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Leverage Constraints and Bank Monitoring: Bank Regulation versus Monetary Policy*

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Abstract

Bank leverage constraints can emerge from regulatory capital requirements as well as from central bank collateral requirements in reserve lending facilities. While these two channels are usually examined separately, we are able to compare them with the help of a bank money creation model in which central bank reserves have to be acquired to settle interbank liabilities. In particular, we show that with regard to bank monitoring, monetary policy via collateral requirements leads to a unique *collateral leverage channel*, which cannot be replicated by standard capital requirements. Through this channel, banks can expand loan supply and deposit issuance when they face liquidity constraints, by raising the collateral value of their loans with tighter monitoring of firms. The collateral leverage channel can improve welfare beyond standard bank capital regulation. Our results may inform current policy debates, such as the design of central bank collateral frameworks or the question whether monetary policy remains effective in times with large central bank reserves.

Keywords: leverage, banks, monitoring, bank regulation, monetary policy

JEL Classification: E42, E52, E58, G21

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1 Introduction

1.1 Motivation and main results

A classical foundation for the existence of banks is their unique, or at least superior, ability to monitor borrowers (Diamond, 1984; Holmstrom and Tirole, 1997). Banks' monitoring activities may reduce moral hazard on the side of potential borrowers with projects offering a positive net present value, to the point that loans to them become economically viable. In many countries, banks play a major role in the allocation of investment funds and the investment returns (De Fiore and Uhlig, 2011).[1] Accordingly, their behavior has a strong impact on the level and the fluctuation of economic activities.

It is thus important to ask how well banks pursue their monitoring activities and which factors actually determine banks' monitoring incentives. Monitoring is influenced by bank regulation and monetary policy through the impact on capital and liquidity constraints, ultimately determining the banks' possibilities to leverage. While these two channels are usually examined and discussed in isolation, in this paper we develop a model in which we can analyze the two, compare them and evaluate to which extent they are substitutes or play a distinctive and unique role in controlling bank monitoring.

Our main insights are as follows. First, monetary policy via collateral requirements in central bank lending operations is a distinct channel to impact bank monitoring that cannot be replicated by standard capital requirements (unweighted or weighted). It thus improves welfare beyond capital requirements. Second, this *collateral leverage channel* we identify only operates properly if available central bank reserves are sufficiently scarce. These results may inform two current debates: The design of central bank collateral frameworks and the effectiveness of monetary policy in times when there are large amounts of central bank reserves. This will be detailed in subsection 1.2.

At a more detailed level, we use a simple model that features a perfectly competitive banking sector, a bank regulator and a central bank. Banks fulfill a dual role in our economy, as they provide credit, in the form of loans to firms, and money, in the form of bank deposits. The latter is the predominant form of today's money and constitutes the only medium of exchange in our economy. Banks can monitor firms in order to avoid any opportunistic behavior. We consider two different monitoring technologies. In our baseline model, bank monitoring increases the chances for a high loan repayment. In an extension, we also consider an alternative monitoring technology that increases the loan repayment only in bad states.

The loans granted by banks are financed through deposits and equity. Bank equity financing is limited and the bank regulator imposes (unweighted) capital requirements. Thus, banks may be capital-constrained. Moreover, as loan repayment is risky, highly levered banks face a solvency risk. The latter, in turn, may cause underinvestment by bankers in monitoring, as they do not obtain the entire benefits of monitoring. The underinvestment is most pronounced with the alternative monitoring technology that only increases returns in bad states, in which the bank defaults anyway. Hence, with a solvency risk, banks may choose shirking instead of

[1] When comparing the United States (US) and the Euro Area (EA), De Fiore and Uhlig (2011) find that the importance of banks in providing financing to non-financial corporations in the real economy is particularly prominent in the EA, as the bank-to-bond finance ratio is 5.48, compared to 0.66 in the US.

monitoring in order to economize on the monitoring costs.

Bank deposits are used by firms to buy investment goods from households, who, in turn, use the received bank deposits later to buy consumption goods. As a result of these transactions, deposits are transferred among banks, giving rise to interbank liabilities that, following today's institutional arrangement, must be settled at the central bank by using reserves. Banks can obtain liquidity in the form of reserves by borrowing from the central bank. In our setting, monetary policy thus comprises two instruments: interest rates on reserve loans and reserve deposits, as well as the collateral requirements for reserve loans. Banks can pledge their firm loans when borrowing reserves, but these assets are reduced in value through a haircut set by the central bank. With sufficiently tight collateral requirements, namely a haircut on bank loans large enough, banks become liquidity-constrained.

On purpose, our model does not involve price rigidities in order to focus on the central bank collateral requirements and their impact on bank monitoring. Accordingly, any interest rate policy of the central bank is irrelevant for the real allocation, i.e., money is neutral. In contrast, the haircut has a direct impact on banks' ability to borrow reserves and, in the presence of liquidity constraints, influences the banks' incentives to engage into loan financing and deposit issuance. A bank only issues deposits and provides more loans to firms if it is certain that it can borrow the reserves required to settle the interbank liabilities resulting form deposit transfers. Otherwise, it would default prematurely.

In our model, the monitoring incentives for banks are twofold: First, monitoring increases the chances for a high loan repayment (or in the extension, the loan repayment in bad states) and thus increases the expected profits of the bank, which we refer to as the *return channel* of monitoring. Second, the higher expected loan repayment increases the collateral value of bank loans, which, ceteris paribus, allows banks to borrow more reserves at the central bank. For liquidity-constrained banks, this implies that they can extend loan supply and deposit issuance in the first place, leading to a higher bank leverage and higher expected profits for the bank. We refer to this second effect as the *collateral leverage channel* of monitoring.

Due to the collateral leverage channel, liquidity-constrained banks have, under any circumstance, more incentives to monitor than capital-constrained banks. We illustrate that the effect of central bank collateral requirements on the banks' monitoring incentives is also unique in comparison with standard contingent (e.g., risk-weighted) capital requirements. Contingent capital requirements give rise to the *regulatory leverage channel* of monitoring that represents a third channel for the benefits from monitoring. We show that one can construct a particular form of contingent capital requirements that can replicate the monitoring benefits following from the collateral leverage channel. However, this particular form of contingent capital requirements may be difficult to implement by the bank regulator, as it would require instant responses to monitoring activities and may contradict other objectives, such as reducing the risk-taking incentives of banks, for instance.

Finally, we explore whether our results hold when banks acquire forms of collateral such as safe corporate or government bonds and use them to ease liquidity constraints. If banks are not constrained by capital requirements, purchasing these securities, and financing these purchases by issuing deposits, will lead to an increase of bank leverage and higher liquidity needs on the side of banks. We can show that under an appropriate haircut policy, the collateral leverage channel is still at work. Namely, in order to keep monitoring incentives for bank loans at the desired level, the central bank would first define the class of assets that can be used as collateral and second simply adjust the haircuts on the assets in this class, such that banks have the same incentives to monitor as without the purchases of safe bonds.

1.2 Contribution to current debates

Our analysis may inform two current policy and academic debates. First, with our analysis, we contribute to the current debate about central bank collateral frameworks. With the financial crisis 2007/08, central banks adopted various unconventional measures in order to incentivize banks to maintain the credit supply to the real economy. On the one hand, central banks set short-term interest rates on reserves at unprecedented lows and exercised additional downward pressure on long-term interest rates through large-scale asset purchases, so-called "quantitative easing". On the other hand, central banks lowered the collateral standards in their lending activities to facilitate the banks' access to liquidity. The possible distortions resulting from a deterioration of collateral requirements during the financial crisis have been widely discussed (Nyborg, 2017; Bindseil et al., 2017). To a large extent, the discussion centered around the so-called "collateral premium", i.e., an increase in the valuation of assets, which is solely due to the fact that these assets can be pledged in liquidity operations of the central bank. The collateral premium can ultimately induce distortions in the real allocation, as it benefits the respective issuers.

Despite potential distortions, there are at least three justifications for central bank collateral requirements (see e.g. Bindseil et al. (2017)): With unsecured liquidity provisions, the central bank would face an increased risk of losses, would require more resources to manage its risk exposure, and might reduce the efficiency of monetary policy implementation. First, losses for the central bank are problematic, as they can harm its reputation and even question its independence. Second, a greater use of resources reduces the central bank's profits and thus comes at the taxpayers' expense. Third, diligent lending of public money without collateral requirements requires that the creditworthiness of each counterparty is evaluated, a time-consuming process that may slow down the implementation of central bank policies and ultimately causes real economic losses. We show with our analysis that, besides the previously mentioned reasons, central bank collateral requirements can also have an important function in maintaining the banks' incentives to monitor.

Second, our work may also inform current debates on potential risks of large central bank balance sheets. The results indicate that through the collateral leverage channel, central banks can affect the banks' monitoring incentives and thus ultimately their monitoring activities, in a unique way. This channel is, however, only active if banks are indeed constrained by liquidity. The unconventional measures adopted by many central banks since the financial crisis 2007/08, such as large-scale asset purchases, for instance, led to the fact that banks currently hold large amounts of reserves, eliminating any liquidity constraints. According to our analysis, with current monetary policies leading to large reserve holdings of banks, a particular effect of central bank collateral frameworks is lost.

As shown in the paper, the collateral leverage channel can be replicated by a particular construction of contingent (e.g., risk-dependent) capital requirements. However, such a replication may be difficult or impossible to implement. On the one hand, risk-dependent capital requirements have the primary purpose to reduce or eliminate excessive risk-taking and typically, the *regulatory* leverage channel for such purposes differs from the *collateral* leverage channel. On the other hand, bank regulation is much more rule-based than monetary policy, leaving bank regulators with less discretion to adjust their regulatory instruments than central bankers when collateral values change, for example.

1.3 Relation to the literature

Our paper relates to three strands of the literature. First, our model features the dual role of banks, providing credit and money to the real economy. We thus rely on the fast-growing literature that emphasizes private money creation by banks, as Faure and Gersbach (2017), Faure and Gersbach (2018) and Benigno and Robatto (2019), for instance. We differ by developing a model that specifically allows us to study the differing impact of capital and liquidity constraints, imposed by bank regulation and monetary policy, respectively, on the banks' monitoring incentives.

Second, our baseline model features a monitoring technology in the spirit of Holmstrom and Tirole (1997), as monitoring rules out any opportunistic behavior of the borrower. Monitoring increases the chances for high firm productivity and thus a high loan repayment. In an extension to our model (see appendix B), we study an alternative monitoring technology that leaves the probability distribution of productivity shocks unchanged but raises firm productivity, and accordingly loan repayment, in bad states.

Third, we relate to a large literature that studies the effect of collateral standards, on asset prices (e.g., Brumm et al. (2015)) or on credit constraints and their relevance for business cycles (e.g., Bernanke et al. (1999), Kiyotaki and Moore (1997), Guerrieri and Iacoviello (2017)), for example. We contribute by illustrating how collateral requirements imposed by the central bank can affect banks' monitoring activities and how this impact may differ from the one induced by the bank regulator. Our analysis thus complements the existing literature that analyzed central bank collateral frameworks, mostly from a policy or empirical perspective, see Bindseil (2004), Bindseil et al. (2017), Chailloux et al. (2008) and Nyborg (2017), for instance.

