Macroeconomic Effects of Bank Recapitalizations*
Work-in-Progress

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Abstract

We build a dynamic stochastic general equilibrium model, where both banks' balance sheets and the balance sheets of non-financial firms play a role in macro-financial linkages. We show that in equilibrium bank capital tends to be scarce, compared to firm capital: a given change in bank capital has a larger impact on the macroeconomy than a corresponding change in firm capital. We then study capital injections from the government to banks. We show that capital injections can be useful as a shock cushion, but they may be counter-productive if the aim is to avoid deleveraging and to boost investments.

1 Introduction

Governments' capital injections to the banking system have been an important tool in attempts to support credit flows during financial crises. In the crisis episodes that took place over the period 1970 to 2007, government recapitalization of banks averaged around eight percent of GDP (Laeven and Valencia, 2012). These resolution measures were present in 33 crisis episodes out of 42. During the ongoing crisis, government capital injections were close to five percent in the US and the UK[1]. By the end of 1990s, the capital injections in Japan reached two per cent of the GDP. During 2008–2012, the recapitalization measures reached 38 percent (of 2012 GDP) in Ireland, 19 percent in Greece and 10 percent in Cyprus.

In this paper we analyse capital injections from the government to the banking sector in a dynamic stochastic general equilibrium (DSGE) model with financial frictions. In our model framework, both banks' balance sheets and the balance sheets of non-financial firms play a role in macro-financial linkages, but in equilibrium bank capital tends to be scarce, compared to firm capital: a given change in bank capital has a larger impact on the macroeconomy than a corresponding change in firm capital. Hence, it is rather natural for the government to target the banks, rather than the non-financial sector.

Our framework builds on the Holmström and Tirole (1997) model of financial intermediation.[2] In the DSGE models building on Holmström and Tirole (1997) (see Aikman and Paustian (2006), Faia (2010) and Meh and Moran (2010)[3]) entrepreneurs and banks can leverage their investments by using

[1]See the calculations by SIGTARP (2014) and EU Commission (2014) respectively.

[2]While earlier models of macro-financial linkages (notable examples include Kiyotaki and Moore 1997, Carlstrom and Fuerst 1997, and Bernanke, Gertler and Gilchrist 1999) typically focused on the balance sheets of non-financial firms and treated financial intermediation as a veil, in recent years an increasing number of macro models with banks has been developed, notable examples include Gertler and Karadi (2010) and Gertler and Kiyotaki (2011). However, many of these new generation macro-banking models abstract from the balance sheets of non-financial firms. The Holmström - Tirole (1997) framework is attractive in the sense that it allows the simultaneous analysis of both banks' balance sheets and the balance sheets of non-financial firms.

[3]Early attempts to introduce a Holmström-Tirole type financial friction in macroeconomic models include Castrén and Takalo (2000) and Chen (2001).

external funding but this leverage creates moral hazard problems. Hence sufficiently large banks' and entrepreneurs' own stakes in the projects are needed to maintain their incentives, which implies that the aggregate amount of informed capital (=the sum of bank capital and entrepreneurial wealth) in the economy plays a crucial role in the propagation of shocks. In this framework, however, quantitative implications of bank capital cannot easily be disentangled from those of entrepreneurial wealth. These models also require a bank's asset portfolio to be completely correlated, and make assumptions that render them incomparable with the standard New Keynesian framework.

We extend the DSGE framework building on Holmström and Tirole (1997) to allow for the separate roles of bank capital and entrepreneurial wealth. There are several novel features in our model: First, like in the simultaneously written paper by Christensen, Meh and Moran (2011), we allow monitoring investments to be continuous: the more the banks invest in costly monitoring, the lower the entrepreneurs' private benefits from unproductive projects but the less the banks can lend. Second, we treat monitoring investments truly monetary and private benefits truly private in the sense that the former has opportunity costs but the latter does not have. These features imply that the banks monitoring investments vary over the business cycle and that not only the aggregate amount of informed capital but also its composition matters in the propagation of shocks. Third, we distinguish between bankers and banks. In our model, a bank is a balance sheet entity with a capital structure but only a banker faces an incentive problem. This is not only realistic but also allows us to relax the assumption of a completely correlated investment portfolio of a bank. The distinction between bankers and banks is also instrumental when we introduce an aggregate investment shock, which plays a key role in our model. Finally, we strive to benchmark our model to the standard New Keynesian framework which requires a number of subtle but important changes to the previous macro literature building on Holmström and Tirole (1997).

The key results of the modelling effort are the following: i) In equilibrium bank capital is scarce in the sense that the ratio of bank capital to entrepreneurial wealth is smaller than what would maximize the investments and output. Also, a given change of bank capital affects aggregate investments more than an equal proportional change of entrepreneurial wealth. ii) Bank capital is more vulnerable to aggregate investment shocks than entrepreneurial capital. iii) Given properties i) and ii), bank capital plays a more important role in the propagation of investment shocks, and in macroeconomic dynamics, than entrepreneurial capital.

Given the importance of bank capital in macro-financial linkages, our model forms an attractive framework for studying capital injections by the government. An *ex post* capital injection distorts bankers' monitoring incentives and the banks' involvement becomes more expensive for the entrepreneurs. This arises because the government-owned capital is more expensive than the households' deposits. In such a situation capital injections may accelerate deleveraging and lower aggregate investments. The result is reversed if the conditions of the government-owned capital are more favourable than those of deposits. Capital injections can be done *ex ante*, i.e. before the investment shock arrives. In such a case, they form a pre-emptive 'cushion' and the policy can be productive in mitigating develeraging and stabilizing the economy.

In the next section we describe the basic model. In Section 3 we explain why bank capital is scarce in equilibrium. In Section 4 we introduce an investment shock into the model, and discuss the distinction between bankers and banks. In Section 5 we explain how we calibrate the model and in Section 6 we study the impulse responses of financial and macro variables to a number of shocks. In Section 7 we analyze capital injections from the government to banks. Finally, Section 8 concludes.

2 The Model

We consider a discrete time, infinite horizon economy that is populated by households with three types of members: workers, entrepreneurs, and bankers. In the financial side of the economy, bankers manage financial intermediaries (banks) that obtain deposits from households and finance entrepreneurs. The real economy contains three sectors: i) competitive firms producing final goods from intermediate goods; ii) monopolistically competitive firms producing the intermediate goods from labour supplied by workers and capital supplied by entrepreneurs, and iii) entrepreneurs producing capital goods. Monopolistic retailers are there only to introduce nominal price rigidites.

Households own banks and all firms, including those producing capital goods. The production of capital is subject to a dual moral hazard problem in the sense of Holmström and Tirole (1997): First, entrepreneurs, who may obtain external finance from households and banks, have temptation to choose less productive projects with higher non-verifiable returns. Second, bank monitoring mitigates the entrepreneurs' moral hazard temptations but since the banks use deposits from the households to finance the entrepreneurs, there is an incentive to shirk in costly monitoring.

2.1 Households

Following Gertler and Karadi (2011) we assume that there is a continuum of identical households of measure unity. Within each household, there are three occupations: in every period t, fraction of the household members become entrepreneurs, another fraction become bankers, and the rest remain workers. After each period, an entrepreneur and a banker exit from their occupations at random according to Poisson processes with constant exit rates $1-\lambda^e$, $\lambda^e \in (0,1)$, and $1-\lambda^b$, $\lambda^b \in (0,1)$, respectively. In a steady state the number of household members becoming entrepreneurs and bankers equals the number of exiting entrepreneurs and bankers.

The head of a household decides on behalf of its members how much to work, consume, and invest in capital and bonds. In Section 2.4 we explain in detail how entrepreneurs invest in risky projects to produce capital goods and how bankers provide funding for these investments. In general, entrepreneurs and bankers earn higher return to their risky investments than workers earn to their deposits. Hence it is optimal for the household to let its entrepreneurs and bankers to keep building their assets until exiting their occupations.

The exiting entrepreneurs and bankers give their accumulated assets to the household which in turn provides new entrepreneurs and bankers with some initial investment capital. Within a household there is a perfect consumption insurance against the risks entrepreneurs and bankers take. Therefore, all household members consume an equal amount in each period.

The problem of a representative household is

$$\max_{\{B_t \geq 0, C_t \geq 0, L_t \geq 0, K_t \geq 0\}_{t=0}^{\infty}} E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{\xi}{1+\phi} L_t^{1+\phi} \right) \right], \quad (1)$$

subject to a budget constraint:

$$B_t + P_t(C_t + q_t K_{t+1} + T_t) = W_t L_t + (1 + r_{t-1}) B_{t-1} + P_t K_t \left[r_t^K + q_t (1-\delta) \right]. \quad (2)$$

In the household's utility function (1), $\xi > 0$, $\phi > 0$ and $\sigma \in (0, 1)$ are parameters, $\beta \in (0, 1)$ is the rate of time preference, and C_t and L_t denote consumption and hours worked in period t, respectively. In the budget constraint (2), B_t denotes the household's holdings of one period nominal bond at the end of period t and $1 + r_{t-1}$ is the gross nominal interest rate on bond holdings, P_t price level of consumption basket, T_t lump-sum transfers (dividends from monopolistically competitive firms owned by the household, and net payouts from entrepreneurs and bankers), W_t nominal wage, K_t is the stock of physical capital, r_t^K the real rental price of capital, q_t is the price of capital goods and, finally, $\delta \in (0, 1)$ is the rate of depreciation of physical capital. Note that we assume, as in Carlstrom and Fuerst (1997), that bank deposits are intra-period deposits. They can, consequently, be excluded from intertemporal budget constraint (2). While being somewhat controversial the assumption facilitates comparison of our model with the standard New Keynesian framework. We later elaborate the implications of this assumption.

Physical capital stock accumulates according to the law of motion

$$K_{t+1} = (1-\delta) K_t + p_H R I_t, \quad (3)$$

where $p_H \in (0,1)$ and $R \geq 1$ are parameters of the capital good production, as will be defined more precisely in Section 2.4.

Solving the household's dynamic optimization problem yields the familiar first order conditions for B_t, L_t and K_{t+1}, respectively:

$$1 = \beta E_t \left\{ (1+r_t) \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\}, \tag{4}$$

$$\frac{\xi L_t^{\phi}}{C_t^{-\sigma}} = \frac{W_t}{P_t}, \tag{5}$$

and

$$q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left[r_{t+1}^K + q_{t+1}(1-\delta) \right] \right\}. \tag{6}$$

2.2 Final Good Production

Competitive firms produce the final good by assembling a continuum of intermediate goods, indexed by $j \in [0,1]$, by using the standard constant-elasticity-of-substitution aggregator

$$Y_t = \left[\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}},$$

where $\epsilon > 0$ is the elasticity of substitution and $Y_t(j)$ denotes the use of intermediate good j in period t. The final good producers choose the level of $Y_t(j)$ for all j and t to maximize their profits subject to a zero-profit condition. Solving this maximization problem yields

$$Y_t(j) = \left[\frac{P_t(j)}{P_t} \right]^{-\epsilon} Y_t, \tag{7}$$

where $P_t(j)$ is the price of intermediate good j and

$$P_t = \left[\int_0^1 P(j)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}} \tag{8}$$

is the aggregate price index.

