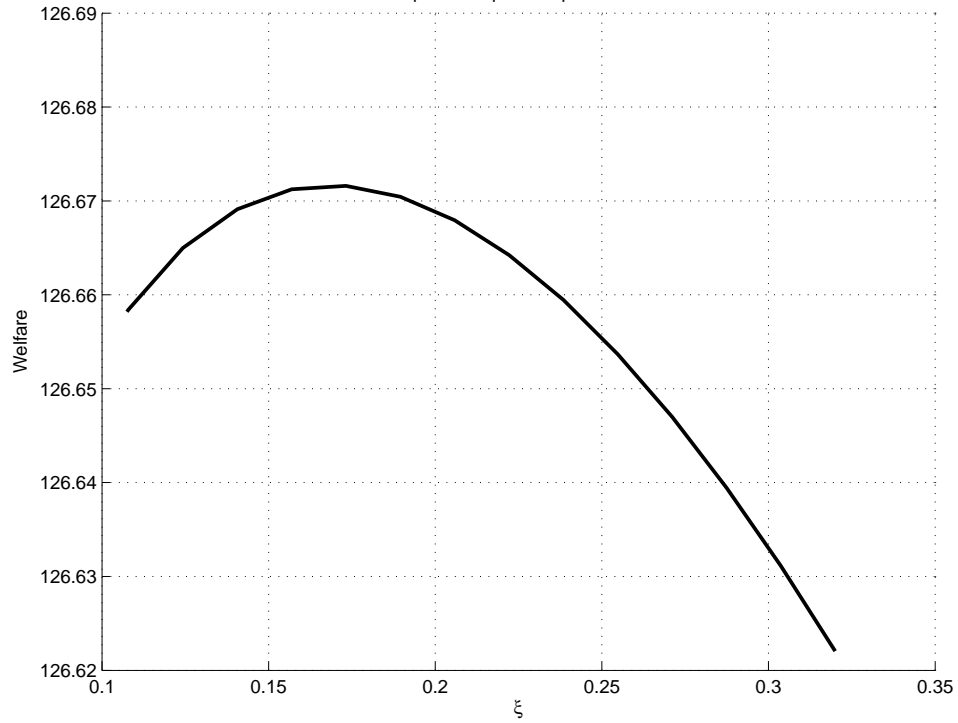
Optimal Capital Requirement without transition dynamics

When transition dynamics are ignored the optimal capital requirement is $\xi = 17\%$, as shown in Figure 5. When transition dynamics are included, bank debt falls by more than what is necessary to reach the new equilibrium. The reason for that is that capital accumulates slowly over time. When transition dynamics are not included, households do not suffer the initial reduction in bank debt to reach the new steady state. This reduces the costs of an increase in the capital requirement, which results in a higher optimal level.

Non-Stochastic Steady State Optimal Capital Requirement

Non-stochastic steady state welfare depends on the capital requirement because ξ determines how much bank debt and consumption are produced. The optimal amount of capital requirement in the steady state trades off the increase (decrease) in consumption against the decrease (increase) in bank debt holdings from higher (lower) capital requirement. In the steady state, the optimal capital requirement is about $\xi = 11\%$ lower than 14% when transition dynamics and shocks are included. Since welfare overall changes only modestly with ξ , the reduction in volatility matters.