The remainder of the paper is structured as follows: Section 2 introduces the model and discusses the optimal choice of the individual agents. In section 3, we characterize the equilibria, optimal bank regulation and optimal monetary policy. Section 4 concludes.

2 Model

2.1 Macroeconomic environment

Our economy features four types of agents—firms, households, bankers, and a government sector, comprising a bank regulator and a central bank—and two goods—a capital good and a consumption good. Transactions are settled instantaneously by using money in the form of bank deposits. Households and bankers are endowed with the capital good which they can sell to firms for the production of the consumption good. Bankers establish banks by committing to use their proceeds from capital good sales for equity financing. Firms finance capital good purchases from households and bankers either by demanding loan financing from banks or by issuing bonds at financial markets. Based on the type of external financing, we differentiate between loan-financed and bond-financed firms. The model features private and public money creation. Private money takes the form of bank deposits which are issued by banks when granting loans to firms. Public money, in turn, is represented by reserves which banks can obtain from the central bank by demanding collateralized reserve loans and that are used by banks to settle interbank liabilities.[2] The latter arise when, in the course of transactions on the good markets, deposits are transferred from one bank to another. Good markets and asset markets are perfectly competitive.

Firms in the loan-financed sector produce subject to idiosyncratic shocks. Moreover, the expected productivity of loan-financed firms is influenced by bank monitoring. In equilibrium, firm productivity and loan repayment are directly linked, so that bank monitoring matters for loan repayment and affects the expected value of bank loans. These loans serve as collateral for reserve loans from the central bank, leading to the fact that the banks' monitoring decision also affects their access to liquidity. The central bank sets the interest rates on reserve loans and reserve deposits, and the haircut on bank loans when used as collateral for reserve loans.

Banks are either constrained by capital or liquidity, i.e., either the capital requirements imposed by the bank regulator or the haircut set by the central bank matter for banks' initial decision about deposit issuance and loan supply to firms. We impose a one-to-one matching of banks and firms, so that the loan portfolio of the individual bank is fully exposed to the idiosyncratic risk of the financed firm. As banks operate with limited equity financing, they are exposed to a solvency risk whenever, in the course of loan financing, the leverage becomes sufficiently large. Bank deposits are safe as they are insured by the government through guarantees. Throughout our analysis, we assume that the governmental budget is balanced, so that the government distributes central bank profits as transfers and finances central bank losses through taxes.

2.2 Timeline

As we focus on a monetary economy with instantaneous settlement of transactions, the timing of interactions among agents matters for the model analysis. Figure 1 outlines the events in our static setting.

[2] For simplification, we abstract from cash. In our framework, this is without loss of generality because holding the alternative form of money, i.e., bank deposits, yields a positive interest.

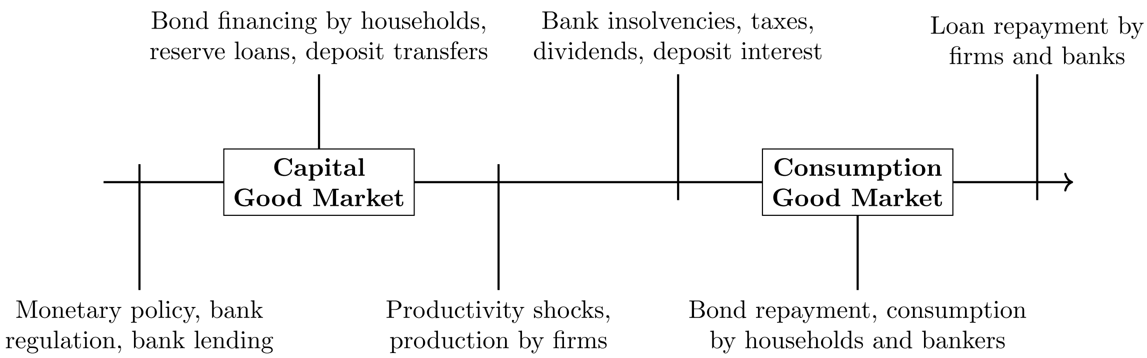

Figure 1: Timeline.

We note that all trades are settled by using bank deposits and prices are in terms of the unit of account of the underlying currency. The consumption good acts as the numeraire of the economy. In the following subsections, we outline the agents' optimization problems and characterize the optimal choices. The proofs relating to the stated results can be found in appendix C.

2.3 Firms

Firms are profit-maximizing, protected by limited liability and penniless. They purchase the capital good from households and bankers to produce the consumption good. There are two types of firms, which we index by L and B. Firms of each type are ex-ante identical and exist in a continuum with mass normalized to one, so that we can focus on a representative firm for each type. Firms of type L are plagued by moral hazard and can only obtain funds through loans by banks. Firms of type B, in turn, can raise funds in a frictionless bond market.[3]

The loan-financed firm purchases the capital good $K^L \geq 0$ from households and bankers at the nominal price $Q > 0$ and uses the capital good to produce the consumption good with the risky technology $A_s^L K^L$, where the marginal productivity $A_s^L \geq 0$ is affected by the idiosyncratic shock s. The productivity can be either low ($s = l$) or high ($s = h$), so that it holds that $A_h^L > A_l^L$. The idiosyncratic productivity shocks are independent and identically distributed (i.i.d.) across firms. A positive shock occurs with probability $\eta_m \in (0, 1)$, which depends on the monitoring activity m of the matched banker. Bankers can engage into costly monitoring ($m = 1$) or shirking ($m = 0$). Monitoring by the matched banker increases the probability for a positive productivity shock, i.e., $\eta_1 = \eta_0 + \triangle$ with $\triangle \in (0, 1 - \eta_0)$.

The bond-financed firm, in turn, purchases capital good $K^B \geq 0$ from households and bankers at the nominal price $Q > 0$ and uses the capital good to produce consumption good with the riskless technology $A^B K^B$, where the marginal productivity satisfies $A^B > 0$.

Both types of firms sell the produced consumption good to households and bankers at a nominal price $P > 0$. The revenues, in the form of bank deposits, are then used to repay the external funds QK^f, with $f \in \{L, B\}$, where $Q > 0$ denotes the nominal capital good price. Depending on the type of the firm, external financing takes the form of loans or bonds. The

[3] The assumption that firms of type B can only raise funds by issuing bonds at financial markets is made for simplification and can be relaxed.

repayment of loans is determined by the interest rate $r_s^L > 0$, whereas the repayment of bonds depends on the interest rate $r^B > 0$. Typically, the interest rates on loans and bonds will differ. Accounting for the fact that firms are profit-maximizing and subject to limited liability, it follows that the optimization problems of the loan-financed firm and bond-financed firm are given in real terms by

$$\max_{K^L \geq 0} \mathbb{E}_m[\{A_s^L - (1+r_s^L)q\}^+]K^L \qquad \text{and} \qquad \max_{K^B \geq 0} \{A^B - (1+r^B)q\}^+ K^B, \tag{1}$$

where we make use of the notation $\{X\}^+ = \max\{X, 0\}$, and apply the notation $q := Q/P$ to represent the capital good price in terms of the consumption good. Note that the expectation operator in (1) is indexed by the banker's monitoring activity m, as the latter affects the probability distribution of productivity shocks.

Due to limited liability, there exists no optimal, finite demand for the capital good if the respective firm is exposed to excess returns in at least one state, i.e., for the loan-financed firm, this means $A_s^L > (1 + r_s^L)q$ for some s, whereas for the bond-financed firm, this means $A^B > (1 + r^B)q$. We denote this case by $K^L = +\infty$ or $K^B = +\infty$, respectively. In contrast, without excess returns, i.e., for the loan-financed firm, this means $A_s^L \leq (1 + r_s^L)q$ for all s, whereas for the bond-financed firm, this means $A^B \leq (1 + r^B)q$, the firms will be indifferent between any amount of capital good put into production, i.e., $K^L \in [0, +\infty)$ and $K^B \in [0, +\infty)$, respectively.

Lemma 1 (Optimal Choice of Firms)
The loan-financed firm optimally chooses the capital good $K^L = +\infty$ if and only if $A_s^L > (1+r_s^L)q$ for some s, and $K^L \in [0, +\infty)$ otherwise. The bond-financed firm optimally chooses capital good $K^B = +\infty$ if and only if $A^B > (1 + r^B)q$, and $K^B \in [0, +\infty)$ otherwise.

In any competitive equilibrium we study, the capital good market must clear, which ultimately requires an optimal, finite demand of capital good on the side of firms.[4] From lemma 1, we know that firms demand a finite amount of capital good if and only if the repayment obligations on external funds weakly exceed the revenues from production, i.e., $A_s^L \leq (1 + r_s^L)q$ for all s and $A^B \leq (1 + r^B)q$. We assume that the agents in our model are rational, so that, in equilibrium, their behavior cannot be subject to predictable errors. As a consequence, no competitive equilibrium can feature firm default. Ensuring a finite demand of capital good and ruling out firm default then implies that, in equilibrium, it holds $A_s^L = (1 + r_s^L)q$ for all s and $A^B = (1 + r^B)q$. As a consequence, firms make zero profits in equilibrium.

For our analysis, we make specific assumptions on firm productivity: First, we assume that a loan-financed firm is more productive on average than a bond-financed firm, even if the matched banker does not monitor. This guarantees that the loan-financed sector is relevant in maximizing aggregate production and, ultimately, welfare. Second, when a loan-financed firm experiences a negative shock, it is less productive than a bond-financed firm. The latter assumption allows us to introduce solvency risk on the side of banks, see subsection 2.6.

[4] In appendix A, we provide the definition of a competitive equilibrium in our framework.

Assumption 1 (Firm Productivities)
$\mathbb{E}_0[A_s^L] > A^B$ *and* $A^B > A_l^L$.

It follows directly from assumption 1 that a loan-financed firm is strictly more productive than a bond-financed firm if it incurs a positive productivity shock, i.e., it holds that $A_h^L > A^B$.

2.4 Households

There is a continuum of identical households with mass normalized to one, so that we can focus on a representative household. The household is endowed with capital good $K > 0$, which can be sold to firms at a nominal price $Q > 0$. The revenues are in the form of deposits and can be invested in bonds, which are subject to a rate of return $r^B > 0$. Deposits, in turn, are credited with interest according to the rate $r^D > 0$. The share of funds held in the form of deposits is denoted by $\gamma \in [0, 1]$. The household owns firms which distribute any available profits Π as dividends. Taking governmental taxes or transfers T, which are assumed to be lump-sum, and dividends Π into account, the household uses deposits credited with interest $\gamma(1 + r^D)QK$ and the revenues from bond investments $(1 - \gamma)(1 + r^B)QK$ to purchase an amount C^H of the consumption good from firms at the nominal price $P > 0$. The household maximizes utility, which we assume to be linearly increasing in consumption. Hence, the household's optimization problem is given in real terms by

$$\max_{\gamma \in [0,1]} [\gamma(1 + r^D) + (1 - \gamma)(1 + r^B)]qK + \tau + \pi, \tag{2}$$

where the taxes and the profits, denoted by lowercase letters, are in terms of the consumption good, i.e., $\tau := T/P$ and $\pi := \Pi/P$.