2.3 Intermediate Good Production

The firms in the intermediate good sector combine capital $K_t(j)$ and labor $L_t(j)$ using the Cobb-Douglas production function

$$Y_t(j) = K_t(j)^{\alpha} \left(Z_t L_t(j)\right)^{1-\alpha},$$

where $\alpha \in (0,1)$, and Z_t is the common labor-augmenting technology. Cost minimization results in the familiar equations for the optimality condition

$$\frac{W_t}{P_t} = \frac{(1-\alpha)\, r_t^K K_t(j)}{\alpha L_t(j)}, \tag{9}$$

and for the real marginal costs (denoted by ψ_t)

$$\psi_t = \left(\frac{r_t^K}{\alpha}\right)^{\alpha} \left(\frac{W_t}{P_t Z_t (1-\alpha)}\right)^{1-\alpha}. \tag{10}$$

Following Calvo (1983) each intermediate good firm gets a possibility to revise price of its product according to a Poisson process with constant arrival rate $1-\theta$, $\theta \in [0,1]$, in any given period. As a result, the fraction $1-\theta$ of firms may change their price in each period while the rest, fraction θ, of the firms keep their price unchanged.[4]

Let $P_t^{\star}$ denote the price level of the firm that receives a price change signal in period t. When making its pricing decision, the firm takes into account that it cannot change the price it chooses now with probability θ over each future period. That is, when a firm can change its price, its problem is

$$\max_{P_t^{\star} \geq 0} E_t \left[\sum_{k=0}^{\infty} \theta^k Q_{t,t+k} \left(\frac{P_t^{\star}}{P_{t+k}}\right)^{-\epsilon} Y_{t+k} \left(P_t^{\star} - \Psi_t\right) \right],$$

where the demand function (7) has been substituted for the firm's output level, Ψ_t denotes the firm's nominal marginal costs and $Q_{t,t+k} \equiv \beta^k \left(C_{t+k}^h / C_t^h\right)^{-\sigma} \left(P_t / P_{t+k}\right)$ is the nominal stochastic discount factor that the

[4]Here, and in what follows, we invoke a common approximation with a continuum of i.i.d. random variables according to which the empirical mean also equals the expectations with probability 1 (Judd, 1985).

household uses to price any financial asset (e.g., our standard household's optimization problem yields the same pricing kernel for the one-period bond (see (4)).

The first order condition for the firm's problem is given by

$$E_t \left[\sum_{k=0}^{\infty} \theta^k Q_{t,t+k} \left(\frac{P_t^\star}{P_{t+k}} \right)^{-\epsilon} Y_{t+k} \left(P_t^\star - \frac{\epsilon}{\epsilon - 1} \Psi_t \right) \right] = 0, \tag{11}$$

where $\epsilon / (\epsilon - 1)$ is the frictionless mark-up. Equation (11) gives the optimal price $P_t^\star$ for all the firms that get an opportunity to set their price level at any given period t. As a result the aggregate price index ((8)) may be re-expressed as

$$P_t = \left[\theta P_{t-1}^{1-\epsilon} + (1-\theta)(P_t^\star)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} .$$

2.4 Production of Capital

Capital demanded by the firms in the intermediate good sector is produced by entrepreneurs who are endowed with investment projects. While the entrepreneurs of a household generally have some initial wealth of their own, they can attempt to leverage their investments by borrowing from other households. It may be best to think that the intermediation of entrepreneurial finance only occurs among households. To clarify how financial intermediation takes place, let us consider three households, A. B, and C. We can either think that the workers of household A invests their funds directly in the projects of the household C's entrepreneurs, along with the capital from the banks of household B, or that the workers of household A first deposit their funds with the banks of household B, who then invest the deposits in the projects of the household C's entrepreneurs along with their own bank capital. For clarity of presentation, we work with the latter interpretation.

All successful investment projects transform i units of final goods to Ri ($R > 1$) verifiable units of capital goods while failed projects yield nothing. The projects differ in their probability of success and the amount of non-verifiable revenues created by them. There is a "good" project that is successful with probability p_H and involves no non-verifiable revenues to the entrepreneur. There is also a continuum of bad projects with common success probability p_L ($0 \leq p_L < p_H < 1$) but with differing amount of non-verifiable revenues bi, $b \in \left(0, \overline{b}\right]$, attached to them. Note that non-verifiable revenues are proportional to investment size as in Holmström and Tirole (1997).[5] But we depart from Holmsröm and Tirole (1997) where bad projects generate non-transferable private benefits.[6] In essence, we assume - like Meh and Moran (2010), Faia (2010), and Christiansen et al. (2012) - that private benefits are divisible and transferable. In our case this assumption is only needed to ensure the smoothness of out-of-equilibrium payoffs: if in an out-of-equilibrium event an entrepreneur had picked a bad project, her project returns should be transferable and divisible among her household members upon her exit from entrepreneurship. Further, we assume that $q_t p_H R > \max\left\{1 + r_t^d, q_t p_L R + \overline{b}\right\}$ to ensure that the good project i) has a positive rate of return and ii) is preferable to all bad projects from the household's point of view.

Bankers are endowed with a monitoring technology that enables them to constrain the entrepreneurs' project choice. Following Holmström and Tirole (1997) and Christiansen et al. (2012), we allow for monitoring to have a variable scale. Monitoring at the intensity level c ($c \geq 0$) eliminates all bad projects where $b \geq b(c)$ from the entrepreneur's project choice set. The threshold level of non-verifiable revenues $b(c)$ is decreasing and convex in the monitoring intensity: $b'(c) \leq 0, b''(c) \geq 0$, and $\lim_{c\to\infty} b'(c) = 0$. Monitoring requires investments of real resources (e.g., labor): to obtain monitoring intensity c, a bank must pay ci units of final goods to workers of its household (this is in line with Christiansen et al., 2012, but in contrast

[5] In contrast, Meh and Moran (2010), Faia (2010), and Christiansen et al. (2012) assume that the non-verifiable revenues of bad projects are proportional to the value of capital goods. Making such an assumption would not qualitatively affect our results.

[6] One interpretatation is, reminiscent of Bolton and Scharfstein (1990), that project revenues are verifiable outside a household only up to R or that only revenues in terms of capital goods are verifiable (but that all revenenues are verifiable within a household). Alternatively, following, e.g., Burkart, Gromp, and Panunzi (1998) we may think that an entrepreneur is able to divert part of her firm's resources to her own use at an interim stage. As in Burkart et al. (1998), such expropriation of outside investors is costly, which is here captured by lower expected project returns in case diversion takes place (i.e., there is a fixed cost of diversion).

to Holmström and Tirole, 1997, where monitoring costs are non-pecuniary). That is, the more a banker invests in monitoring the less his bank can lend to entrepreneurs. Hence the banker must be provided incentives to monitor. Note also that because of diminishing returns to monitoring investments, the banker will never want to eliminate all bad projects. Therefore, despite monitoring, entrepreneurs must be provided incentives to choose the good project. In sum, there are two moral hazard problems among different households: one between bankers and entrepreneurs (borrowers), and another between bankers and workers (depositors). The moral hazard problems may be solved by designing a proper financing contract.

2.4.1 The Financing Contract

In each period t, there are three contracting parties: entrepreneurs, bankers, and depositors (workers). Following the standard practice in the macro literature we assume limited liability and inter-period anonymity, and focus on the class of one-period optimal contracts where the entrepreneurs invest all their own wealth n_t in their projects. The financial contract then stipulates how much of the required funding of the project of size i_t comes from banks (a_t) and depositors (d_t) and how the project's return R in case of success is distributed among the entrepreneur (R_t^e), her bankers (R_t^b), and depositors (R_t^w).

A banker, given his share from the project returns, maximizes the bank's profits by choosing monitoring intensity, c_t. We assume that banks behave competitively. As a result, the banks offer the same contract that would be offered by a single bank that would maximize the entrepreneur's expected proftis. The optimal financing contract therefore solves the following program:

$$\max_{\left\{i_t, a_t, d_t, R_t^e, R_t^b, R_t^w, c_t\right\}} q_t p_H R_t^e i_t$$

subject to the entrepreneur's and her banker's incentive constraints

$$q_t p_H R_t^e i_t \geq q_t p_L R_t^e i_t + b\left(c_t\right) i_t, \tag{12}$$

$$q_t p_H R_t^b i_t \geq q_t p_L R_t^b i_t + \left(1 + r_t^d\right) c_t i_t, \tag{13}$$

the depositors' and the banker's participation constraints

$$q_t p_H R_t^w i_t \geq \left(1 + r_t^d\right) d_t, \tag{14}$$

$$q_t p_H R_t^b i_t \geq (1 + r_t^a) a_t, \tag{15}$$

and the resource constraints for the investment inputs and outputs

$$a_t + d_t - c_t i_t \geq i_t - n_t, \tag{16}$$

$$R \geq R_t^e + R_t^b + R_t^w. \tag{17}$$

In words, (16) implies that the aggregate supply of investment funds must satisfy their aggregate demand and (17) that the total returns must be enough to cover the total payments.

All constraints bind in equilibrium. It is also clear that the entrepreneur wants to invest as much as possible, i.e., she wants to raise as much funds from outside as possible without breaking the depositors' and banker's participation and incentive constraints. Using these standard equilibrium properties, we solve the entrepreneur's program in two steps. In the first step we take the intensity of monitoring c_t and, by implication, the level of private revenues $b(c_t)$ as given and solve for the maximum size of the investment project i_t for a given level of entrepreneurial wealth n_t. As the second step, we solve for the equilibrium level of monitoring c_t.

2.4.2 Investment, Leverage, and Monitoring at the Project Level

In the Holmström-Tirole framework the maximum investment size depends on how much funds can be raised from outside which in turn depends on how much of the project returns can credibly be pledged to depositors. From the entrepreneur's and the banker's incentive constraint (12) and (13) we see that the entrepreneur and the banker must get no less that $b(c_t) / (q_t \Delta p)$ and $\left(1 + r_t^d\right) c_t / (q_t \Delta p)$, respectively, in case of success, as otherwise they will misbehave. Substitution of $R_t^b = \left(1 + r_t^d\right) c_t / \left(q_t \Delta p\right)$ and $R_t^e = b\left(c_t\right) / \left(q_t \Delta p\right)$ for the return-sharing constraint (17) shows that depositors can be promised at most

$$R_t^w = R - \frac{\left(1 + r_t^d\right) c_t + b\left(c_t\right)}{q_t \Delta p}. \tag{18}$$

Substituting (18) for the depositor's participation constraint (14) yields

$$p_H \left\{ q_t R - \frac{\left[\left(1 + r_t^d\right) c_t + b\left(c_t\right)\right]}{\Delta p} \right\} = \left(1 + r_t^d\right) \frac{d_t}{i_t}. \tag{19}$$

Next, we combine the banker's incentive constraint (13) with his participation constraint (15) and the input resource constraint (16) to obtain

$$\frac{d_t}{i_t} = 1 + c_t - \frac{p_H \left(1 + r_t^d\right) c_t}{\Delta p \left(1 + r_t^a\right)} - \frac{n_t}{i_t},$$

which can be then substituted for equation (19) . Solving the resulting equation for i_t gives

$$i_t = \frac{n_t}{g\left(r_t^a, r_t^d, q_t, c_t\right)} \tag{20}$$

where

$$g\left(r_t^a, r_t^d, q_t, c_t\right) = \frac{p_H b\left(c_t\right)}{\Delta p (1 + r_t^d)} + \left[1 + \frac{p_H}{\Delta p}\left(1 - \frac{1 + r_t^d}{1 + r_t^a}\right)\right] c_t - \rho_t \tag{21}$$

is the inverse degree of leverage, i.e., the smaller is $g\left(\cdot\right)$ the larger the size of the investment project i_t for a given level of entrepreneurial wealth n_t. The first term on the right-hand side of equation (21) shows how larger possibilities to extract private revenues decrease leverage by discouraging participation of outside investors. This effect can be reduced by increasing monitoring. However, the second term shows how more intense monitoring also has two negative effects on leverage since it consumes resources that could have otherwise been invested in the project, and makes it harder to satisfy the banker's incentive constraint. These two effects are captured by the first and second term in the square brackets, respectively (note that in equilibrium we must have $r_t^a \geq r_t^d$). Finally, the term $\rho_t \equiv \frac{p_H q_t R}{1 + r_t^d} - 1 > 0$

denotes the net rate of return on the good investment project; the larger the rate of return the easier to attract outside funding.

The optimimal choice of c_t maximizes the entrepreneur's expected profits $p_H q_t R_t^e i_t$, which may be rewritten by using equations (12) and (20) as $p_H b(c_t) n_t / \left[g\left(r_t^a, r_t^d, q_t, c_t\right) \Delta p \right]$. Therefore the optimal level of monitoring solves the following problem:

$$\max_{c_t \geq 0} \frac{b(c_t)}{g\left(r_t^a, r_t^d, q_t, c_t\right)}. \tag{22}$$

As can be seen from equations (21) and (22) the effects of monitoring on the entrepreneur's expected payoff are complex. The denominator in the problem (22) shows how larger scope of extracting private revenues implies a larger equilibrium share of the project returns for the entrepreneur, which dilutes monitoring incentives. Monitoring incentives are also adversely affected by the negative effects of monitoring costs on leverage (the second term in $g(\cdot)$ in equation (21)). However, striving to obtain larger leverage requires giving up possibilities of diverting private revenues so as to raise the costly bank capital (the first term in $g(\cdot)$ in equation (21)). This provides an incentive for monitoring.