Figure 5:
Optimal Capital Requirement

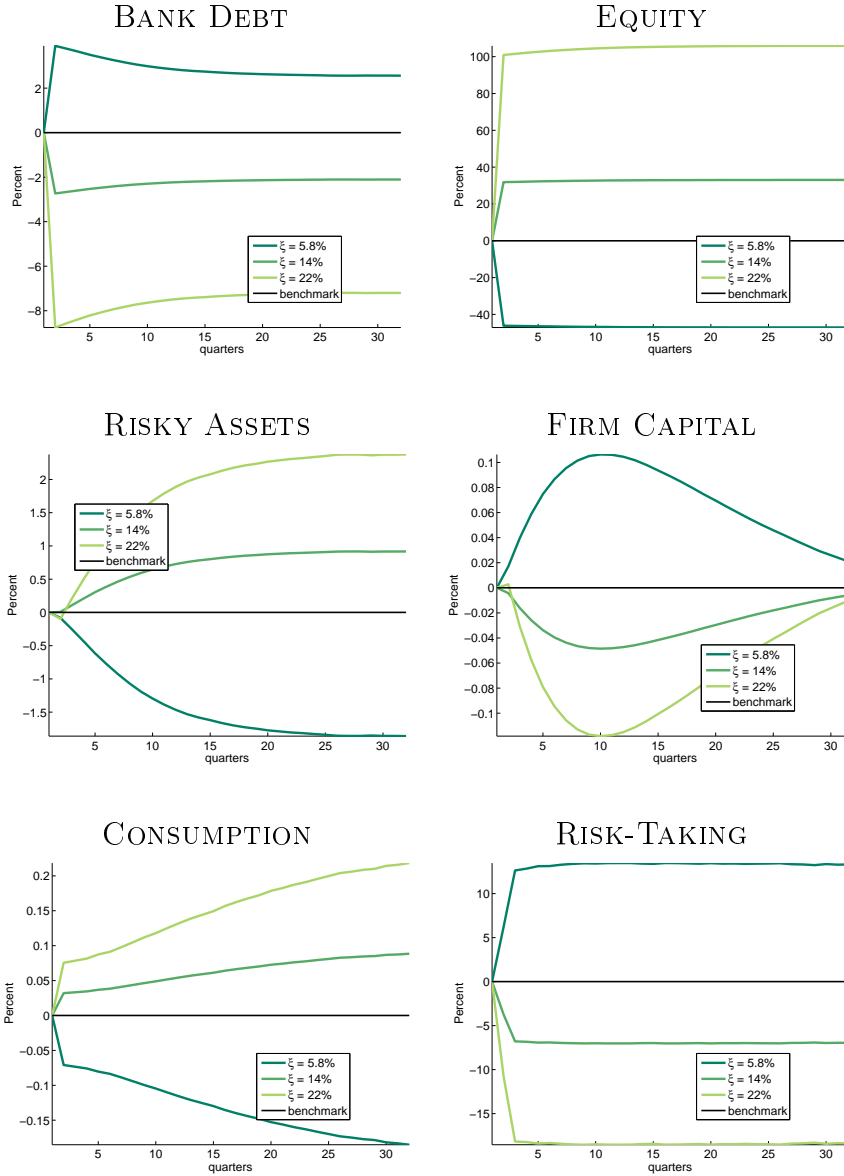


This shows that it is important to take into account the effects of shocks as well as the effects from the transition when determining the optimal level of a capital requirement.

A.4.3 Transition Dynamics

Figure 6 presents the time path of bank debt (left panel) and equity (right panel) for different levels of capital requirement over the transition period.

Figure 6: TRANSITIONS



A.5 Motivation for Transfer Function

The main goal of the paper is to analyze how capital requirements impact banks' choice of lending scale and liquidity provision in the presence of aggregate risk and excessive risk-taking incentives. The reduced form transfer function allows me to carry out exactly this analysis without explicitly modeling endogenous default, i.e. keeping the model tractable. Alternative quantitative general equilibrium frameworks with endogenous default either require to abstract from aggregate risk (see

Nguyen (2014) for an endogenous default model without aggregate risk), or from analyzing the efficient scale of bank lending.⁴⁶

I motivate the transfer function through a two period model with bailout and limited liability by banks. Banks choose first risk σ^h given a starting value of equity e and assets k^h . From the balance sheet identity $e + s = k^h$, profits $\Pi(\sigma^h, \epsilon) = Z^h(k^h)^v - \delta k^h - rs$ are only a function of the shocks and the risk choice through Z^h . The technology variable Z^h depends on the risk choice variable σ^h and the shock in the following way: $\log Z^h(\sigma^h) = (\phi_1 - \phi_2 \sigma^h) \sigma^h + \sigma^h \epsilon$ where $\epsilon \sim N(0, 1)$. There exists a government that pursues the following bailout policy:

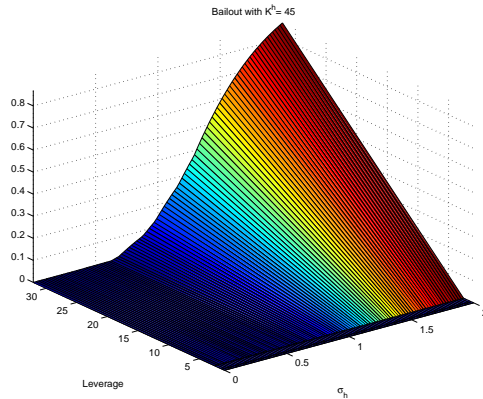
$$Bailout = \max\{0, -\{e + \Pi\}\}.$$

Banks have the following objective:

$$\max_{\sigma^h} \mathbf{E} \left[\left(e + \Pi(\sigma^h, \epsilon) + Bailout \right) \right].$$

This objective is thus the expectation of the sum of the bank business part $e + \Pi(\sigma^h, \epsilon)$ and the *Bailout* part. The value of the expected *Bailout* depends on σ^h, k^h , and e .

The following plot shows the value of the three-dimensional expected bailout function over different values of leverage k^h/e and σ^h , keeping fix the scale of the bank k^h . The value of the expected bailout increases in leverage and σ^h . Given the size of the bank and when leverage is given by the regulator through a binding capital constraint, the expected bailout depends only on risk-taking. When banks could choose leverage freely, they could maximize the value from the expected bailout by being highly leveraged and taking on a lot of risk at the same time.



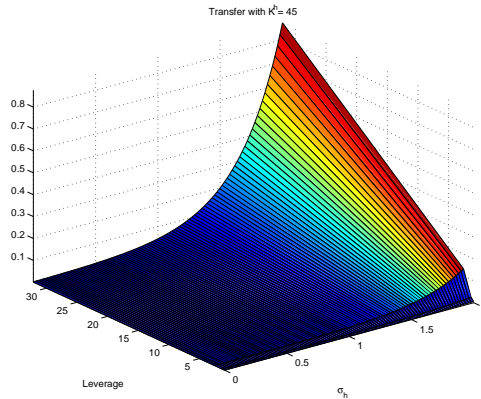
This graph suggests that the bailout is an increasing function of leverage, risk-taking, and assets with complementarities in leverage and risk-taking. In a model with limited liability of banks

⁴⁶Endogenous default can be modeled with a constant mass of banks whose problem is homogenous of degree 1 in their scale when they are hit by idiosyncratic iid valuation shocks. This leads a fraction of banks to default. In order to introduce default, Elenev, Landvoigt, and Van Nieuwerburgh (2015) use a similar trick using idiosyncratic shocks to agents' utility.

and government bailout, higher levels of leverage increase the probability of a default in which the government would need to step in and bailout the bank. Likewise, higher risk-taking by banks increases the probability of a default. And finally, the absolute amounts of transfers are greater for larger banks as measured by assets. The payments by the government occurring in the future can be also expressed as a constant stream of subsidies that depends on equity after the realization of profits, risky assets, and risk-taking by banks. These variables would otherwise affect the probability of a default. The subsidy function thus becomes:

$$TR\left(k^h, \frac{\tilde{e}}{k^h}, \sigma^h\right) = \omega_3 k^h \exp\left(-\omega_1 \left(\frac{\tilde{e}}{k^h}\right) + \omega_2 \sigma^h\right).$$

The ω parameters are found by minimizing the difference between the expected subsidy function and the expected bailout. With the parameters values of $\omega_1 = 5.025$, $\omega_2 = 2.81$, and $\omega_3 = .0001$ the transfer function takes on the following shape.



That is, the reduced form subsidy function captures roughly the bailout function that was derived from first principles.