The optimal choice of the household is of knife-edge type. Whenever the rate of return on deposits exceeds the one on bonds ($r^D > r^B$), the household holds all revenues from capital good sales in the form of deposits ($\gamma = 1$). Similarly, whenever the bond return exceeds the return on deposits ($r^D < r^B$), the household invests all funds into bonds ($\gamma = 0$). And finally, when the interest rates on both assets equal ($r^D = r^B$), the household is indifferent between holding deposits and investing into bonds ($\gamma \in [0, 1]$). The household's optimal choice is summarized in the following lemma.

Lemma 2 (Optimal Choice of the Household)
$\gamma = 1$ *(*$\gamma = 0$*) if* $r^D > (<) r^B$ *and* $\gamma \in [0, 1]$ *otherwise.*

We focus on environments where the interest rates on deposits and bonds equal, i.e., $r^D = r^B$.[5] As a consequence, the household is always indifferent between holding funds in deposits or bonds.

2.5 Government sector

Banks grant loans to firms and ultimately fund them with deposits and equity. Accordingly, banks operate under a certain leverage (i.e., loans-to-equity ratio), which we denote by φ.

[5] In subsection 3.2, we further outline under which conditions this identity holds.

The bank regulator imposes a capital requirement for banks, leading to a regulatory leverage constraint $\varphi \leq \varphi^R$, where $\varphi^R \in [1, +\infty)$ represents the regulatory maximum leverage following from the capital requirements.

The central bank provides banks with liquidity in the form of reserves, which banks use to settle interbank liabilities. Reserves can be borrowed from the central bank via collateralized loans. The only pledgeable assets available to banks are the bank loans provided to firms. The value of these bank loans is reduced by a haircut $\psi \in [0, 1]$, which is chosen by the central bank. In subsection 2.6, we provide the ensuing borrowing constraint on the side of banks. Reserve deposits at the central bank are credited with interest according to the rate $r^D_{CB} > 0$, while reserve loans require a repayment that follows from the rate $r^L_{CB} > 0$. For simplicity, we assume that the two interest rates equal.

Assumption 2 (Reserve Rates)
$r^D_{CB} = r^L_{CB}$.

Banks can face a solvency risk if, in the course of loan financing to firms, the leverage becomes sufficiently large; a detailed discussion is provided in subsection 2.6. In any equilibrium we consider, default by firms is ruled out (see subsection 2.3), so that banks are the only agents in our economy which can default on their liabilities. The government insures deposits through guarantees, so that it must impose taxes on households to balance bank losses, which in the aggregate and in nominal terms, are denoted by $\Pi^{b,-}$.[6] The government also uses taxes to cover losses of the central bank, while it can distribute central bank profits by using transfers. We denote nominal central bank profits or losses by Π^{CB}. As we assume that the governmental budget is balanced, lump-sum taxes or transfers are given in nominal terms by $T = \Pi^{b,-} + \Pi^{CB}$.

In our setting, the government aims at maximizing utilitarian welfare. We introduce the optimization problem and characterize the optimal mix of bank regulation and monetary policy in subsection 3.2. We also discuss the optimal bank regulation, taking monetary policy as given, as well as the optimal monetary policy, taking bank regulation as given.

2.6 Bankers

There is a continuum of ex-ante identical bankers with mass normalized to one, so that we can focus on a representative banker. Bankers are endowed with capital good $E > 0$, which they can sell to firms at the nominal price $Q > 0$. The banker commits to using the entire proceeds from capital good sales to establish a bank with equity financing $E^b = QE$.[7] Banks are matched one-to-one with firms, so that the individual bank holds a non-diversified loan portfolio and is fully exposed to the idiosyncratic risk of the financed firm. The decision about loan supply L^b to the matched firm pins down the loans-to-equity ratio $\varphi = L^b/E^b$ and the bank's deposit

[6] We focus in our analysis on a representative bank, which leads to the fact that under equal reserve rates (see assumption 2), the repayment obligation for reserve loans always matches the claim for reserve deposits. An insolvent bank thus only defaults on the deposit funding and bank losses only consist of the unmet liabilities towards depositors.

[7] This assumption is without loss of generality, as based on assumption 1 and the direct link between interest rates and firm productivity in equilibrium, no other asset (i.e., bond or deposit) yields a higher expected return than bank equity. The banker is risk-neutral, so that only the expected return is relevant for the investment decision.

financing $D^b = L^b - E^b$ after capital good transactions have been settled and the banker used the proceeds to acquire equity shares of the owned bank.

The banker can also decide to engage into monitoring of the financed firm, which increases the probability of a positive idiosyncratic shock and thus the chances for a high loan repayment (see subsection 2.3). Monitoring is costly, as it causes a non-monetary utility loss κL^b for the banker, which scales with the granted loan amount.[8] The parameter $\kappa > 0$ measures the monitoring efforts per unit of loan financing. The monitoring decision itself is denoted by $m \in \{0, 1\}$, where zero (one) represents shirking (monitoring).

The bank has a demand for liquidity in the form of central bank reserves because transactions on the capital good market lead to interbank deposit flows.[9] Specifically, we assume that a share $\alpha \in (0, 1]$ of deposits $D^b = L^b - E^b$ is temporarily outflowing.[10] The interbank liabilities following from the deposit outflows must be settled without netting the deposit inflows, i.e., the central bank applies a gross settlement procedure. The bank's reserve borrowing and reserve deposits then satisfy $L^{CB} \geq \alpha D^b$ and $D^{CB} \geq \alpha D^b$. As the interest rates on reserve loans and reserve deposits equal (see assumption 2), borrowing reserves is profit-neutral for the bank and we can, without loss of generality, assume that it holds that $L^{CB} = \alpha D^b$. Moreover, as we focus on a representative bank, deposit outflows must match deposit inflows, so that, after capital good transactions have been settled, it holds $D^{CB} = L^{CB} = \alpha D^b$ and the balance sheet identity $L^b + D^{CB} = D^b + L^{CB} + E^b$ applies. Using the structure of reserve deposits, the bank's assets satisfy $L^b + D^{CB} = (1 + \alpha)L^b - \alpha E^b$ and the assets-to-equity ratio is given by $\tilde{\varphi} = (L^b + D^{CB})/E^b = (1 + \alpha)\varphi - \alpha$. For what follows, we will focus on the loans-to-equity ratio φ, as it allows for a more natural representation of the banker's optimization problem. For simplicity, we will in the following refer to φ as the *bank leverage* and to $\tilde{\varphi}$ as the *integrated bank leverage*, accounting specifically for the reserve holdings of the bank. As outlined in subsection 2.5, the bank is also subject to a regulatory leverage constraint $\varphi \leq \varphi^R$, with $\varphi^R \in [1, +\infty)$.

The interest rate on loans granted by the bank is given by $r^L_s > 0$, which depends on the idiosyncratic shock s of the financed firm. Deposits are credited with interest according to the rate $r^D > 0$. The nominal equity returns are then given by

$$(1 + r^E_s)E^b = \left\{(1 + r^L_s)L^b + (1 + r^D_{CB})D^{CB} - (1 + r^D)D^b - (1 + r^L_{CB})L^{CB}\right\}^+ ,$$

where we use $\{X\}^+ = \max\{X, 0\}$ to account for the limited liability of the bank. Using the structure of deposit financing, reserve loans and reserve deposits, it follows that the nominal equity returns are given by

$$(1 + r^E_s)E^b = \left\{(1 + r^L_s)L^b + [(1 + r^D_{CB})\alpha - (1 + r^D) - (1 + r^L_{CB})\alpha](L^b - E^b)\right\}^+ .$$

With assumption 2, which imposes the equality of interest rates on reserves ($r^D_{CB} = r^L_{CB}$), and the definition of the bank leverage $\varphi = L^b/E^b$, we obtain that the rate of return on bank equity

[8]The assumption that monitoring costs scale with the amount of loan financing is of technical nature, as it simplifies the analysis of the banker's optimization problem.

[9]We abstract from deposit flows due to transactions on the consumption good market, since this solely complicates the analysis but does not yield further insights.

[10]We implicitly assume that the deposits of the banker do not cause deposit outflows, but remain at the bank and are used to acquire equity shares directly after the settlement of capital good transactions.

is given by

$$r_s^E(\varphi) := \{(r_s^L - r^D)\varphi + 1 + r^D\}^+ - 1.$$

Based on the explanations in subsection 2.3 and 2.4, we know that, in equilibrium, the interest rates on loans and deposits satisfy $r_s^L = A_s^L/q - 1$ for all s, and $r^D = r^B = A^B/q - 1$. Accordingly, the equilibrium rate of return on bank equity can be expressed with economic fundamentals, i.e., it holds that

$$r_s^E(\varphi) := \{(A_s^L - A^B)\varphi + A^B\}^+/q - 1. \tag{3}$$

It follows with our assumptions on firm productivity (see assumption 1 in subsection 2.3) that only with a low productivity of the financed firm ($s = l$), the bank is making losses on loans that have been funded with deposits. We can derive a maximum leverage, denoted by φ^S, which guarantees solvency of the bank in all states. This leverage is obtained by setting the equity return in the low productivity state to zero, i.e.,

$$1 + r_l^E(\varphi^S) = 0 \quad \Leftrightarrow \quad (A_l^L - A^B)\varphi^S + A^B = 0 \quad \Leftrightarrow \quad \varphi^S := \frac{A^B}{A^B - A_l^L}. \tag{4}$$

Based on assumption 1, we know that this leverage threshold is finite, i.e., it holds that $\varphi^S < +\infty$.