To derive a tractable analytic solution to the problem (22), we specify the following functional form for $b(c_t)$:

$$b(c_t) = \begin{cases} \Gamma c_t^{-\frac{\gamma}{1-\gamma}} & \text{if } c_t > \underline{c} \\ \bar{b} & \text{if } c_t \leq \underline{c} \end{cases}, \tag{23}$$

where $\Gamma > 0$, $\bar{b} > 0$, $\gamma \in (0,1)$, and $\underline{c} \geq 1$. The first row of equation (23) shows how $b(c_t)$ is differentiable and strictly convex for $c_t > \underline{c}$ and that the monitoring technology is the more efficient the larger is γ or the smaller is Γ. The second row implies that there is a minimum efficient scale for monitoring investments or an upper bound for the private revenues. This upper bound ensures that the net rate of return on a bad project is negative even for low levels of c_t.[7]

[7]Naturally, we have experimented with many other functional forms but they result in

Under the minimum scale requirement, the entrepreneur may choose a corner solution with no monitoring $c_t = 0,\ b(c_t) = \overline{b}$, or a unique interior solution $c_t = c_t^*$. After substitution of equations (21) and (23) we can write the unique interior solution to the entrepreneur's problem (22) as

$$c_t^* = \frac{\gamma \rho_t}{1 + \frac{p_H}{\Delta p}\left(1 - \frac{1+r_t^d}{1+r_t^a}\right)}. \tag{24}$$

In the appendix we study the conditions under which we can rule out the corner solution. (These conditions are met around the steady state in which we focus on in this paper.). The optimal level of monitoring intensity has intuitive properties: It is increasing in the elasticity of monitoring technology (directly related to γ) and in the rate of return on the good project (ρ_t). Also, the larger the negative effects of monitoring on leverage (the larger is the denominator), the smaller the optimal level of monitoring.

2.5 Monetary Policy

We assume that monetary policy follows a simple Taylor rule

$$1 + r_t = \frac{\Pi_t^{\phi_\pi}}{\beta}$$

where $\Pi_t \equiv P_t / P_{t-1}$ is the (gross) inflation rate and $\phi_\pi > 1$.

2.6 Timing of Events

Within each period t there are three main stages. In the first stage the monetary authority sets the interest rate, the household members separate into their occupations, the heads of households make their consumption-savings decisions, intermediate goods are produced, using capital and labor, and then final goods are produced, using the intermediates.

The production of capital goods takes place in the second stage. The capital production stage is divided to five substages: First, financing contracts

considerably uglier algebra than specification (23) without yielding additional insights.

among entrepreneurs, bankers and depositors (workers) are signed. That contract determines whether and how the project is financed, its size, and how eventual revenues are divided. Depositors place their funds in banks, who extend funding to entrepreneurs according to the financing contract. Second, bankers choose their intensity of monitoring. Third, entrepreneurs choose their projects. Fourth, successful projects yield new units of capital goods that are sold. Finally, the proceeds are divided among depositors, bankers and entrepreneurs according to the terms of the financial contract.

In the third main stage survival probabilities of bankers and entrepreneurs are realized. Exiting bankers and entrepreneurs give their accumulated assets to households.

Note that entrepreneurs are assumed to sell the capital goods that they produce. Yet our equations in Section 2.3 show that intermediate good firms are renting - not owning - the capital stock that they need in production. This is consistent with the existence of perfectly competitive capital rental firms, fully owned by households. These capital rental firms purchase capital goods from successful entrepreneurs, rent capital services to intermediate goods firms, and refund the rental income to its owners.

Note also that bankers can commit to monitoring before entrepreneurs make their project choice, as in Holmström and Tirole (1997). This sequential timing rules out mixed strategy equilibria. But in some other cases the results are not senstive to the timing of events specified above. For example we could assume that capital goods from successful projects are first divided among the contracting parties who will subsequently sell them to capital rental firms.

2.7 Aggregation

We proceed under the assumption that all projects will be monitored with the same intensity given by equation (24), and all entrepreneurial firms have the same capital structure. That is, for all projects, the ratios a_t/i_t, d_t/i_t, and n_t/i_t are the same (The project sizes may nonetheless differ: the larger the entrepreneur's wealth n_t, the larger her investment i_t). Given this symmetry, moving from the project level to the economy-wide level is simple. Clearly,

$$\frac{a_t}{i_t} = \frac{A_t}{I_t}, \ \frac{d_t}{i_t} = \frac{D_t}{I_t}, \text{ and } \frac{n_t}{i_t} = \frac{N_t}{I_t}. \tag{25}$$

where capital letters stand for aggregate level variables.

Let us first characterize the equilibrium rate of return on bank capital. Combining (25) with the banker's incentive and participation constraints (13) and (15) yields

$$c_t^* = \frac{\Delta p \left(1 + r_t^a\right) A_t}{p_H \left(1 + r_t^d\right) I_t}. \tag{26}$$

Since in equilibrium the monitoring intensity given by equation (26) must be equal to the one in equation (24), we have

$$1 + r_t^{a*} = \frac{\left(1 + r_t^d\right)\left(1 + \frac{\gamma \rho_t I_t}{A_t}\right)}{1 + \frac{\Delta p}{p_H}}. \tag{27}$$

For equation (27) to characterize the equilibrium rate of return on bank capital, it must hold that

$$r_t^{a*} > r_t^d. \tag{28}$$

Otherwise, $r_t^{a*} = r_t^d$. We proceed under the assumption that inequality (28) holds, verifying that the assumption is fulfilled in equilibrium later.

Next, we study aggregate investment and leverage. Equations (16) and (25) imply

$$\frac{D_t}{I_t} = 1 + c_t^* - \frac{A_t + N_t}{I_t}. \tag{29}$$

Substituting equations (29) ,(23), (26), (27), and (25) for equation (19) yields after some algebra

$$\left(\frac{A_t}{I_t^*} + \gamma \rho_t\right)^\gamma \left[\frac{N_t}{I_t^*} + (1 - \gamma)\rho_t\right]^{1-\gamma} = \left[\frac{\Gamma p_H}{\left(1 + r_t^d\right)\Delta p}\right]^{1-\gamma} \left(1 + \frac{p_H}{\Delta p}\right)^\gamma \tag{30}$$

Equation (30) implicitly determines the aggregate investment level I_t^* in the economy.

In our model aggregate capital good stock simply evolves according to equation (3). However, it is also important to determine the evolution of bank and entrepreneurial capital. After the investment projects are realized, surviving entrepreneurs and bankers receive the proceeds from the sales of capital goods to capital rental firms so that the aggregate amount of final goods held by entrepreneurs and bankers at the end of period t are $\lambda^e p_H R_t^e I_t$ and $\lambda^b p_H R_t^b I_t$, respectively (recall that λ^e and λ^b are the entrepreneur's and banker's survival probabilities). Furthermore, the surviving entrepreneurs and bankers receive rental income r_{t+1}^K from the capital rental firms they own. The value of a unit of undepreciated capital good at the beginning of period $t+1$ is $(1-\delta)\, q_{t+1}$. As a result, the aggregate amount of capital held by bankers at the beginning of period $t+1$ is given by

$$A_{t+1} = \left[r_{t+1}^K + q_{t+1}(1-\delta)\right] \lambda^b p_H R_t^b I_t, \tag{31}$$

which may be combined with conditions (15) and (25) to get the following law of motion for the aggregate bank capital:

$$A_{t+1} = \frac{A_t \lambda^b (1 + r_t^a) \left[r_{t+1}^K + (1-\delta)\, q_{t+1}\right]}{q_t}. \tag{32}$$

Similarly, the aggregate entrepreneurial capital is given by

$$N_{t+1} = \left[r_{t+1}^K + q_{t+1}(1-\delta)\right] \lambda^e p_H R_t^e I_t, \tag{33}$$

which we can rewrite as

$$N_{t+1} = \frac{N_t \lambda^e (1 + r_t^e) \left[r_{t+1}^K + (1-\delta)\, q_{t+1}\right]}{q_t} \tag{34}$$

where $1 + r_t^e \equiv q_t p_H R_t^e I_t / N_t$ denotes the rate of return on entrepreneurial capital. Equation (34) gives the law of motion for aggregate entrepreneurial capital.

2.8 Equilibrium

Since in our model deposits occur within a period, they carry no interest rate, i.e., $r_t^{d*} = 0$.[8] In addition to $r_t^{d*} = 0$, a competitive equilibrium of the economy is a time path

$$\left\{K_t, C_t, L_t, q_t, W_t/P_t, \psi_t, P_t^*, R_t^b, R_t^w, c_t^*, r_t^{a*}, D_t, I_t^*, A_{t+1}, N_{t+1}\right\}_{t=0}^{\infty}$$

that satisfies (3), (4), (5), (6), (9), (10), (11), (18), (24), (27), (29), (30), (32), and (34). In what follows, we study a dynamic equilibrium in the neighborhood of a non-stochastic steady state of the model.

3 Structure of Informed Capital

Let $v_t \equiv A_t/N_t$ denote the ratio of bank capital to entrepreneurial capital, and call it the ratio of informed capital. We first seek a steady state value of v_t, (denoted by v, i.e., $\lim_{t\to\infty} v_t = v$.)

Proposition 1 *If $\beta > \max\left\{\lambda^e, \lambda^b\right\}$, there exists a steady state satisfying condition (28) where the ratio of informed capital (ν) is given by*

$$\nu = \frac{\gamma\left(\frac{\beta}{\lambda^e} - 1\right)}{(1-\gamma)\left[\frac{\beta}{\lambda^b}\left(1 + \frac{\Delta p}{p_H}\right) - 1\right]} > 0.$$

Proof. In the Appendix. ■

In other words, Proposition 1 implies that a steady state with a meaningful role for bank capital ($v > 0$ and $r_t^{a*} > 0$) exists if the entrepreneur's and banker's survival probabilities are smaller than the household's rate for time preference (which equals the household's nominal stochastic discount factor at a steady state). Intuitively the household must be sufficiently patient to let its bankers and entrepreneurs retain their earnings. Note that if $\lambda^b > \lambda^e$ the requirement $\beta > \max\left\{\lambda^e, \lambda^b\right\}$ is a sufficient condition for the existence of the steady state with $v > 0$ (see the Appendix).

[8] We plan to relax the assumption of intra-period deposits in future work.

Next, we determine the value of v_t (denoted by v^{**}) that would maximize leverage and investments in the economy, and by implication, the economy's output.

Proposition 2 *i) The ratio of informed capital maximizing output (v^{**}) is given by*

$$\nu^{**} = \frac{\gamma}{1-\gamma}.$$

Proof. In the Appendix. ■

Proposition 2 shows that the output maximizing ratio of informed capital is equal to the elasticity of monitoring technology. To understand the result, note that maximizing leverage is practically equivalent to maximizing the (expected) pledgeable income, $p_H q_t \left(R_t - R_t^b - R_t^e\right)$, (i.e., the highest revenue share that can be pledged to depositors without jeopardizing entrepreneurs' and bankers' incentives), minus the cost of monitoring, c_t (because monitoring costs consume real resources in our model). But there is a tradeoff: an increase in the bank monitoring will increase the entrepreneur's pledgeable income but reduce the banker's pledgeable income and consume bank capital that could otherwise have been loaned to entrepreneurs. This tradeoff is optimally balanced when the ratio of informed capital equals to the elasticity of monitoring technology: the more (less) elastic the monitoring technology, the more (less) resources should be devoted to bank monitoring.

Comparison of Proposition 2 with Proposition 1 immediately yields our main analytical result:

Proposition 3 $v^{**} \gtreqless v$ *if*

$$\frac{\lambda^b}{\lambda^e} \lesseqgtr 1 + \frac{\Delta p}{p_H}.$$

In words, Proposition 3 suggests that the question of whether there is relative *scarcity* of bank or entrepreneurial capital in a steady state only depends on bankers' and entrepreneurs' exit rates and success probabilities of projects. The scarcity of bank capital prevails in a steady state for a larger range of parameter values than the scarcity of entrepreneurial capital: Only if the bankers' survival probability is larger than the entrepreneurs' survival probability by a factor that is strictly larger than one, the bankers may accumulate more capital than what is needed to maximize investments and output in the economy.

Proposition 3 has an important implication: Differentiating equation (30) around the steady state yields (see the Appendix for details)

$$\left.\frac{dN}{dA}\right|_{I^*} = -\frac{1+\frac{\Delta p}{p_H}-\frac{\lambda^b}{\beta}}{\left(1+\frac{\Delta p}{p_H}\right)\left(1-\frac{\lambda^e}{\beta}\right)}.$$

If we view $I_t^*\left(A_t, N_t\right)$ as given by equation (30) as the economy's production technology, $dN/dA|_{I^*}$ defines the marginal rate of technical subtitution of bank and entrepreneurial capital. It is immediate that

$$\left.\frac{dN}{dA}\right|_{I^*} \lesseqqgtr -1$$

if

$$\frac{\lambda^b}{\lambda^e} \lesseqqgtr 1+\frac{\Delta p}{p_H}.$$

In words, if bank capital is scarce, the (absolute) value of marginal rate of technical subsitution is above one and, as a result, increasing bank capital boosts the aggregate investments more than increasing entrepreneurial capital by an equal amount (and vice versa if entrepreneurial capital is scarce).

To gain more insights into the results, let us assume that $\lambda^e = \lambda^b$, in which case Proposition 3 implies that there is too little bank capital in a steady state. Then, dividing equation (31) by equation (33) shows that in a steady state we have $v = R^b/R^e$. That is, because it is optimal for the household to let its entrepreneurs and bankers to retain and reinvest all their earnings, bankers and entrepreneurs accumulate capital in relation to their conditional project returns in a steady state.

Recall next that to maximize the economy's investments, the (expected) pledgeable income should maximized at the cost of reducing the amount of bank capital that can be loaned to entrepreneurs. Therefore the optimal amount of bank involvement solves the following program:

$$\max_{c_t \geq 0} p_H q_t \left(R_t - R_t^b - R_t^e \right) - c_t$$

subject to equations (12), (13), (23), and $r_t^{d*} = 0$. The first-order condition for this problem may be written as

$$\frac{R_t^b}{R_t^e} + \frac{c_t}{p_H q_t R_t^e} = \frac{\gamma}{1-\gamma}.$$

Using $v = R^b/R^e$, $v^{**} \equiv \gamma/(1-\gamma)$ and equations (12) and (23), a steady state version of this condition may be written as

$$v + \frac{c^{\frac{1}{1-\gamma}} \Delta p}{\Gamma p_H} = v^{**}.$$

This suggests how the aggregate leverage is maximized when bankers' accumulation of capital also takes into account the real costs of monitoring in addition to their revenue share. In a steady state, however, the bankers' capital accumulation only reflects their revenue share. Therefore there is too little bank capital in a steady state.

4 Investment Shocks

Until now we have assumed that investment projects only involve idiosyncratic uncertainty: individual investment projects succeed with probability p_τ, $\tau \in \{H, L\}$. In this section we introduce an aggregate shock by assuming that in some period t project success probabilities are given by

$$\widetilde{p}_{\tau t} = p_\tau (1 + \eta_t), \ \tau \in \{H, L\}, \tag{35}$$

where $\eta_t \in (-1, 1/p_H - 1)$ is an investment shock. We assume that the investment shock is realized after financing contracts have been signed, monitoring and project choices made, and price of capital goods determined. We assume that the investment shock is unanticipated in the sense that neither pricing of capital goods nor financial contracts cannot be made contingent on the realization of the shock. In essence, we are assuming that the shock is not verifiable and that capital goods are sold via forward contracts where price of capital goods is agreed upon simultaneously with the (other) terms of the financing contract, before the delivery of capital goods occurs (see the timing of events in Section 2.6). This means that the price capital goods in period t, q_t, is unaffected by the shock of period t. As a result, financing contracting terms are unaffected by the shock, too.[9]

To model the effects of an aggregate shock, we need to make a distinction between *bankers* and *banks* explicit. In our model, each bank employs a large number of bankers. Each banker monitors a single investment project. If the project succeeds, the entrepreneur retains his share of the project returns (R_t^e). The rest of the returns ($R - R_t^e$) are credited to the common account of the bank. If the project fails, neither the entrepreneur nor the bank gets anything. After the returns from all successfull projects of the bank are collected, the bank compensates its bankers and refunds depositors according to the financing contract. A banker is paid only if the project which she monitored was successful.

If the economy encounters an investment shock, we assume that depositor claims are senior. Then successful bankers become residual claimants. In other words, we assume that depositors are first paid from the bank's common funds and successful bankers then share what is left at the bank. In case of a negative investment shock we for brevity assume that its size is small enough relative to the bank's capital so that the bank never defaults on deposit contracts, i.e., the bank's sequential service constraint never binds. As a result, both entrepreneurs and depositors always receive their promised share of the project returns whereas bankers may get less (in case of a negative investment shock) or more (in case of a positive investment shock) than stipulated by the initial financing contract.

Note that even though each successful entrepreneur gets his share according to the financing contract, the aggregate entrepreneurial capital is reduced

[9]Some of these assumptions can be relaxed: in Appendix B we introduce a more complex model of the investment shock where we allow for spot trading of capital goods.

(increased) in the aftermath of a negative (positive) investment shock, because a smaller (larger) fraction of the entrepreneurs are successful. The shock has the same, direct effect on the aggregate bank capital. However, there is also an indirect effect via banker's revenue share, which *amplifies* the effect of the shock on the aggregate bank capital. For example, in the aftermath of a negative investment shock, not only fewer bankers see their projects succeed but also each successful bankers get a smaller share of the revenues.

More formally, following an investment shock in period t, the aggregate entrepreneurial capital in period $t+1$ is given by

$$N_{t+1}(\eta_t) = \left[r_{t+1}^K + q_{t+1}(1-\delta)\right] \lambda^e I_t R_t^e p_H (1+\eta_t).$$

This directly follows from equations (33) and (35). Following the steps outlined in Section 2.5, we may rewrite this as

$$N_{t+1}(\eta_t) = N_t \lambda^e \left(\frac{r_{t+1}^K + (1-\delta) q_{t+1}}{q_t}\right) (1+r_t^e)(1+\eta_t).$$

Dividing $N_{t+1}(\eta_t)$ by N_{t+1} from equation (34) yields $1+\eta_t$, i.e., the shock affects the aggregate entrepreneurial capital only via its direct effect on the project success probability.

In contrast, the aggregate bank capital in period $t+1$ following an investment shock in period t is given by

$$A_{t+1}(\eta_t) = \left[r_{t+1}^K + q_{t+1}(1-\delta)\right] \lambda^b I_t p_H \left[(R - R_t^e)(1+\eta_t) - R_t^w\right],$$

where the latter square brackets on the right-hand side is the amount of project revenues received by each successful banker. Using conditions (13), (14) (recalling that $r_t^{d*} = 0$), (17), and (25) the evolution of the aggregate bank capital maybe re-expressed as

$$A_{t+1}(\eta_t) = A_t \lambda^b \left(\frac{r_{t+1}^K + (1-\delta) q_{t+1}}{q_t}\right) (1+r_t^a) \left[1 + \eta_t + \eta_t \frac{D_t}{(1+r_t^a) A_t}\right].$$

Now dividing $A_{t+1}(\eta_t)$ by A_{t+1} from equation (32) yields $1 + \eta_t[1 + D_t/((1+r_t^a)A_t)]$. That is, compared with the effect of the shock on the aggregate entrepreneurial capital, its effect on the aggregate bank capital is amplified by the factor $D_t/((1+r_t^a)A_t)$ That is the higher the aggregate debt-to-equity ratio in the banking sector, the higher the multiplier of the shock.

Although the shock has an asymmetric effect on the sharing of project revenues it does not affect the conditional project returns. Therefore its effect on the accumulation of physical capital is again directly related to its effect on project success probability. Equations (3) and (35) then imply that the aggregate physical capital in period $t+1$ following an investment shock in period t is given by

$$K_{t+1}(\eta_t) = (1-\delta)K_t + p_H R I_t (1+\eta_t).$$

5 Calibration

In calibrating the model, we follow the standard New-Keynesian calibration where ever possible. In addition to the standard technology shock, we have aggregate investment shock. Due to this reason, we calibrate the variance of the technology shock smaller than in the RBC literature to Match the variance of output. The calibration of the financial block boils down matching excess return to banks' and entrepreneurial firms' capital, their capital ratios and monitoring costs.

The household utility function is calibrated to imply relatively modest risk aversion ($\sigma = 2$). The labour supply is dampened by the choice of $\phi = 3$ and $\xi = 0.5$. The capital factor share is the usual $\alpha = 1/3$. We work with quarterly data, so that $\beta = 0.995$ and the annualized real interest rate is 2 %. The quarterly depreciation rate is $\delta = 0.025$ matching the (annual) investment to capital ratio of 0.07. To keep the model as close as possible to the basic 'text-book' New Keynesian framework, we adopt the normalization $p_H R = 1$. This results in the law of motion of the physical capital stock (3) as $K_{t+1} = (1-\delta)K_t + I_t$. The persistence of the technology shock is

$\rho = 0.979$ and its' standard deviation $\sigma_\varepsilon = 0.0072$.

The steady-state mark-up is calibrated to 10 percent ($\epsilon = 11$), commonly used in the business cycle literature. The Calvo parameter $\theta = 0.8$ implies average time between price changes is 5 quarters. Monetary policy follows the strict inflation targeting responding only ($\phi_\pi = 1.5$) to the inflation deviating from the target of zero percent.

We construct the steady-state such that there is a fixed subsidy to compensate the imperfect competition. Similarly, we assume investment subsidy to redress the moral hazard in investments. These results efficient steady-state that corresponds that of the standard real business cycle model. Investments' output share is 20 per cent, and that of the consumption is 80 per cent.

The key data moments in the financial block are the following:

- Albertazzi and Gambacorta (2009) estimate the return on equity to various countries and country blocks. The average return on equity[10] in 1999–2003 varies from 15 % in the UK and 14 % in the USA to 7 % in the euro area. Haldane and Alessandri (2009) estimate the post 1960's pretax return on equity in the UK to be around 20 % on average. *The* excess *rate of return on bank capital,* $\bar{r}^a$, is calibrated to be on the upper tail of these values since the bank capital in our theoretical model corresponds the "core", informed capital of banks.

- In calculating the measure of *the excess rate of return on entrepreneurial capital*, $\bar{r}^e$, we use the standard RBC measure 6.5 % for average return to capital in the economy and substract the riskless rate of 2 %.

- *Non-financial firms' capital ratio*, N/I, seems to be hard to pin down. Rajan and Zingales (1995), Graham and Leary (2011), Graham, Leary and Roberts (2014) and de Jong, Kabir and Ngyen (2008) report substantial temporal and cross-section/country variation. We choose the

[10]The return on equity is given by profit after tax as a percentage of capital and reserves.

magnitude 0.45 that is close to the post-1990 estimate for the US by Graham *et al* (2014).

- In computing the parameter values of the financial block, we correct *banks' capital ratio* by subtracting monitoring costs from the banks' assets. In our case the banks' capital is the informed capital, i.e. banks' own stake in the project. The closest empirical counterpart would be Tier 1 capital that contains banks' common stocks and retained earnings. We calibrate this measure to be 4 per cent.

- Philippon (2013) measures the unit cost of financial intermediation (finance income to intermediated assets ratio) in the U.S. When adjusted for changes in households' and firms' characteristics, the unit cost measurement is relatively stable in the range $1.5-2$ percent during the post-WWII period. This figure is also consistent with the range of $1-4$ estimated by Albertazzi and Gambacorta (2009). The unit cost measure, however, involves activities in addition to monitoring. The closest approximation to monitoring costs is provided by Altinkilic and Hansen (2000) who report firms' bond underwriter spreads in the range of $0.61-1.24$. Since underwriting contains a liquidity premium in addition to monitoring, we calibrate the *monitoring costs to asset ratio* to 0.8 percent (per annum).