When capital good transactions are settled, the bank requires liquidity in the form of reserves which it can borrow from the central bank by pledging the bank loans granted to the matched firm. At that point in time, productivity shocks have not realized yet, so that the expected value of bank loans is given by $(1 + \mathbb{E}_m[r_s^L])L^b$. The central bank applies a haircut $\psi \in [0, 1]$ on the value of bank loans, so that the overall collateral available to the bank, also referred to as *collateral capacity*, is given by $(1 - \psi)(1 + \mathbb{E}_m[r_s^L])L^b$. Taking the repayment obligation on reserve loans into account, the reserve borrowing L^{CB} of the bank cannot exceed the collateral capacity, which leads to the liquidity constraint

$$(1 - \psi)(1 + \mathbb{E}_m[r_s^L])L^b \geq (1 + r_{CB}^L)L^{CB}.$$

With assumption 2, which states the equality of interest rates on reserves ($r_{CB}^D = r_{CB}^L$), the structure of reserve loans $L^{CB} = \alpha(L^b - E^b)$, and the definition of the bank leverage $\varphi = L^b/E^b$, we can reformulate the latter inequality as

$$(1 - \psi)(1 + \mathbb{E}_m[r_s^L])\varphi \geq \alpha(1 + r_{CB}^D)(\varphi - 1).$$

We can then define a maximum leverage, up to which liquidity of the bank is guaranteed. This leverage, denoted by $\varphi_m^L(\psi)$, is determined through the binding liquidity constraint, i.e.,

$$(1 - \psi)(1 + \mathbb{E}_m[r_s^L])\varphi_m^L(\psi) = \alpha(1 + r_{CB}^D)[\varphi_m^L(\psi) - 1],$$

so that

$$\varphi_m^L(\psi) = \frac{\alpha(1 + r_{CB}^D)}{\alpha(1 + r_{CB}^D) - (1 - \psi)(1 + \mathbb{E}_m[r_s^L])}. \tag{5}$$

The banker's monitoring decision m affects the leverage threshold $\varphi_m^L(\psi)$, as monitoring increases the expected productivity and thus the expected loan repayment of the financed firm. A higher valuation of bank loans increases the collateral capacity of the bank, allowing it to borrow, ceteris paribus, more reserves at the central bank. The improved access to central bank reserves then translates into an expansion of loan supply and deposit issuance in the first place, i.e., the maximum leverage is increasing with bank monitoring ($\varphi_1^L(\psi) > \varphi_0^L(\psi)$). Further, note that the banker never chooses a leverage larger than $\varphi_m^L(\psi)$, as it leads to illiquidity with certainty, in which case the government seizes all bank assets and thus the potential returns on bank equity are eliminated.

We allow for an active interbank market, where the bank can borrow, lend as well as deposit at other banks. The interbank loans are collateralized through bank loans, which are reduced in value by the same haircut $\psi \in [0, 1]$ as applied by the central bank. When paying interest on deposits, banks cannot differentiate between deposits held by other banks and deposits held by households. Accordingly, the deposit rate prevailing on the interbank market is given by $r^D > 0$. It follows that independent of whether the bank is constrained by capital or liquidity, the deposit rate equals the central bank rate, as stated in the following lemma.

Lemma 3 (Deposit Rate)
$r^D = r_{CB}^D$.

The identical pricing of deposits and reserves has two implications in our economy. First, we can deduce how in equilibrium, the capital good price Q and the consumption good price P form, i.e., based on the equilibrium conditions $r^D = r^B = A^B/q - 1$ and assumption 3, it holds that

$$r_{CB}^D = A^B/q - 1 \qquad \Leftrightarrow \qquad \frac{P}{Q} = \frac{1 + r_{CB}^D}{A^B}. \tag{6}$$

An increase of the interest rate r_{CB}^D on reserves leads to an increase in the consumption good price P or a decrease in the capital good price Q or both. Second, using equation (5) and the equilibrium condition (6), we can express the maximum leverage $\varphi_m^L(\psi)$ guaranteeing liquidity of the bank using economic fundamentals, i.e., it holds that

$$\varphi_m^L(\psi) = \frac{\alpha A^B}{\alpha A^B - (1 - \psi)\mathbb{E}_m[A_s^L]}. \tag{7}$$

The banker uses the returns on bank equity $[1 + r_s^E(\varphi)]E^b$ to purchase consumption good C_s^B at the nominal price $P > 0$. The banker is maximizing the expected utility, which we assume to be linearly increasing in consumption. Accordingly, the optimization problem of the banker is given in real terms by

$$\max_{\substack{\varphi \in [1, \overline{\varphi}_m(\theta)], \\ m \in \{0,1\}}} \{1 + \mathbb{E}_m[r_s^E(\varphi)] - m\kappa\varphi\} qE, \tag{8}$$

where we made use of the definitions $E^b = QE$ and $\varphi = L^b/E^b$ to obtain $m\kappa L^b = m\kappa\varphi QE$. We also introduced the notation $\overline{\varphi}_m(\theta) := \min\{\varphi^R, \varphi_m^L(\psi)\}$ to represent the maximum possible bank leverage, where $\theta := (\varphi^R, \psi)$ denotes the policy measures implemented by the bank regulator and the central bank. Note that the expectation operator in (8) is indexed by the monitoring activity m, as the monitoring decision affects the probability distribution of productivity shocks for the financed firm and thus the expected equity returns.

We now discuss the optimal choice of the banker, as summarized in the following lemma. First, note that the banker always optimally chooses the maximum leverage, i.e., it holds that $\varphi = \overline{\varphi}_m(\theta)$. The reason is that, in equilibrium, the interest rates on loans and deposits are directly linked to firm productivity, i.e., it holds that $r_s^L = A_s^L/q - 1$ for all s and $r^D = r^B = A^B/q - 1$, and that, based on assumption 1, a loan-financed firm is, even without monitoring by the banker, more productive in expectation than a bond-financed firm, i.e., it holds that $\mathbb{E}_0[A_s^L] > A^B$.

Second, note that the banker's optimal monitoring decision generally depends on the exposure to solvency risk. Due to limited liability, the banker does not fully internalize the benefits of monitoring if the bank defaults for a negative productivity shock of the financed firm. Moreover, through the central bank collateral requirements, the maximum possible leverage $\overline{\varphi}_m(\theta)$ may vary with the banker's monitoring activity m, while the solvency leverage threshold φ^S is not affected by monitoring. Accordingly, we have to differentiate between three cases: (I) no solvency risk, i.e., the banker is not exposed to a solvency risk, independent of the monitoring decision, (II) "partial" solvency risk, the banker faces solvency risk only with monitoring, and (III) "full" solvency risk, i.e., the banker is always exposed to a solvency risk, independent of the monitoring decision. As the maximum possible leverage $\overline{\varphi}_m(\theta)$ weakly increases with monitoring, the banker can never face a situation where there exists a solvency risk only without monitoring. In the decision about monitoring, the banker must trade off the benefits against the costs in the form of the non-monetary utility loss. The benefits from monitoring are generally twofold: First, monitoring increases the probability for a high productivity of the financed firm and thus a high loan repayment. We refer to this effect as the *return channel* of monitoring. Second, monitoring may allow the bank to leverage more, i.e., expand deposit issuance and loan supply. The reason is that monitoring increases the expected value of bank loans and thus the collateral capacity of the bank, allowing it to borrow more reserves from the central bank. We refer to this effect as the *collateral leverage channel* of monitoring. This channel is only active if the bank is liquidity-constrained, at least without monitoring. In this case, the maximum possible bank leverage varies with monitoring, i.e., it holds that $\overline{\varphi}_0(\theta) < \overline{\varphi}_1(\theta)$. In contrast, if the bank is only constrained by the capital requirements imposed by the bank regulator, independent of the monitoring decision, i.e., $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, the collateral leverage effect is not at work. In that case, the banker's monitoring decision is only influenced by the benefits following from the return channel and by the monitoring costs.

Lemma 4 (Optimal Choice of the Banker)
In equilibrium, the banker's optimal choice of leverage is given by $\varphi = \overline{\varphi}_m(\theta)$ and the banker's optimally monitors (i.e., $m = 1$) if and only if

(I) without solvency risk, i.e., $\overline{\varphi}_m(\theta) \leq \varphi^S$ for all m, it holds that $\mathcal{M}_N(\theta) \geq 0$, where

$$\mathcal{M}_N(\theta) := \triangle(A_h^L - A_l^L) + (\mathbb{E}_0[A_s^L] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q,$$

(II) with partial solvency risk, i.e., $\overline{\varphi}_1(\theta) > \varphi^S \geq \overline{\varphi}_0(\theta)$, it holds that $\mathcal{M}_P(\theta) \geq 0$, where

$$\begin{aligned}\mathcal{M}_P(\theta) :=& \triangle(A_h^L - A^B) + (1-\eta_0)(A^B - A_l^L) - \frac{(1-\eta_1)A^B}{\overline{\varphi}_1(\theta)} \\ &+ (\mathbb{E}_0[A_s^L] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q,\end{aligned}$$

(III) with full solvency risk, i.e., $\overline{\varphi}_m(\theta) > \varphi^S$ for all m, it holds that $\mathcal{M}_F(\theta) \geq 0$, where

$$\mathcal{M}_F(\theta) := \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\overline{\varphi}_1(\theta)} + \eta_0(A_h^L - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q.$$

In the three different situations that depend on the bank's exposure to solvency risk, the monitoring costs in the banker's decision about monitoring are always given by κq. The benefits stemming from the return channel differ in the three cases: Without solvency risk, the banker internalizes all the expected productivity gains of the financed firm, so that the benefits from the return channel are given by $\triangle(A_h^L - A_l^L)$. With partial solvency risk or even full solvency risk, the banker does not internalize all direct effects of monitoring, as the bank defaults if the financed firm incurs a negative productivity shock. In these two cases, the benefits from the return channel are given by

$$\triangle(A_h^L - A^B) + (1-\eta_0)(A^B - A_l^L) - \frac{(1-\eta_1)A^B}{\overline{\varphi}_1(\theta)} \qquad \text{and} \qquad \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\overline{\varphi}_1(\theta)},$$

respectively. The benefits from monitoring can, however, also emerge from the collateral leverage channel, which in the cases of no or partial and full solvency risk takes the form

$$(\mathbb{E}_0[A_s^L] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] \qquad \text{and} \qquad \eta_0(A_h^L - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right],$$

respectively. Note that the collateral leverage channel is not active, i.e., the latter terms vanish in the banker's monitoring decision, if the collateral requirements set by the central bank are sufficiently loose, so that the banker is never constrained by liquidity. In any such case, the maximum possible bank leverage satisfies $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$.

3 Equilibria, Bank Regulation and Monetary Policy

3.1 Equilibrium properties

In this subsection, we first provide necessary conditions for the existence of a competitive equilibrium and for the bank's exposure to a solvency risk. Then, we characterize welfare, using economic fundamentals, and further discuss the monitoring decision of the banker.

Existence and solvency risk. The existence of an equilibrium crucially depends on the clearing of the capital good market. Specifically, an equilibrium exists only if banks do not grant more loans than are needed to purchase the entire capital good in the economy, i.e., it holds that $QK^L = L^b = \overline{\varphi}_m(\theta)QE \leq Q(K+E)$ or, with the notation $\varphi^M := 1 + K/E$ equivalently, $\overline{\varphi}_m(\theta) \leq \varphi^M$. From the latter inequality, we can derive a condition on the capital requirements or the collateral requirements, depending which are binding for the bank. First, if the bank is constrained by capital, i.e., $\varphi^R \leq \varphi^L_m(\psi)$, it must hold $\varphi^R \leq \varphi^M$. In turn, if the bank is constrained by collateral, i.e., $\varphi^L_m(\psi) < \varphi^R$, the haircut set by the central bank must satisfy $\varphi^L_m(\psi) \leq \varphi^M$. The latter condition can be used to derive the smallest feasible haircut ψ^M_m, which, if implemented by the central bank, allows banks to provide as much loan financing as needed to allow loan-financed firms to acquire the entire capital good in the economy. Any haircut lower than ψ^M_m conflicts with the clearing condition for the capital good market and thus does not permit an equilibrium, whereas any haircut larger than ψ^M_m guarantees the existence of an equilibrium, but restricts the bank leverage below the maximum feasible one, i.e., $\varphi^L_m(\psi) < \varphi^M$.