The resulted parameter values[11] rule out the corner solution and impose the market discipline. They are reported in the lower panel of table 1.

6 Impulse responses

Figures $1-2$ show the impulse responses of a number of key macro variables and financial variables to a technology and an investment shocks. As a benchmark, we also show the impulse responses of the macro variables in the corresponding standard New Keynesian model, with capital but without financial frictions or financial intermediation.

[11]See appendix C for calculating parameter values based on the moments above.

Table 1: Calibrated parameter values

Parameter	value	note
		Parameters of the New-Keynesian block
β	0.9951	discount factor
α	0.33	capital share
δ	0.025	rate of decay of capital
ξ	2	parameter of the disutility of labor
ϕ	0.5	$1/\phi$ Frish elasticity of labor supply
ρ	0.9	persistence of technology shock
σ_ε	0.0072	standard deviation of the technology shock innovation
σ	2	$1/\sigma$ elasticity of intertemporal substitution
θ	0.8	Calvo parameter
ϵ	11	10 % mark-up
ϕ_π	1.5	Taylor rule
		Parameters of the financial block
λ^e	0.9842	survival rate of entrepreneurs
λ^b	0.9507	survival rate of bankers
γ	0.2992	$\gamma/(1-\gamma)$ elasticity of monitoring function
Γ	0.0089	parameter of monitoring function
p_H	0.95	success probability of a good inv. project
$\frac{\Delta p}{p_H}$	0.0478	$\Delta p \equiv p_H - p_L = 0.0454$

Impulse responses in Figure 1 indicate that the financial frictions introduced in this paper tend to dampen the effects on consumption, wages, hours and inflation, while to augment the effect on investments. This results from the gradual dynamics of bank capital and entrepreneurial wealth in the model with financial frictions.

The main finding that emerges from the impulse responses is that financial frictions greatly amplify the effects of investment shocks (Figure 2). The mechanism behind this amplification is twofold.

First, as explained in Section 4, investment shocks have a very strong effect on bank capital: Banks tend to be highly leveraged, with most of their funding consisting of deposits. Even if the investment projects are (as a whole) less successful than expected (there is a negative investment shock), the banks still have to pay the depositors the full a face value of the deposits. Then bank capital serves as a shock buffer and absorbs most of the losses. Likewise, a positive investment shock has a levered effect on bank capital.

By contrast, aggregate entrepreneurial wealth is much less affected by investment shocks. Basically, the investment shock only hits those entrepreneurs whose projects fail, and limited liability is a back-stop to the size of losses. The response of the entrepreneurial wealth is positive in the medium run, since due to less monitoring they need to have an higher stake in the project. The make them behave, they also must given larger share of the cake as is portrayed by the response of R_t^e.

Second, as explained in Section 3, in equilibrium bank capital tends to be scarce, relative to entrepreneurial wealth. Then a change in bank capital has a very pronounced effect on aggregate investment. This strong effect on investment then also translates into a sizeable effect on real output, employment and other key macro variables. By contrast, an equal (proportional) change in entrepreneurial wealth has a smaller effect on the macro variables.

7 Equity injections

In this section we analyze capital injections from the government to the banks. The analysis of capital injections is motivated by two observations,

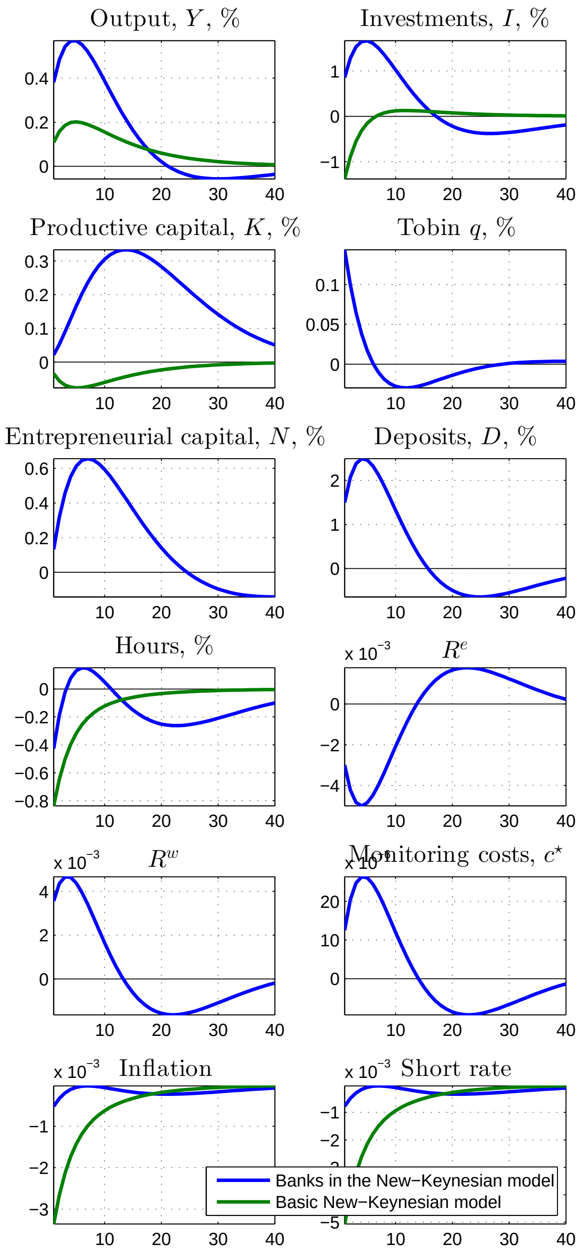

Figure 1: Impulse responses to a positive technology shock (1 %)

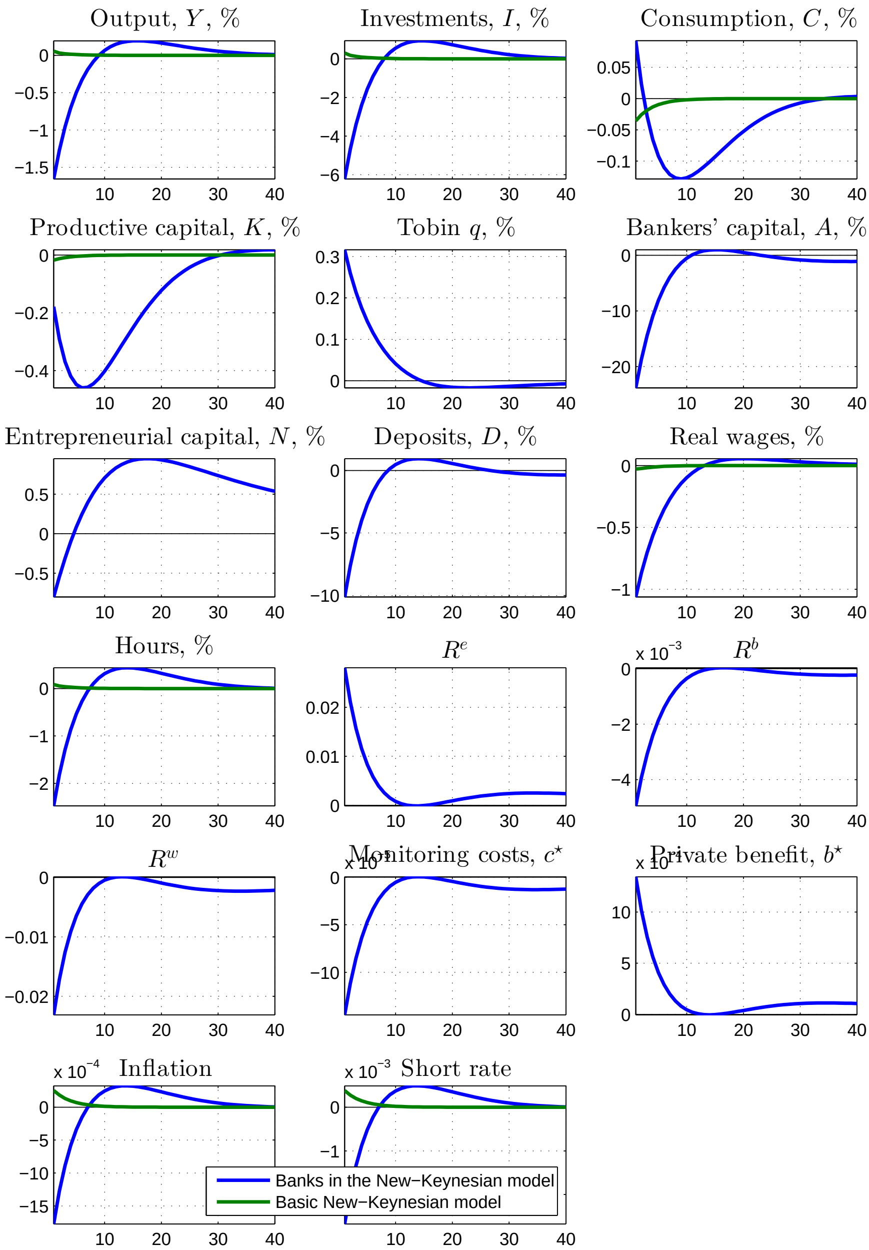

Figure 2: Impulse responses to a negative investment shock (-0.01)

mentioned in earlier in this paper. First, in equilibrium bank capital is scarce, compared to entrepreneurial capital, and changes in bank capital have significant effects on investments. Second, bank capital is vulnerable to investment shocks.

Capital injections may have at least two different objective. One objective is be to provide banks a cushion against future negative (investment) shocks. Another possible objective is to avert deleveraging by banks, and to boost aggregate investments. In our framework, capital injections achieve the first objective (to provide a cushion against shocks). However the second objective (to boost investments) may not be attained.

7.1 Capital injections and deleveraging

In fact, if policy makers have the second objective in mind, recapitalizing banks may prove to be counter-productive: capital injections may actually accelerate deleveraging and lower aggregate investments. The key assumptions and intuition behind this perhaps somewhat surprising, and provocative, result are as follows. Essentially, capital injections from the government have the wrong effects on the bankers' incentives to monitor: bankers' do not care about what happens to government-owned capital. To put it somewhat differently, bank involvement, i.e. monitoring by bankers, becomes more costly to the entrepreneurs. The entrepreneurs have to give the banker a certain share of proceeds to provide monitoring incentives. But on top of that, also the government-owned capital has to be paid.

Yet another way to express the key intuition is to note that from the point of view of the 'insiders' (bankers and entrepreneurs) government-owned capital is essentially comparable to 'outsider capital', i.e. deposits. Moreover, government-owned capital is typically expensive, compared to capital from households. One plausible assumption is that the government requires the same rate of return $1 + r_t^a$ as bankers. In equilibrium this is higher than the deposit rate.

Then government-owned capital crowds out (more than one-to-one) resources from outsiders (households). Thus in equilibrium there will be less monitoring, and the investment projects will be smaller. The end result is that the aggregate scale of investments falls.

On top of the essentially static effects outlined above, capital injections have dynamic effects as well. While government-owned capital makes bank involvement costlier and less attractive to entrepreneurs (who have to pay both banker-owned and government owned bank capital), the rate of return to banker-owned capital falls. Then a capital injection actually slows down the recovery of banker-owned capital after, say, a negative investment shock. This then further lowers aggregate investments in subsequent periods.

The counter-productive effects of capital injections are illustrated in Figure 3, which shows the impulse responses of the key variables after a negative investment shock. The size of the shock is one percentage point in the success probabilities. In the exercise, capital injection takes place after the negative investment shock has realized. The blue line is the impulse response without capital injections, while the green line is the impulse response with capital injections.

The counter-productivity result rests on two assumptions: (i) Bankers do not care about government-owned capital; to bankers government-owned capital is essentially like outside funding. (ii) Government-owned capital is more expensive than funding received from outsiders (households). There are several ways to get around these assumptions. Then capital injections can *increase* aggregate investments.