If an equilibrium exists, i.e., $\varphi^R \leq \varphi^M$ or $\psi \geq \psi^M_m$, the bank is exposed to a solvency risk if the attained leverage is sufficiently large to exceed the leverage threshold guaranteeing solvency, i.e., $\overline{\varphi}_m(\theta) > \varphi^S$. Clearly, this is only possible if the regulatory leverage constraint is sufficiently loose, i.e., $\varphi^R > \varphi^S$, and the haircut set by the central bank is sufficiently small so that $\varphi^L_m(\psi) > \varphi^S$. We can use the condition $\varphi^L_m(\psi) = \varphi^S$ to derive the smallest possible haircut ψ^S_m guaranteeing solvency of the bank in all states. For any haircut ψ lower than ψ^S_m, the bank is exposed to a solvency risk, assuming that capital requirements are also sufficiently loose ($\varphi^R > \varphi^S$). Proposition 1 summarizes the previous explanations.

Proposition 1 (Existence and Solvency Risk)
A competitive equilibrium exists only if $\varphi^R \leq \varphi^M$ or $\varphi^L_m(\psi) \leq \varphi^M$, where the latter inequality is equivalent to

$$\psi \geq \psi^M_m := 1 - \frac{\alpha A^B}{\mathbb{E}_m[A^L_s](1 + E/K)},$$

and the bank is exposed to a solvency risk only if $\varphi^R > \varphi^S$ and $\varphi^L_m(\psi) > \varphi^S$, where the latter inequality is equivalent to

$$\psi < \psi^S_m := 1 - \frac{\alpha A^L_l}{\mathbb{E}_m[A^L_s]}.$$

The banker's monitoring decision m follows from lemma 4.

The smallest feasible haircut ψ^M_m and the smallest possible haircut ψ^S_m guaranteeing solvency of the bank both depend on the monitoring activity m. Note that bank monitoring increases the probability for a positive idiosyncratic shock of the respective firm ($\eta_1 = \eta_0 + \triangle$), and thereby also increases the expectation about loan repayment, i.e.,

$$(1 + \mathbb{E}_1[r_s^L])q = \mathbb{E}_1[A_s^L] = \mathbb{E}_0[A_s^L] + \triangle(A_h^L - A_l^L) = (1 + \mathbb{E}_0[r_s^L])q + \triangle(A_h^L - A_l^L).$$

The smallest feasible haircut ψ_m^M and the smallest possible haircut ψ_m^S guaranteeing solvency of banks both increase with monitoring (i.e., $\psi_1^M > \psi_0^M$ and $\psi_1^S > \psi_0^S$), as monitoring increases the collateral value of bank loans, but leaves the maximum feasible bank leverage φ^M as well as the leverage threshold for solvency φ^S unchanged. To keep bank lending at the maximum feasible level or at the level which rules out solvency risk, the central bank must steer against the monitoring-induced, increased collateral value of bank loans by setting stricter collateral requirements in the form of a higher haircut.

Welfare. The following lemma provides a characterization of utilitarian welfare, using economic fundamentals. Due to our assumption of linear utility for households and bankers, utilitarian welfare comprises aggregate consumption as well as bankers' utility losses due to monitoring, i.e., welfare denoted by W satisfies $W = C^H + C_m^B - m\kappa\varphi qE$, where $C_m^B = \mathbb{E}_m[C_s^B] = (1 + \mathbb{E}_m[r_s^E])qE$ represents aggregate consumption by bankers.[11] Welfare is generally affected by three factors: the regulatory maximum leverage φ^R and the haircut ψ, with at least one of them limiting bank leverage and thus determining the capital allocation between loan-financed and bond-financed firms, and the monitoring activity of bankers m, influencing the productivity in the loan-financed sector. The banker's monitoring decision may also be shaped by the policy measures in the form of the regulatory maximum leverage φ^R and the haircut ψ (see lemma 4).

Lemma 5 (Welfare)
In equilibrium, welfare is given by $W_m(\theta) = (\mathbb{E}_m[A_s^L] - A^B - m\kappa q)\overline{\varphi}_m(\theta)E + A^B(K + E)$.

Monitoring. We now further discuss the banker's monitoring decision, as outlined in lemma 4, by contrasting two situations: In the first one, the banker is solely constrained by the capital requirements imposed by the bank regulator, as collateral requirements set by the central bank are sufficiently loose, i.e., the maximum possible leverage satisfies $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$. In the second situation, in turn, the banker is constrained by liquidity, at least without monitoring, i.e., it holds that $\overline{\varphi}_0(\theta) < \overline{\varphi}_1(\theta) \leq \varphi^R$. Note that monitoring weakly increases the maximum possible bank leverage ($\overline{\varphi}_1(\theta) \geq \overline{\varphi}_0(\theta)$). Thus, in the first (second) situation, the haircut ψ set on bank loans used as collateral must satisfy $\overline{\varphi}_0(\theta) = \varphi_0^L(\psi) \geq (<)\varphi^R$ or, equivalently,

$$\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}_0[A_s^L]} \geq (<)\varphi^R \qquad \Leftrightarrow \qquad \psi \leq (>)\tilde{\psi}_0(\varphi^R) := 1 - \frac{\alpha A^B}{\mathbb{E}_0[A_s^L]}\frac{\varphi^R - 1}{\varphi^R},$$

where we used equation (5) to express the leverage threshold $\varphi_m^L(\psi)$ with model primitives.

Note that the banker is also constrained by liquidity with monitoring of the financed firm, whenever the collateral requirements are sufficiently tight, i.e., it holds that $\overline{\varphi}_1(\theta) = \varphi_1^L(\psi) < \varphi^R$

[11] Note that banks and firms are matched one-to-one and the idiosyncratic productivity shocks are i.i.d. across firms. Thus, by the law of large numbers, expected consumption by the banker equals aggregate consumption by bankers.

or, equivalently,

$$\frac{\alpha A^B}{\alpha A^B-(1-\psi)\mathbb{E}_1[A_s^L]}<\varphi^R \qquad \Leftrightarrow \qquad \psi>\tilde{\psi}_1(\varphi^R):=1-\frac{\alpha A^B}{\mathbb{E}_1[A_s^L]}\frac{\varphi^R-1}{\varphi^R},$$

where we again used the representation of $\varphi_m^L(\psi)$ following from equation (5). The collateral value of bank loans, and thus the borrowing limit for reserves, increases with monitoring. So, we can conclude that if there are liquidity constraints with monitoring, they will also be present without monitoring, i.e., it holds that $\tilde{\psi}_0^S(\varphi^R)<\tilde{\psi}_1^S(\varphi^R)$.

Next, we further characterize the banker's monitoring decision for any environment where the collateral requirements set by the central bank are sufficiently loose, so that the banker is only constrained by the capital requirements set by the bank regulator. The formal details are provided in the following corollary.

Corollary 1 (Monitoring Decision without Liquidity Constraints)
If collateral requirements set by the central bank are sufficiently loose, i.e., $\psi\le\tilde{\psi}_0(\varphi^R)$, so that $\overline{\varphi}_0(\theta)=\overline{\varphi}_1(\theta)=\varphi^R$, the banker optimally monitors (i.e., $m=1$) if and only if

(I) without solvency risk, i.e., $\varphi^R\le\varphi^S$, it holds that $\tilde{\mathcal{M}}_N\ge 0$, where

$$\tilde{\mathcal{M}}_N:=\triangle(A_h^L-A_l^L)-\kappa q,$$

(II) with full solvency risk, i.e., $\varphi^R>\varphi^S$, it holds that $\tilde{\mathcal{M}}_F(\varphi^R)\ge 0$, where

$$\tilde{\mathcal{M}}_F(\varphi^R):=\triangle(A_h^L-A^B)+\frac{\triangle A^B}{\varphi^R}-\kappa q.$$

Furthermore, it holds that $\lim_{\varphi^R\searrow\varphi^S}\tilde{\mathcal{M}}_F(\varphi^R)=\tilde{\mathcal{M}}_N$. Environments with partial solvency risk (see case (II) in lemma 4) do not exist with sufficiently loose collateral requirements.

First, note that with sufficiently loose collateral requirements, the collateral leverage channel of monitoring is not active. Thus, the banker's monitoring decision is only shaped through the benefits following from the return channel of monitoring and the costs associated with monitoring.

Second, based on corollary 1, we know that there is no environment with partial solvency risk and that for a regulatory leverage φ^R approaching the leverage threshold for solvency φ^S, the banker's incentives for monitoring in the presence of solvency risk $\tilde{\mathcal{M}}_F(\varphi^R)$ converge to those without solvency risk, i.e., it holds that $\lim_{\varphi^R\searrow\varphi^S}\tilde{\mathcal{M}}_F(\varphi^R)=\tilde{\mathcal{M}}_N$.

Third, note that in the case without solvency risk, the regulatory maximum leverage φ^R is irrelevant for the banker's monitoring decision. The banker monitors without solvency risk if and only if $\triangle(A_h^L-A_l^L)\ge\kappa q$. In contrast, with solvency risk, the regulatory maximum leverage influences the banker's monitoring decision. Specifically, with increasing leverage, the banker's incentives to monitor decrease, i.e., it holds that

$$\frac{\partial\tilde{\mathcal{M}}_F(\varphi^R)}{\partial\varphi^R}=-\frac{\triangle A^B}{(\varphi^R)^2}<0.$$

Knowing that the banker's incentives increase with decreasing leverage, we can first conclude that there exists no leverage that induces the banker to monitor if it holds that $\triangle(A_h^L - A_l^L) < \kappa q$. Second, for $\triangle(A_h^L - A^B) \geq \kappa q$, the banker always monitors with solvency risk, independent of the regulatory maximum leverage φ^R. Third and last, if it holds that $\triangle(A_h^L - A_l^L) \geq \kappa q > \triangle(A_h^L - A^B)$, there exists a leverage $\varphi^* > \varphi^S$, with

$$\tilde{\mathcal{M}}_F(\varphi^*) = \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\varphi^*} - \kappa q = 0 \quad \Leftrightarrow \quad \varphi^* = \frac{\triangle A^B}{\kappa q - \triangle(A_h^L - A^B)}, \tag{9}$$

so that for any regulatory maximum leverage $\varphi^R \leq \varphi^*$, the banker monitors.

In the subsequent analysis, we focus on situations where monitoring is socially optimal, but the costs associated with monitoring and the exposure to a solvency risk may incentivize the banker to shirk.

Assumption 3 (Monitoring Costs)
$\triangle(A_h^L - A_l^L) > \kappa q > \triangle(A_h^L - A^B)$.

To simplify the comparison of monitoring incentives of capital-constrained and liquidity-constrained bankers, we also rule out environments with a partial solvency risk if collateral requirements may not be sufficiently loose. We achieve this by assuming that loan-financed firms that experience a negative idiosyncratic shock do not produce any output, i.e., it holds that $A_l^L = 0$. As a result, banks face solvency risk whenever they fund loans with deposits, i.e., whenever it holds that $\varphi = \overline{\varphi}_m(\theta) > \varphi^S = 1$, where the latter equality follows directly from equation (4).

Assumption 4 (Solvency Risk)
$A_l^L = 0$, *so that* $\varphi^S = 1$.

We can show that with and without solvency risk, the collateral leverage channel increases the incentives for the banker to monitor. The collateral leverage channel is, however, only active if the banker is liquidity-constrained, at least without monitoring. In the case without solvency risk, the increased monitoring incentives due to the collateral leverage channel are irrelevant, as based on assumption 3, the banker always monitors. Hence, proposition 2 details the increased incentives for monitoring following from the collateral leverage channel only in the case with solvency risk. Based on assumption 4, we know that banks are always exposed to a solvency risk if they finance loans to firms with deposits (i.e., $\varphi > 1$) to some extent. Note that, in proposition 2, we only analyze the incentives for monitoring but do not impose that the bank has to attain the same leverage with capital constraints and liquidity constraints, respectively. Both dimensions, the banker's monitoring activity and the bank's leverage, will then be jointly considered in subsection 3.2, where we outline the optimal bank regulation and the optimal monetary policy.

Proposition 2 (Collateral Leverage Channel of Monitoring)
For given capital requirements leading to the regulatory maximum leverage φ^R*, tight collateral requirements set by the central bank, i.e., the haircut satisfies* $\psi > \tilde{\psi}_0(\varphi^R)$*, increase, compared to*

loose collateral requirements, i.e., the haircut satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$, in the presence of solvency risk the banker's incentives to monitor, as it holds that

$$\mathcal{M}_F(\theta) - \tilde{\mathcal{M}}_F(\varphi^R) = \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi)}{\overline{\varphi}_1(\theta)}\right] + \triangle A^B\left[\frac{1}{\overline{\varphi}_1(\theta)} - \frac{1}{\varphi^R}\right] > 0,$$

where for any haircut $\psi \leq \tilde{\psi}_1^S(\varphi^R)$, it holds that $\overline{\varphi}_1(\theta) = \varphi^R$, and $\overline{\varphi}_1(\theta) = \varphi_1^L(\psi) < \varphi^R$ otherwise. Furthermore, it holds that $\lim_{\psi \searrow \tilde{\psi}_0(\varphi^R)} \mathcal{M}_F(\theta) - \tilde{\mathcal{M}}_F(\varphi^R) = 0$.

It follows directly from proposition 2 that there exist environments where the banker attains the same leverage with a capital constraint and a liquidity constraint, but the collateral leverage channel is decisive in incentivizing the banker to monitor. Formally, this follows from the fact that for any haircut $\tilde{\psi}_0^S(\varphi^R) < \psi \leq \tilde{\psi}_1^S(\varphi^R)$, the banker attains the regulatory maximum leverage with monitoring ($\overline{\varphi}_1(\theta) = \varphi^R$), and is liquidity-constrained without monitoring ($\overline{\varphi}_0(\theta) = \varphi_0^L(\psi) < \varphi^R$), so that the collateral leverage channel is active, i.e., it holds that

$$\mathcal{M}_F(\theta) - \tilde{\mathcal{M}}_F(\varphi^R) = \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi)}{\varphi^R}\right] > 0.$$

Note that the latter expression is maximized for the haircut $\psi = \tilde{\psi}_1^S(\varphi^R)$, which just allows the bank to attain the maximum regulatory leverage φ^R with monitoring.

3.2 Optimal bank regulation and optimal monetary policy

In our economy, the government aims at maximizing utilitarian welfare, which can be achieved through an appropriate bank regulation and monetary policy. The bank regulator imposes capital requirements leading to a regulatory maximum leverage φ^R, while the central bank sets the interest rate r_{CB}^D on reserves and the collateral requirements in the form of the haircut ψ on bank loans, determining the banks' access to liquidity.

We start by observing that the interest rate r_{CB}^D on reserves does not affect welfare, as it is irrelevant for the banker's monitoring decision and the capital allocation, see lemma 4 and lemma 5. It then follows with the equilibrium condition (6) that the interest rate r_{CB}^D only influences prices in our economy. This is a manifestation of the neutrality of money, i.e., the interest rate policy of the central bank has no effect on the real allocation.[12]

Note that the capital and collateral requirements, as captured by the regulatory maximum leverage φ^R and the haircut ψ, both influence bank leverage and thus the allocation of capital among loan-financed and bond-financed firms. In addition, they may influence the monitoring decision m of the banker (see lemma 4). Formally, the optimization problem of the government is given by

$$\max_{\theta \in \Theta_m} W_m(\theta) = \max_{\theta \in \Theta_m} (\mathbb{E}_m[A_s^L] - A^B - m\kappa q)\overline{\varphi}_m(\theta)E + A^B(K + E),$$

where we used lemma 5 to express welfare $W_m(\theta)$ and applied the notation $\Theta_m := [1, +\infty) \times$

[12]We stress that the neutrality result is solely a consequence of flexible prices in our economy and not due to the fact that $r_{CB}^D = r_{CB}^D$. Even if a wedge between the two interest rate existed, the neutrality result would continue to hold.

$[\psi_m^M, 1]$ to represent the set of feasible policy measures, which itself depends on the monitoring decision of the banker. Not only the monitoring activity m is influenced by the haircut ψ set by the central bank and the regulatory maximum leverage φ^R imposed by the bank regulator, also the central bank's set of feasible haircuts $[\psi_m^M, 1]$ is affected by the banker's monitoring activity m. As outlined in subsection 3.1, the smallest feasible haircut increases with monitoring, i.e., it holds that $\psi_1^M > \psi_0^M$. Thus, if the banker monitors (i.e., $m = 1$), the central bank finds itself unable to set any haircut ψ lower than ψ_1^M.

As stated in subsection 2.4, we only focus on situations where the interest rates on deposits and bonds equal ($r^D = r^B$). This, however, requires that banks issue deposits and bond-financed firms operate. Accordingly, we need to exclude situations where the bank regulator or the central bank restrict banks to fully fund loans with equity (i.e., $\varphi^R = 1$ or $\psi = 1$), and where the bank regulator and the central bank allow banks to attain the maximum feasible leverage (i.e., $\varphi^R = \varphi^M$ and $\psi = \psi_m^M$), as this would rule out production by bond-financed firms. The conditions $\varphi^R > 1$ and $\psi < 1$ are not restrictive, as based on assumption 1, a loan-financed firm is more productive in expectation than a bond-financed firm, even without monitoring, and thus the government always prefers to allow as much loan financing as possible. In fact, the optimal policies of the bank regulator and the central bank never include a regulatory maximum leverage $\varphi^R = 1$ or a haircut $\psi = 1$. In contrast, based on assumption 1, there are situations where the bank regulator or the central bank would prefer to allow banks to attain the maximum feasible bank leverage (i.e., $\varphi^R = \varphi^M$ and $\psi = \psi_m^M$). We rule out such cases, but allow the regulatory maximum leverage and the haircut to be arbitrary close to the polar measures, i.e., in these cases the regulatory maximum leverage is given by $\varphi^R = \varphi^M - \epsilon$ and the haircut is given by $\psi = \psi_m^M + \epsilon$ with $\epsilon \to 0$. The optimal policies discussed in the following are thus only ϵ-optimal in certain situations, namely if the government wants banks to attain the maximum feasible bank leverage. To ease our notation, we will use the limit $\varphi^R = \varphi^M$ and $\psi = \psi_m^M$ to represent the ϵ-optimal policies of the bank regulator and the central bank.

We first study the optimal bank regulation in the presence of sufficiently loose collateral requirements set by the central bank, so that the bank is liquidity-constrained under no circumstances, i.e., we assume the central bank sets a haircut ψ that satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$. Given this particular monetary policy, we know that welfare is maximized if bank lending is at its maximum and bankers monitor. This reasoning follows from assumption 1, stating that even without monitoring, a loan-financed firm is more productive than a bond-financed firm, and assumption 3, which ensures that monitoring is socially optimal, i.e., the productivity gains outweigh the monitoring costs. However, the costs associated with monitoring and the exposure to a solvency risk may lead to shirking of the banker under a sufficiently large leverage. As outlined in the previous subsection, we know that there exists a critical leverage φ^* that satisfies

$$\tilde{\mathcal{M}}_F(\varphi^*) = \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\varphi^*} - \kappa q = 0 \qquad \Leftrightarrow \qquad \varphi^* = \frac{\triangle A^B}{\kappa q - \triangle(A_h^L - A^B)} > \varphi^S = 1.$$

The banker then monitors in the presence of loose collateral requirements, whenever the regulatory maximum leverage satisfies $\varphi^R \leq \varphi^*$. As a result, the bank regulator chooses capital requirements such that banks can attain the maximum feasible leverage, i.e., $\varphi^R = \varphi^M$, whenever $\varphi^M \leq \varphi^*$. This policy maximizes bank lending and induces bankers to monitor. Even if bankers do not monitor under the maximum feasible bank leverage, i.e., $\varphi^M > \varphi^*$, it may be optimal for the bank regulator to implement capital requirements that lead banks to attain the maximum feasible leverage ($\varphi^R = \varphi^M$). This is the case whenever maximum bank lending and no monitoring yields a higher welfare than reducing bank leverage to φ^* and thereby inducing monitoring, which is captured by condition (10) in proposition 3. In all other situations, the bank regulator will optimally choose to implement the regulatory maximum leverage $\varphi^R = \varphi^*$, restricting bank lending but inducing bankers to monitor.

Proposition 3 (Optimal Bank Regulation without Liquidity Constraints)
Suppose the central bank sets sufficiently loose collateral requirements, so that the bank is never liquidity-constrained, i.e., the haircut satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$.

Then, the bank regulator optimally sets $\varphi^R = \varphi^M$ *whenever (i)* $\varphi^M \leq \varphi^*$, *so that bank lending is maximized and the banker monitors, or (ii)* $\varphi^M > \varphi^*$, *so that bank lending is maximized and the banker does not monitor, but restricting the bank leverage to induce monitoring does not yield a welfare gain, i.e.,*

$$\frac{\varphi^M}{\varphi^*} \geq 1 + \frac{\triangle(A_h^L - A_l^L) - \kappa q}{\mathbb{E}_0[A_s^L] - A^B}. \tag{10}$$

Otherwise, the bank regulator optimally sets $\varphi^R = \varphi^*$, *so that bank lending is not maximized but the banker monitors.*

Next, we describe the optimal monetary policy for environments where capital requirements are sufficiently loose, so that the banker is always liquidity-constrained. Specifically, the regulatory maximum leverage following from the capital requirements set by the bank regulator satisfies $\varphi^R \geq \varphi_m^L(\psi)$, where ψ is the haircut chosen by the central bank and m is the banker's monitoring decision under the prevailing collateral requirements. Under these circumstances, the optimal monetary policy, which is formally outlined in the next proposition, follows in its logic the optimal bank regulation in the presence of loose collateral requirements.