First the government can provide capital to banks under favorable terms. Above we assumed that the rate of return to government-owned capital is the same as the rate of return to banker-owned capital, $1 + r_t^a$. However, the government can content with a more modest rate of return. Indeed, if the rate of return to government-owned capital is lower than the deposit rate $1 + r_t^d$ (assumed to be one in our model), government owned-capital is actually less expensive than the funds provided by outside investors. This cheap source of funding increases the size of the investment projects, and boosts aggregate investments.

Alternative, the government could also donate the capital to the bankers rather than take an ownership share in the banks. In that case, the capital

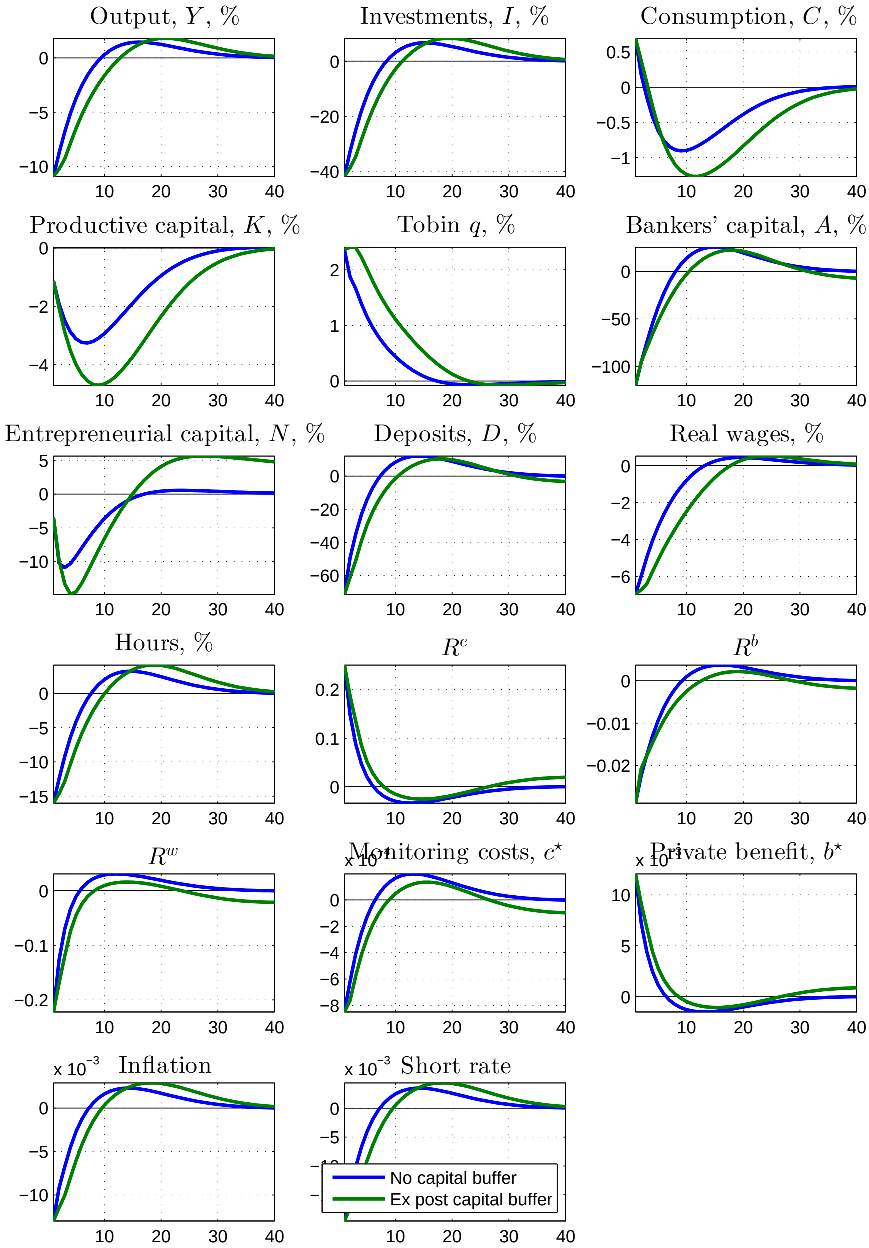

Figure 3: Impulse responses to a negative investment shock (−0.05); Ex post capital injection (50 %)

that is injected to banks provides the bankers the right incentives to monitor, and aggregate investments are boosted. Obviously, this kind of arrangement would be subject to serious moral hazard problems.

Finally, when deriving the counter-productivity result, we assumed that government-owned capital is essentially like outside funding for the bankers' point of view. However, there could be incentives in place (not modelled here) so that the bankers would also care about government-owned capital. If this were the case, capital injections would again boost aggregate investments.

7.2 Capital injections as a shock cushion

As mentioned above, in our framework, capital injections do provide a shock cushion. If there is a negative investment shock, government-owned capital takes a part of the hit, and banker-owned capital is less badly affected. The effect of an investment shock to banker-owned bank capital is proportional to bank leverage

$$LEVB_t = \frac{D_t}{A_t + A_t^g}$$

where A_t^g is government-owned bank capital.

Actually, government-owned capital lowers leverage, and protects the bank in two ways. First, total capital $A_t^{tot} = A_t + A_t^g$ goes up. Second, deposits D_t go down. As discussed above, government-owned capital crowds out funds from outsiders (households) in the financing of investment projects.

The role of government-owned bank capital is illustrated in Figure 4, which shows the recovery of the economy from a negative investment shock with (green line) and without (blue line) capital injections. In the exercise, the government-owned bank capital is already in place, when the negative investment shock hits.

The government-owned bank capital dampens the effect of a negative investment shock on impact. However, also in this setting capital injection slows down the recovery of the economy in the later periods due to the channels discussed above.

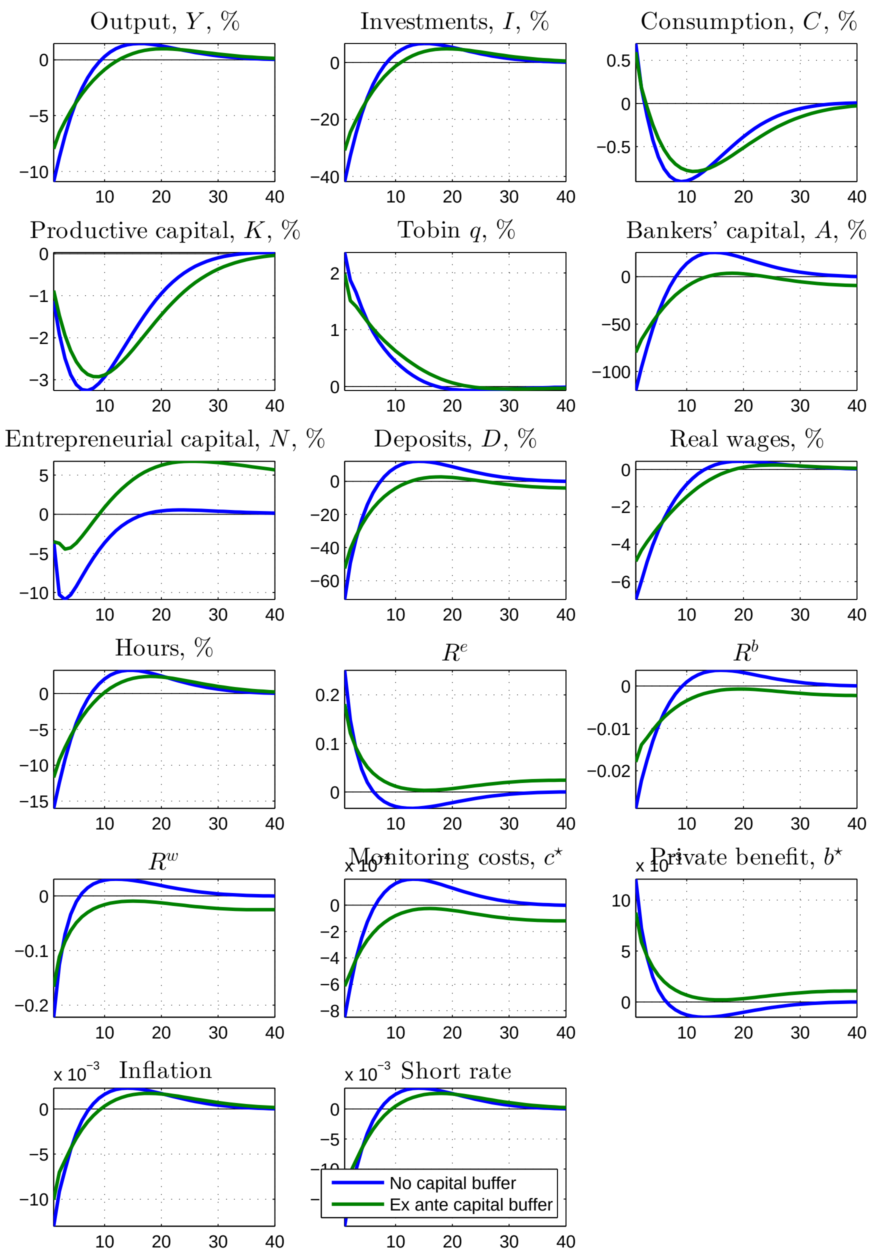

Figure 4: Impulse responses to a negative investment shock (−0.05). Ex ante capital injection (50 %).

8 Concluding remarks

In this paper we developed a macro-finance model, where both banks' and firms' balance sheets matter. We showed that in equilibrium, bank capital tends to be scarce, compared to firm capital. Then, a given change in bank capital has a larger impact on aggregate investments than a corresponding change in firm capital. Also, due to bank leverage, bank capital is vulnerable to (negative) investment shocks. For these reasons, bank capital may play a more crucial role in macro-financial linkages, and macro dynamics, than firm capital.

We also studied capital injections from the government to banks. We showed that capital injections can be useful as a shock cushion, but they may be counter-productive if the aim is to avoid deleveraging and to boost investments.

The model can be extended in various directions: we are working with an extension that aims in analysing the investment shocks in "normal" and turbulent times separately by modifying the model to incorporate risk-averse bankers. Equity injections could be more productive in turbulent times. The model may also be extended to allow for government-owned banks.

References

Aikman, David and Paustian, Matthias (2006): Bank Capital, Asset Prices, and Monetary Policy, Bank of England Working Paper no. 305.

Albertazzi, Ugo and Leonardo Gambacorta (2009): Bank profitability and the business cycle, *Journal of Financial Stability*, 5, 393–409.

Alessandri, Piergiorgio and Andrew G Haldane (2009): *Banking on the State*, unpublished note, Bank of England.

Altinkilic, Oya and Robert S. Hansen (2000): Are there Economies of Scale in Underwriting Fees? Evidence of Rising External Financing Costs, *The Review of Financial Studies*, Vol. 13, No. 1, pp- 191–218.

Bernanke, Ben, Gertler, Mark and Gilchrist, Simon (1999): The financial accelerator in a quantitative business cycle framework, in Taylor, J. and Woodfords M. (eds.), *Handbook of Macroeconomics*, Elsevier Science, Amsterdam.

Calvo, Guillermo (1983): Staggered Prices in a Utility-Maximizing Framework, *Journal of Monetary Economics*, 12, 383-398.

Carlstrom, Charles T. and Fuerst, Timothy S. (1997): Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis, *American Economic Review*, 87, 893-910.

Castrén, Olli and Takalo, Tuomas (2000): Captial Market Development, Corporate Governance, and the Credibility of Currency Pegs, European Central Bank Working Paper no. 34.

Chen, Nan-Kuang (2001): Bank Net Worth, Asset Prices, and Economic Activity, *Journal of Monetary Economics*, 48, 415-436.

Christensen, Ian, Meh, Cesaire A. and Moran, Kevin (2011): Bank Leverage Regulation and Macroeconomic Dynamics, Unpublished manuscript, Bank of Canada & Université Laval.

de Jong, Abe, Rezaul Kabir, Thuy Thu Nguyen (2008): Capital structure around the world: The roles of firm- and country-specific determinants, *Journal of Banking & Finance*, Vol. 32, Issue 9, 1954–1969

European Commission (2014): State Aid Scoreboard 2013, Aid in the context of the financial and economic crisis. `http://ec.europa.eu/competition/`

state_aid/scoreboard/financial_economic_crisis_aid_en.html, March 2014.