Proposition 4 (Optimal Monetary Policy without Capital Constraints)
Suppose the bank regulator sets sufficiently loose capital requirements, so that the banker is never capital-constrained, i.e., the regulatory maximum leverage satisfies $\varphi^R \geq \varphi_m^L(\psi)$.

Then, the central bank optimally sets $\psi = \psi_1^M$ *whenever* $\varphi^M \leq \varphi^{**}$, *so that bank lending is maximized and the banker monitors. Moreover, the central bank optimally sets* $\psi = \psi_0^M$ *whenever* $\varphi^M > \varphi^{**}$, *so that bank lending is maximized and the banker does not monitor, but reducing the bank leverage to induce monitoring does not yield a welfare gain, i.e.,*

$$\frac{\varphi^M}{\varphi^{**}} \geq 1 + \frac{\triangle(A_h^L - A_l^L) - \kappa q}{\mathbb{E}_0[A_s^L] - A^B}, \tag{11}$$

where $\varphi^{**} = \varphi_1^L(\psi^{**}) > \varphi^S$, with ψ^{**} satisfying $\mathcal{M}_F(\theta^{**}) = 0$, where $\theta^{**} = (\varphi^R, \psi^{**})$. Otherwise, the central bank optimally sets $\psi = \psi^{**}$, so that bank lending is not maximized but the banker monitors.

Finally, we derive the optimal mix of bank regulation and monetary policy. Due to the collateral leverage channel of monitoring (see proposition 2), it follows that a liquidity-constrained banker monitors under a larger leverage compared to capital-constrained banker, i.e., it holds that $\varphi^{**} > \varphi^*$. We can thus conclude that it is optimal to restrict bank leverage by imposing collateral requirements instead of capital requirements. The optimal mix of bank regulation and monetary policy is thus represented by the regulatory maximum leverage satisfying $\varphi^R \geq \varphi_m^L(\psi)$ and the haircut ψ following proposition 4.

Corollary 2 (Optimal Bank Regulation and Optimal Monetary Policy)
It holds that $\varphi^{**} > \varphi^*$. Accordingly, it is optimal to set sufficiently loose capital requirements, i.e., $\varphi^R \geq \varphi_m^L(\psi)$, and collateral requirements, in the form of the haircut ψ, according to proposition 4.

3.3 Contingent capital requirements

From our previous analysis, we can deduce that the monitoring incentives of bankers depend on whether they are capital- or liquidity-constrained. In the latter case, bankers have increased incentives to monitor. It thus seems that compared to capital requirements, collateral requirements are special to some extent. This conclusion is certainly true when comparing collateral requirements to unweighted capital requirements.

However, if capital requirements are contingent, such that they ultimately vary with the monitoring activity, they can have a similar (or even the same) effect on the monitoring incentives. We refer to the monitoring benefits induced through contingent capital requirements as the *regulatory leverage channel* of monitoring. Contingent capital requirements already exist in the form of risk-dependent capital requirements implemented by bank regulators, for instance. In the following, we explore how contingent, risk-dependent capital requirements fit into our current framework.

Let σ_m denote the measure of risk which depends on the banker's monitoring activity. A lower parameter σ_m represents a lower risk exposure. The capital requirements set by the bank regulator are then assumed to be contingent on the risk exposure of the individual banker, i.e., the regulatory maximum leverage satisfies $\varphi^R(\sigma_m)$. A risk measure might, for example, be the standard deviation of loan returns; acknowledging that, in practice, risk is often measured differently, using the value-at-risk, for instance. Note that loan returns are, in equilibrium, directly linked to the productivity of firms, i.e., in the loan-financed sector, it holds that $(1 + r_s^L)q = A_s^L$ for all s. Based on assumption 4, the standard deviation of loan returns is then given by

$$\sigma_m = \sqrt{\eta_m(1-\eta_m)}A_h^L/q.$$

Note that it holds that $\eta_1(1-\eta_1) = \eta_0(1-\eta_0) + \triangle(1-2\eta_0-\triangle)$, so that for $\eta_0 > (\leq)(1-\triangle)/2$, the standard deviation decreases (increases) with bank monitoring, i.e., $\sigma_1 < (\geq)\sigma_0$.

We can always find a schedule for the risk-dependent capital requirements, so that the *regulatory* leverage channel is identical to the *collateral* leverage channel of monitoring, i.e., there exists a $\varphi^R(\cdot)$ such that $\varphi^L_m(\psi) = \varphi^R(\sigma_m)$ for all m. For $\eta_0 > (\leq)(1-\triangle)/2$, mimicking the collateral leverage channel with contingent capital requirements allows implicitly for less (more) risk-taking on the side of banks.

It thus follows that, under certain conditions, our analysis could also be interpreted as a comparison of non-contingent and contingent capital requirements regarding their effect on monitoring incentives. The collateral leverage channel could then be interpreted as the regulatory leverage channel. Using the standard deviation as a risk measure, we could illustrate that contingent capital requirements may indeed be used to replicate the collateral leverage channel of monitoring. However, doing so may not be in line with other objectives of contingent capital requirements, such as discouraging the banks' risk-taking, for instance. Collateral requirements implemented by the central bank have thus a unique effect on bankers' monitoring incentives.

4 Conclusion and Ramifications

The unique, or at least superior, ability to monitor is seen as a classical justification for the existence of banks. As banks play a central role in the allocation of funds (and thus resources) in our economy, it is important to understand the fundamental forces shaping banks' monitoring incentives. We develop a simple model that allows to study the monitoring incentives of banks in environments where banks are capital- and/ or liquidity-constrained. In our baseline model, the monitoring technology considered is in the spirit of Holmstrom and Tirole (1997), as it avoids any opportunistic behavior of the bank borrowers, which are firms in our setting.

In this paper, we show that capital constraints, following from regulatory (unweighted) capital requirements, and liquidity constraints, following from collateral requirements in central bank lending facilities, have different effects on the monitoring incentives of bankers. Specifically, we show that the benefits from monitoring are twofold: First, monitoring leads to greater chances for a high loan repayment and thus, ceteris paribus, it leads to increased expected profits of the bank. We dub this effect the *return channel* of monitoring. Second, as monitoring increases the expected value of bank loans, these loans increase in their collateral value, allowing the respective bank to borrow more reserves. This, in turn, induces any liquidity-constrained bank to grant more loans and issue more deposits in the first place, leading to higher expected profits for the bank as the leverage increases. We refer to this effect as *the collateral leverage channel* of monitoring. This channel, however, is only active if bankers are liquidity-constrained. Accordingly, we find that liquidity-constrained bankers have more incentives to monitor than capital-constrained bankers under any circumstance. We also show that the effect of central bank collateral requirements on bankers' monitoring incentives is also unique in comparison with contingent (e.g., risk-dependent) capital requirements. While such capital requirements lead to a regulatory leverage channel that can replicate the collateral leverage channel, such action may contradict other objectives, as discouraging the banks' risk-taking.

We have focused on loans as assets that can be used as collateral by banks to obtain central bank reserves. In practice, banks can use other assets such as corporate bonds with low default risk or government bonds as collateral to obtain central bank reserves. We can easily extend our model to allow banks in our model to buy corporate bonds from households by issuing deposits in order to use them as collateral at the central bank. If banks are not constrained by capital requirements, purchasing these securities, and financing these purchases with deposits, will lead to an increase of bank leverage and higher liquidity needs on the side of banks. However, under an appropriate haircut policy of the central bank, the collateral leverage channel is still at work. Namely, in order to keep monitoring incentives for bank loans at the desired level, the central bank would first define the class of assets that can be used as collateral and second simply adjust the haircuts on the assets in this class, such that banks have the same incentives to monitor as without the purchases of safe bonds.[13]

The model we developed has a simple structure and can be extended in various further ways: First, the production structure can be modeled in a more general way, assuming strictly concave technologies in at least one of the sectors, for instance. Second, bank default is frictionless in our economy, i.e., there are no further costs arising from banks defaulting on their liabilities. A more realistic version of our model would account for such costs, arising from default resolution, for instance. Third, in our framework, the collateral leverage channel was established through the collateral-enhancing effect of bank monitoring. However, such a leverage channel can also be established in other ways, with monitoring concerning a bank's in-house processes: For example, if banks have access to costly monitoring technologies that reduce their liquidity demand, a similar leverage channel emerges, induced by (binding) central bank collateral requirements.

[13] Details are available upon request.

References

Benigno, P. and Robatto, R. (2019). Private money creation, liquidity crises, and government interventions. *Journal of Monetary Economics*, 106:42–58.

Bernanke, B. S., Gertler, M., and Gilchrist, S. (1999). The financial accelerator in a quantitative business cycle framework. *Handbook of Macroeconomics, Edited by Taylor, John B and Woodford, Michael*, 1:1341–1393.

Bindseil, U. (2004). *Monetary Policy Implementation: Theory, Past, and Present.* Oxford University Press, Oxford.

Bindseil, U., Corsi, M., Sahel, B., and Visser, A. (2017). The Eurosystem collateral framework explained. *European Central Bank Occasional Paper*, 189.

Brumm, J., Grill, M., Kubler, F., and Schmedders, K. (2015). Collateral requirements and asset prices. *International Economic Review*, 56(1):1–25.

Chailloux, A., Gray, S., and McCaughrin, R. (2008). Central bank collateral frameworks: Principles and policies. *International Monetary Fund Working Paper*, 222.

De Fiore, F. and Uhlig, H. (2011). Bank finance versus bond finance. *Journal of Money, Credit and Banking*, 43(7):1399–1421.

Diamond, D. W. (1984). Financial intermediation and delegated monitoring. *Review of Economic Studies*, 51(3):393–414.

Faure, S. and Gersbach, H. (2017). Money creation and destruction. *CESifo Working Paper*, 6565.

Faure, S. and Gersbach, H. (2018). Money creation in different architectures. *CEPR Discussion Paper*, 13156.

Guerrieri, L. and Iacoviello, M. (2017). Collateral constraints and macroeconomic asymmetries. *Journal of Monetary Economics*, 90:28–49.

Holmstrom, B. and Tirole, J. (1997). Financial intermediation, loanable funds, and the real sector. *Quarterly Journal of Economics*, 112(3):663–691.

Kiyotaki, N. and Moore, J. (1997). Credit cycles. *Journal of Political Economy*, 105(2):211–248.

Nyborg, K. G. (2017). *Collateral Frameworks: The Open Secret of Central Banks.* Cambridge University Press, Cambridge.

A Equilibrium definition

Throughout our analysis, we focus on competitive equilibria as defined hereafter. We use the notation $C_m^B = \mathbb{E}_m[C_s^B] = (1 + \mathbb{E}_m[r_s^E])qE$ to represent aggregate consumption by bankers and $Y_m = \mathbb{E}_m[A_s^L]K^L + A^B K^B$ to represent aggregate production. As idiosyncratic productivity shocks are i.i.d. across firms and we assume a continuum of firms, we obtain by the law of large numbers that aggregate production by the loan-financed sector equals expected production of the loan-financed firm. Moreover, banks and firms are matched one-to-one, so that the expected consumption by the banker equals aggregate consumption of bankers.