Faia, Ester (2010): Credit Risk Transfers and the Macroeconomy, Unpublished manuscript, Goethe University.

Galí, Jordi, Mark Gerler and David Lopez-Salido (2001): European Inflation Dynamics, *European Economic Review*, 45, 1237–1270.

Gertler, Mark and Karadi, Peter (2010): A Model of Unconventional Monetary Policy, *Journal of Monetary Economics*, 58, 17-34.

Gertler, Mark and Kiyotaki, Nobuhiro (2011): Financial Intermediation and Credit Policy in Business Cycle Analysis, *Handbook of Monetary Economics*

Graham, John R. and Leary , Mark T. (2011): A Review of Empirical Capital Structure Research and Directions for the Future, *Annual Review of Financial Economics*, Vol. 3.

Graham, John R., Leary , Mark T. and Roberts, Michael R. (2014): A Century of Capital Structure: The Leveraging of Corporate America, forthcoming in *Journal of Financial Economics*

Haldane, Andrew and Piergiorgio Alessandri (2009), *Banking on the State*, presentation delivered at the Federal Reserve Bank of Chicago twelfth annual International Banking Conference on "The International Financial Crisis: Have the Rules of Finance Changed?", Chicago, 25 September 2009.

Holmström, Bengt and Tirole, Jean (1997): Financial Intermediation, Loanable Funds, and the Real Sector, *Quartely Journal of Economics* 112, 663-691.

Kiyotaki,Nobuhiro and Moore,John (1997): Credit cycles, *Journal of Political Economy* 105,211–248.

Laeven, Luc and Fabian Valencia (2012): *Systemic Banking Crises Database: An Update*, IMF Working Paper, WP/12/163.

Meh, Cesaire A. and Moran, Kevin (2010): The Role of Bank Capital in the Propagation of Shocks, *Journal of Economic Dynamics & Control*, 34, 555-576

Philippon, Thomas (2013): *Has the U.S. Finance Industry Become Less Efficient? On the Theory and Measurement of Financial Intermediation*, Working Paper, December 2013. http://pages.stern.nyu.edu/~tphilipp/

`papers/Finance_Efficiency.pdf`
Rajan, Raghuram G and Luigi Zingales (1995): What Do We Know about Capital Structure? Some Evidence from International Data, *The Journal of Finance*, Vol. L, No. 5.

Sbordone, Argia (2002): Prices and Unit Labour Costs; Testing Models of Pricing Behaviour, *Journal of Monetary Economics*, 45, 265–292.

A Appendix

A.1 Proof of Proposition 1

Proof. Substitution of the incentive constraints (12) and (13), together with equation (23) and $r^{d*} = 0$ for equations (31) and (33) gives

$$A_{t+1} = \frac{\left[r^K_{t+1} + q_{t+1}(1-\delta)\right]}{q_t \Delta p} p_H \lambda^b c_t I_t$$

and

$$N_{t+1} = \frac{\left[r^K_{t+1} + q_{t+1}(1-\delta)\right]}{q_t \Delta p} p_H \lambda^e \Gamma c_t^{-\frac{\gamma}{1-\gamma}} I_t.$$

Thus, in a steady state we must have

$$A = \left(\frac{r^K}{q} + 1 - \delta\right) \frac{p_H}{\Delta p} \lambda^b c I \tag{36}$$

and

$$N = \left(\frac{r^K}{q} + 1 - \delta\right) \frac{p_H}{\Delta p} \lambda^e \Gamma c^{-\frac{\gamma}{1-\gamma}} I. \tag{37}$$

Here and in what follows we denote a steady state of some time-depenent variable X_t by X, i.e., $\lim_{t \longrightarrow \infty} X_t = X$. Dividing equation (36) by equation (37) implies that

$$v \equiv \frac{A}{N} = \frac{\lambda^b}{\lambda^e} \frac{c^{\frac{1}{1-\gamma}}}{\Gamma}. \tag{38}$$

Next, substitution of equation (27) for equation (24) yields after some algebra the steady state value of c as

$$c = \frac{\gamma \rho + \frac{A}{I}}{1 + \frac{p_H}{\Delta p}}. \tag{39}$$

Equation (30) can be rewritten at a steady state as

$$\frac{\gamma \rho + \frac{A}{I}}{1 + \frac{p_H}{\Delta p}} = \left[\frac{\frac{p_H}{\Delta p}\Gamma}{(1-\gamma)\rho + \frac{N}{I}}\right]^{\frac{1-\gamma}{\gamma}}. \tag{40}$$

Combining equations (39) and (40) and solving for ρ yields

$$\rho = \frac{1}{1-\gamma}\left(\frac{p_H}{\Delta p}\Gamma c^{-\frac{\gamma}{1-\gamma}} - \frac{N}{I}\right). \tag{41}$$

Inserting equation (41) into (39) gives

$$c\left(1+\frac{p_H}{\Delta p}\right) = \frac{\gamma p_H \Gamma}{(1-\gamma)\,\Delta p}c^{-\frac{\gamma}{1-\gamma}} + \frac{A}{I} - \frac{\gamma N}{(1-\gamma)\,I}.$$

After substituting equations (36) and (37) for the above formula we obtain

$$1+\frac{\Delta p}{p_H} = \Gamma c^{-\frac{1}{1-\gamma}}\left[\frac{\gamma}{1-\gamma} + \lambda^e\left(\frac{r^K}{q}+1-\delta\right)\left(\frac{\lambda^b}{\lambda^e}\frac{c^{1+\frac{\gamma}{1-\gamma}}}{\Gamma} - \frac{\gamma}{1-\gamma}\right)\right].$$

By using the definition v from equation (38) , this may be rewritten as

$$v\frac{\lambda^e}{\lambda^b}\left(1+\frac{\Delta p}{p_H}\right) = \frac{\gamma}{1-\gamma} + \lambda^e\left(\frac{r^K}{q}+1-\delta\right)\left(v - \frac{\gamma}{1-\gamma}\right).$$

Solving for v from the above equation gives

$$v = \left(\frac{\gamma}{1-\gamma}\right)\left[\frac{\frac{1}{\lambda^e} - \frac{r^K}{q} - 1 + \delta}{\frac{1}{\lambda^b}\left(1+\frac{\Delta p}{p_H}\right) - \frac{r^K}{q} - 1 + \delta}\right]. \tag{42}$$

Finally, note from the household's Euler equation (6) that in steady state we must have

$$\beta = \frac{q}{r^K + (1-\delta)\,q}. \tag{43}$$

Using equation (43), equation (42) can be rewritten as

$$v = \left(\frac{\gamma}{1-\gamma}\right)\left[\frac{\frac{\beta}{\lambda^e} - 1}{\frac{\beta}{\lambda^b}\left(1+\frac{\Delta p}{p_H}\right) - 1}\right].$$

It is evident that $v > 0$ if condition

$$\beta > \max\left\{\lambda^e, \lambda^b\right\}. \tag{44}$$

holds. Clearly, if $\lambda^b > \lambda^e$, condition (44) is a sufficient condition. Furthermore if condition (44) holds, equation (32) implies that in a steady state we must have $r^{a*} > 0$, i.e., condition (28) is satisfied. ■

A.2 Proof of Proposition 2

Proof. We seek the value of v_t that maximizes the aggeregate leverage $1/G_t = I_t/(A_t+N_t)$ and by implication, aggregate investments and output for a given level of aggregate informed capital A_t+N_t. By using $A_t/I_t = v_t G_t/(1+v_t)$ and $N_t/I_t = G_t/(1+v_t)$ (and recalling that $r_t^{d*} = 0$) we can rewrite equation (30) - which determines the equilibrium aggregate investment level I_t^* - as

$$\left(\frac{v_t G_t^*}{1+v_t} + \gamma\rho_t\right)^{\gamma} \left[\frac{G_t^*}{1+v_t} + (1-\gamma)\,\rho_t\right]^{1-\gamma} = \left(\frac{\Gamma p_H}{\Delta p}\right)^{1-\gamma} \left(1 + \frac{p_H}{\Delta p}\right).$$

Differentiating this equation with respect to G_t^* and v_t gives

$$\left.\frac{dG_t^*}{dv_t}\right|_{I_t^*} = \frac{G_t^*\left\{1-\gamma - \left(\frac{v_t G_t^*}{1+v_t} + \gamma\rho_t\right)^{-1}\left[\frac{G_t^*}{1+v_t} + (1-\gamma)\,\rho_t\right]\gamma\right\}}{(1+\nu_t)\left\{\left(\frac{v_t G_t^*}{1+v_t} + \gamma\rho_t\right)^{-1}\left[\frac{G_t^*}{1+v_t} + (1-\gamma)\,\rho_t\right]\gamma\nu_t + 1 - \gamma\right\}}. \quad (45)$$

The aggregate leverage is maximized when G_t^* is minimized. A potential minimum is obtained the term in the curly brackets in the numerator in the right-hand side of equation (45) is zero, i.e., when

$$\frac{\frac{\nu_t}{1+\nu_t} G_t^* + \gamma\rho_t}{\frac{G_t^*}{1+\nu_t} + (1-\gamma)\,\rho_{tt}} = \frac{\gamma}{1-\gamma}.$$

This simplifies to

$$v_t = \frac{\gamma}{1-\gamma} \equiv v^{**}.$$

It is easy to see from equation (45) that $dG_t^*/d\nu_t|_{I_t^*} < 0$ for $v_t < v^{**}$ and $dG_t^*/d\nu_t|_{I_t^*} > 0$ for $v_t > v^{**}$. Therefore, v^{**} indeed characterizes the value of v_t that minimizes G_t^* and thereby maximizes the aggregate leverage and output. ∎

A.3 Calculation of Marginal Rate of Technical Substitution

Differentiating (30) with respect to A_t and N_t gives

$$\left.\frac{dN_t}{dA_t}\right|_{I_t^*} = -\frac{\gamma}{(1-\gamma)}\left[\frac{\frac{N_t}{I_t^*} + (1-\gamma)\,\rho_t}{\frac{A_t}{I_t^*} + \gamma\rho_t}\right].$$

Evaluating this at a steady state and using equations (41) and (39) in the numerator and the denominator of the term in the square brackets, respectively, give after some algebra

$$\left.\frac{dN}{dA}\right|_{I^*} = -\frac{\gamma\Gamma c^{-\frac{1}{1-\gamma}}}{(1-\gamma)\left(1+\frac{\Delta p}{p_H}\right)}.$$

Using equation (38) to substitute $\lambda^b/(\lambda^e v)$ for $\Gamma c^{-\frac{1}{1-\gamma}}$ yields

$$\left.\frac{dN}{dA}\right|_{I^*} = -\frac{\gamma\lambda^b}{(1-\gamma)\left(1+\frac{\Delta p}{p_H}\right)\lambda^e v}.$$

After using Proposition 1 to eliminate $[\gamma/(1-\gamma)\,v]$ we get

$$\left.\frac{dN}{dA}\right|_{I^*} = -\frac{\lambda^b}{\left(1+\frac{\Delta p}{p_H}\right)\lambda^e}\left[\frac{\frac{\beta}{\lambda^b}\left(1+\frac{\Delta p}{p_H}\right)-1}{\frac{\beta}{\lambda^e}-1}\right].$$

This simplifies to

$$\left.\frac{dN}{dA}\right|_{I^*} = -\frac{1+\frac{\Delta p}{p_H}-\frac{\lambda^b}{\beta}}{\left(1+\frac{\Delta p}{p_H}\right)\left(1-\frac{\lambda^e}{\beta}\right)}.$$

A.4 Ruling out the corner solution

In this appendix we study the conditions under which the corner solution $(c_t = 0,\ b(c_t) = b_0)$ can be ruled out. Assume that a firm chooses to be monitored ($c_t = 0$). Then its (maximum) leverage is $i_t/n_t = \frac{1}{g\left(r_t^a, r_t^d, q_t; c_t=0, b_t=b_0\right)}$, and by (21)

$$g\left(r_t^a, r_t^d, q_t; c_t = 0, b_t = b_0\right) = \frac{p_H}{\Delta p} b_0 - \chi_t$$

Then the expected rate of return to entrepreneurial capital is

$$\widehat{r}_t^e = \frac{\frac{p_H}{\Delta p} b_0}{g\left(r_t^a, r_t^d, q_t; 0, b_0\right)} = \frac{\chi_t}{\frac{p_H}{\Delta p} b_0 - \chi_t}$$

To rule out the corner solution, we must have

$$\widehat{r}_t^e < r_t^e \tag{46}$$

where r_t^e is the expected rate of return to entrepreneurial capital, if the entrepreneur chooses the interior solution $c_t = c_t^*$. In particular, the condition (46) should apply in the steady state, so that we get the condition

$$b_0 \geq \frac{\Delta p}{p_H} \frac{1 + \overline{r}^e}{\overline{r}^e} \overline{\chi}$$

One can show that in steady state the rate of return corresponding to the interior solution $\overline{r}^e = \frac{\beta}{\lambda^e} - 1$, while the net present value of the investment project

$$\overline{\chi} = \frac{p_H}{\Delta p} \frac{\Gamma^{1-\gamma}}{1-\gamma} \left(1 - \frac{\lambda^e}{\beta}\right) \widehat{\nu}^{-\gamma}$$

where

$$\widehat{\nu} \equiv \frac{\lambda^e}{\lambda^b} \frac{\overline{A}}{\overline{N}} = \frac{\gamma}{1-\gamma} \frac{1 - \frac{\lambda^e}{\beta}}{1 - \frac{\lambda^b}{\beta} + \frac{\Delta p}{p_H}}$$

so that the condition takes the form

$$b_0 \geq \frac{\Gamma^{1-\gamma}}{1-\gamma} \widehat{\nu}^{-\gamma} \tag{47}$$

On the other hand, we must also guarantee that it is optimal to choose the "good" project and the level of monitoring c_t^*, rather than the "bad" project, maximum level of private payoffs b_0 and no monitoring. For this condition to hold in the steady state, we must have

$$\begin{aligned} p_H R - \overline{c}^* &\geq p_L R + b_0 \Leftrightarrow \\ b_0 &\leq \frac{\Delta p}{p_H} p_H R - \overline{c}^* \end{aligned} \tag{48}$$

One can show that in the steady state

$$\overline{c}^* = (\Gamma \widehat{\nu})^{1-\gamma}$$

Now, to rule out a corner solution, we must find a value of b_0 that satisfies both (47) and (48). Such a value b_0 exists if and only if

$$\begin{aligned} \frac{\Gamma^{1-\gamma}}{1-\gamma} \widehat{\nu}^{-\gamma} &< \frac{\Delta p}{p_H} p_H R - (\Gamma \widehat{\nu})^{1-\gamma} \Leftrightarrow \\ (\Gamma \widehat{\nu})^{1-\gamma} \left(\frac{1}{1-\gamma} + \frac{1}{\widehat{\nu}} \right) &< \frac{\Delta p}{p_H} p_H R \end{aligned} \tag{49}$$

With our calibration, the condition (49) is satisfied.

B Modelling an Investment Shock

In Section 4 we introduce an aggregate investment shock by assuming that price and delivery of capital goods are fixed before the project maturity (forward contracting of capital goods) and that the rate of interest of deposits is also fixed from the outset (fixed deposit contracts). Here we introduce an alternative way to model an investment shock that relaxes these assumptions.

B.1 Timing of events

The timing of events in the investment stage is the following:

1. Contracts are designed and signed
2. The banks decide how much to monitor, the entrepreneurs choose the project (in equilibrium they always choose the good project)

3. The projects are carried out
4. The projects are completed, and the capital goods are sold (to capital rental firms) at price q_t
5. The proceeds are divided between the entrepreneur, the bank and the outside investors (depositors)
6. **Investment shock:** The quality of some of the capital goods is not appropriate. The capital rental firms (that have bought the defective capital goods) are reimbursed by the entrepreneurs and the bankers (but not by the depositors/outside investors) .

B.2 More detailed structure of stages 4-6

4) The projects are completed, and trade in the capital markets takes place. The market price q_t is determined.

- At this point it is commonly known that the fraction $\widehat{p}_H$ ($< p_H$) of the projects have succeeded (the capital goods are of the appropriate quality).
- On the other hand, there is also a (small) fraction $\overline{p}_H$ of projects, whose success is uncertain at this point. We assume that on an average, or as an expectation value, one half of these projects succeed. Then the expected success rate of projects is

$$\widehat{p}_H + \frac{1}{2}\overline{p}_H = p_H$$

- Since trading in capital markets takes place in step 4) the price of capital q_t can only depend on the expected value p_H.
- The capital rental firms pay for the fraction $\widehat{p}_H$ of capital goods (which are known to be of good quality).
- Payments for the remaining projects (fraction $\overline{p}_H$) will take place later on, in stage 6.

5) The proceeds are divided between the entrepreneur(s), the banker(s) and the outside investors (depositors)

- The entrepreneurs get $\widehat{p}_H * R_t^e$, where R_t^e is the entrepreneur's share of proceeds, as stipulated by the contract
- The banks collect the remaining share $\widehat{p}_H * R^B$, where $R^B = R - R^e$.
- Notice: The way the bank's share R^B is divided between the bankers ($\widetilde{R}_t^b$) and the depositors/households/outside investors ($\widetilde{R}_t^h$) depends on the realization of the investment shock (thus the tilde)
- The banks pay the depositors $(1 + r_t^d) * D_t$, where r_t^d is the interest rate on deposits (following Calstrom and Fuerst 1997, we assume for simplicity that $r_t^d = 0$), and D_t is aggregate deposits
- Notice: All deposits D_t (+ plus possible interests $r_t^d D_t$) are paid at this point.
  - Important: the payments to the depositors / outside investors do not depend on the realization of the investment shock (in stage 6)
  - Motivation: The payments to depositors can only depend on commonly observed (macro) variables. The price of capital q_t (determined in stage 4) does not depend on the realization of the investment shock.
  - Since the fraction of project that are known to have succeeded ($\widehat{p}_H$) is large, while the fraction of projects that are still pending ($\overline{p}_H$) is small, the banks can always pay the depositors with the income stream $\widehat{p}_H R^B q_t I_t$ they receive in stage 4.

6) It becomes known what share of the remaining (pending) projects has succeeded. The capital goods (of appropriate quality) are delivered to the capital rental firms, as agreed in stage 4, at price q_t per unit of capital. (The capital goods of inappropriate quality are not delivered and there are no payments for these goods.)

- The entrepreneurs get their share R_t^e of the proceeds.

- The banks collect the remaining share $R_t^B = R - R^e$. Since the depositors have already been paid the full amount, in stage 5, the bankers can keep all this money.

B.3 Investment shocks: summary

- In sum, the overall success rate of projects in period t, $\widetilde{p}_{Ht}$, can be expressed as follows

$$\widetilde{p}_{Ht} = p_H(1 + \varepsilon_t^I)$$

  where ε_t^I is an investment shock.

- To keep the analysis simple, we also make assumptions guaranteeing that the ratio

$$\frac{\Delta\widetilde{p}}{\widetilde{p}_H} = \frac{\Delta p}{p_H} = \text{constant}$$

- This then means that

$$\Delta\widetilde{p} = \widetilde{p}_H \frac{\Delta p}{p_H}$$

  and

$$\widetilde{p}_L = \widetilde{p}_H - \Delta\widetilde{p} = \widetilde{p}_H \frac{p_L}{p_H} = p_L(1 + \varepsilon_t^I)$$

C Calibration of the Financial Block

The calibration of the parameters of the financial block of the model is based on the following observables:

- *Excess* rate of return to bank capital $\overline{r}^a$

- *Excess* rate of return to entrepreneurial capital $\overline{r}^e$

  In each period, bankers earn the gross rate of return $(1 + \overline{r})(1 + \overline{r}^a)$ and entrepreneurs earn the rate of return $(1 + \overline{r})\left(1 + \overline{r}^b\right)$, where $\overline{r}$ is the real interest rate earned by workers.

- Non-financial firms' capital ratio

$$\overline{CRF} = \frac{\overline{N}}{\overline{I}}$$

- Banks' capital ratio

$$\overline{CRB} = \frac{\overline{A}}{\overline{A} + \overline{D} - \overline{c}^* \overline{I}} = \frac{\overline{A}}{\overline{I} - \overline{N}}$$

  Note that $\overline{A} + \overline{D} - \overline{c}^* \overline{I}$ is the amount of funds that the banks have allocated to the investment projects; here we have substracted the monitoring costs of the banks $\overline{c}^* \overline{I}$ from the amount of total funds $\overline{A} + \overline{D}$. Initially I tried the alternative definition $\overline{CRB}_{alt} = \frac{\overline{A}}{\overline{A}+\overline{D}}$. However using this definition, I did not manage to get fully solved analytical formulations for all the paremeters. Anyway, since $\overline{c}^* \overline{I}$ is pretty small, $\overline{CRB}$ and $\overline{CRB}_{alt}$ do not probably differ that much from each other.

  Notice also the difference between the balance sheets of non-financial firms and banks. Non-financial firms have funds from bankers and outsiders (i.e. depositors), plus entrepreneurs' own capital, in their balance sheets. The grand total is $\overline{I}$. Banks have funds from bankers and outsiders (depositors), and the aggregate amount of funds is $\overline{I} - \overline{N}$.

- Banks' monitoring costs, as a ratio of banks' assets

$$\overline{CORB} = \frac{\overline{c}^* \overline{I}}{\overline{I} - \overline{N}}$$

The financial parameters to be calibrated are

1. The exit rate of bankers λ^b

$$\lambda^b = \frac{\beta}{1 + \overline{r}^a} = \frac{1}{(1 + \overline{r}^a)(1 + \overline{r})}$$

2. The exit rate of entrepreneurs λ^e

$$\lambda^e = \frac{\beta}{1+\overline{r}^e} = \frac{1}{(1+\overline{r}^e)(1+\overline{r})}$$

3. The (relative) difference in the success probabilities of good and bad projects $\frac{\Delta p}{p_H}$ (only this ratio, rather than the probabilities p_H and p_L as such, is relevant here),

$$\frac{\Delta p}{p_H} = \frac{\overline{CORB}}{\overline{CRB}\,(1+\overline{r}^a)}$$

4. The elasticity of the monitoring function $\frac{\gamma}{1-\gamma}$,

$$\frac{\gamma}{1-\gamma} = \left(\frac{\overline{r}^a\overline{CRB}+\overline{CORB}}{\overline{r}^e\overline{CRF}}\right)\left(1-\overline{CRF}\right) \Longleftrightarrow$$
$$\gamma = \frac{\overline{r}^a\overline{CRB}+\overline{CORB}}{\overline{r}^e\frac{\overline{CRF}}{1-\overline{CRF}}+\overline{r}^a\overline{CRB}+\overline{CORB}}$$

Notice that $\frac{\overline{CRF}}{1-\overline{CRF}} = \frac{\overline{N}}{\overline{I}-\overline{N}}$ is the ratio of entrepreneurial captial to non-entrepreneurial capital in non-financial firms' balance sheets. Then γ can be re-expressed in yet another way

$$\gamma = \frac{\overline{r}^a\overline{A}+\overline{c}^*\overline{I}}{\overline{r}^e\overline{N}+\overline{r}^a\overline{A}+\overline{c}^*\overline{I}}$$
$$= \frac{\text{banks' profits} + \text{banks' monitoring costs}}{\text{entrepreneurs' profits} + \text{banks' profits} + \text{banks' monitoring costs}}$$

5. The coefficient of the monitoring function is given by $c^\gamma b^{1-\gamma} = \Gamma$, then

$$\Gamma = \left(\frac{1+\overline{r}^e}{1+\overline{r}^a}\right)^{1-\gamma}\left(\frac{\overline{CRF}}{\overline{CRB}}\right)^{1-\gamma}\left(1-\overline{CRF}\right)^\gamma\overline{CORB}$$