Definition 1 (Competitive Equilibrium)
Given a monetary policy $r_{CB}^D > 0$ and $\psi \in [0,1]$, a competitive equilibrium is a set of prices $P > 0$ and $Q > 0$, interest rates $r^D > 0$, $r_s^L > 0$, with $s \in \{\underline{s}, \overline{s}\}$, and $r^B > 0$, and choices K^L, K^B, γ, φ and m, such that

- *given P, Q and r_s^L, with $s \in \{\underline{s}, \overline{s}\}$, the choice K^L maximizes the expected profits of the loan-financed firm,*

- *given P, Q and r^B, the choice K^B maximizes the expected profits of the bond-financed firm,*

- *given P, Q, r^D and r^B, the choice γ maximizes the utility of the household,*

- *given P, Q, r_{CB}^D, ψ, r_s^L, with $s \in \{\underline{s}, \overline{s}\}$, and r^D, the choices φ and m maximize the expected utility of the banker,*

- *the loan, bond, capital good and consumption good markets clear, i.e., $QK^L = \varphi QE$, $QK^B = \gamma QK$, $K^L + K^B = K + E$ and $C^H + C_m^B = Y_m$.*

B Alternative monitoring technology

In this section, we study the collateral leverage channel, assuming a different monitoring technology. Specifically, monitoring does not increase the probability for a positive idiosyncratic shock but directly affects the productivity in the case where a negative productivity shock realizes. In what follows, we outline the changes in the setup for loan-financed firms and bankers, and then discuss the resulting equilibrium properties. The alternative monitoring technology does not lead to changes for bond-financed firms, households and the government sector, including the bank regulator and the central bank.

B.1 Loan-financed firms

The loan-financed firm uses the capital good $K^L \geq 0$ to produce consumption good with the risky technology $A^L_{s,m}K^L$, where the marginal productivity $A^L_{s,m} \geq 0$ is not only affected by an idiosyncratic shock s, but also by the monitoring activity m of the matched banker. The productivity can be either low ($s = l$) or high ($s = h$), so that it holds that $A^L_{h,m} > A^L_{l,m}$. The idiosyncratic productivity shocks are i.i.d. across firms, where a positive idiosyncratic shock occurs with probability $\eta \in (0, 1)$. Bankers can engage into costly monitoring ($m = 1$) or shirking ($m = 0$). Monitoring by the matched banker limits the impact of a negative idiosyncratic productivity shock. Formally, monitoring has the following effect on the productivity of the loan-financed firm: $A^L_{h,1} = A^L_{h,0}$ and $A^L_{l,1} = A^L_{l,0} + \triangle$, where $\triangle > 0$.

The external funds QK^L borrowed by the firm from the matched bank requires a repayment that is determined by the interest rate $r^L_{s,m} > 0$, which depends on the idiosyncratic shock s of the firm and the monitoring activity m of the matched banker. Accounting for the fact that firms are profit-maximizing and subject to limited liability, it follows that the optimization problem of the loan-financed firm is given in real terms by

$$\max_{K^L \geq 0} \mathbb{E}[\{A^L_{s,m} - (1 + r^L_{s,m})q\}^+]K^L, \tag{12}$$

where we use the notation $q := Q/P$ to denote the capital good price in terms of the consumption good.

Due to limited liability, there exists no optimal, finite demand of capital good if the firm is exposed to excess returns in at least one state. In contrast, without excess returns, the firm will be indifferent between any amount of capital good put into production. The previous explanations are formally summarized in the following lemma.

Lemma 6 (Optimal Choice of the Loan-Financed Firm)
The loan-financed firm optimally chooses capital good $K^L = +\infty$ if and only if $A^L_{s,m} > (1+r^L_{s,m})q$ for some s, and $K^L \in [0, +\infty)$ otherwise.

In equilibrium, the optimal demand for capital good must be finite and firm default cannot arise due to the rationality of all agents in the economy. Accordingly, it must hold that in equilibrium, $(1 + r^L_{s,m})q = A^L_{s,m}$ for all s, m.

We make specific assumptions on firm productivity: First, we assume that a loan-financed firm is more productive on average than a bond-financed firm, even if the matched banker does not monitor. This assumption guarantees that the loan-financed firms—and thus banks—are needed to maximize aggregate production and ultimately welfare. Second, only when a loan-financed firm experiences a negative idiosyncratic shock, it is less productive than a bond-financed firm, even if the matched banker monitors the loan-financed firm. The latter assumption allows us to introduce solvency risk on the side of banks, as outlined in subsection B.2.

Assumption 5 (Firm Productivities)
$\mathbb{E}[A^L_{s,0}] > A^B$, *and* $A^B > A^L_{l,1}$.

Note that, based on assumption 5, we implicitly imposed an upper bound on the effect of monitoring, as the condition $A^B > A^L_{l,1}$ translates into $\triangle < A^B - A^L_{l,0}$. Moreover, it follows from assumption 5 that independent of the monitoring activity by the matched banker, a loan-financed firm is strictly more productive than a bond-financed firm if it incurs a positive productivity shock, i.e., it holds that $A^L_{h,m} > A^B$ for all m.

B.2 Bankers

The interest rate on loans granted by the bank is given by $r^L_{s,m} > 0$, which depends on the idiosyncratic shock s as well as on the banker's monitoring decision m. Deposits are credited with interest according to the rate $r^D > 0$. The nominal equity returns are then given by

$$(1 + r^E_{s,m})E^b = \left\{(1 + r^L_{s,m})L^b + (1 + r^D_{CB})D^{CB} - (1 + r^D)D^b - (1 + r^L_{CB})L^{CB}\right\}^+,$$

where we use $\{X\}^+ = \max\{X, 0\}$ to account for the limited liability of the bank. Using the structure of deposit financing, $D^b = L^b - E^b$, reserve loans and reserve deposits, $L^{CB} = D^{CB} = \alpha(L^b - E^b)$ (for a derivation, see subsection 2.6), it follows that the nominal equity returns are given by

$$(1 + r^E_{s,m})E^b = \left\{(1 + r^L_{s,m})L^b + [(1 + r^D_{CB})\alpha - (1 + r^D) - (1 + r^L_{CB})\alpha](L^b - E^b)\right\}^+.$$

Using assumption 2, which imposes the equality of interest rates on reserves ($r^D_{CB} = r^L_{CB}$), and using the definition of bank leverage $\varphi = L^b/E^b$, we obtain the rate of return on bank equity

$$r^E_{s,m}(\varphi) := \{(r^L_{s,m} - r^D)\varphi + 1 + r^D\}^+ - 1.$$

Based on the explanations in subsection 2.3 and 2.4, we know that, in equilibrium, the interest rates on loans and deposits satisfy $r^L_{s,m} = A^L_{s,m}/q - 1$ for all s and $r^D = r^B = A^B/q - 1$. Accordingly, the equilibrium rate of return on bank equity can be expressed using economic fundamentals, i.e., it holds that

$$r^E_{s,m}(\varphi) := \{(A^L_{s,m} - A^B)\varphi + A^B\}^+/q - 1. \tag{13}$$

It follows with our assumptions on firm productivity (see assumption 5) that only in the presence of a low productivity ($s = l$), the bank is making losses on loans funded with deposits. We can derive a maximum leverage, denoted by φ_m^S, which guarantees solvency of the bank in all states. This leverage is obtained by setting the equity return in the low productivity state to zero, i.e.,

$$1 + r_{l,m}^E(\varphi_m^S) = 0 \quad \Leftrightarrow \quad (A_{l,m}^L - A^B)\varphi_m^S + A^B = 0 \quad \Leftrightarrow \quad \varphi_m^S := \frac{A^B}{A^B - A_{l,m}^L}. \tag{14}$$

Note that the leverage threshold φ_m^S depends on the banker's monitoring activity m, as the latter increases the productivity of the financed firm whenever it incurs a negative shock, i.e., it holds that $A_{l,1}^L = A_{l,0}^L + \triangle$ with $\triangle > 0$. Thus, with monitoring, the bank can leverage more, i.e., issue more deposits and provide more loan financing, until it is exposed to a solvency risk ($\varphi_1^S > \varphi_0^S$).

When capital good transactions are settled, the bank requires liquidity in the form of reserves which it can borrow from the central bank by pledging the bank loans granted to the matched firm. At that point in time, productivity shocks have not realized yet, so that the expected value of bank loans is given by $(1 + \mathbb{E}[r_{s,m}^L])L^b$. The central bank applies a haircut $\psi \in [0, 1]$ on the value of bank loans, so that the overall collateral available to the bank, also referred to as the "collateral capacity", is given by $(1 - \psi)(1 + \mathbb{E}[r_{s,m}^L])L^b$. Taking the repayment obligation on reserve loans into account, the reserve borrowing L^{CB} of the bank cannot exceed the bank's collateral capacity, which leads to the liquidity constraint

$$(1 - \psi)(1 + \mathbb{E}[r_{s,m}^L])L^b \geq (1 + r_{CB}^L)L^{CB}.$$

Using the structure of reserve loans, $L^{CB} = \alpha(L^b - E^b)$, and the definition of the bank leverage, $\varphi = L^b/E^b$, we can reformulate the latter inequality as

$$(1 - \psi)(1 + \mathbb{E}[r_{s,m}^L])\varphi \geq \alpha(1 + r_{CB}^D)(\varphi - 1),$$

where we also made use of assumption 2, stating the equality of interest rates on reserves deposits and reserve loans ($r_{CB}^D = r_{CB}^L$). We can then define a maximum leverage, up to which liquidity of the bank is guaranteed. This leverage, denoted by $\varphi_m^L(\psi)$, is determined by the binding liquidity constraint, i.e.,

$$(1 - \psi)(1 + \mathbb{E}[r_{s,m}^L])\varphi_m^L(\psi) = \alpha(1 + r_{CB}^D)[\varphi_m^L(\psi) - 1],$$

so that

$$\varphi_m^L(\psi) = \frac{\alpha(1 + r_{CB}^D)}{\alpha(1 + r_{CB}^D) - (1 - \psi)(1 + \mathbb{E}[r_{s,m}^L])}. \tag{15}$$

The banker's monitoring decision m affects the leverage threshold $\varphi_m^L(\psi)$, as monitoring increases the productivity and ultimately the loan repayment of the financed firm in the presence of a negative idiosyncratic shock. Higher loan repayment in one state increases the valuation of bank loans and finally the collateral capacity of the bank, allowing it to borrow more reserves at the central bank. Thus, the bank grants more loans, funded with deposits, in the first place, i.e., the maximum leverage is increasing with bank monitoring ($\varphi_1^L(\psi) > \varphi_0^L(\psi)$). The bank never chooses a leverage larger than $\varphi_m^L(\psi)$, as it would lead to illiquidity with certainty, in which case the government would seize all bank assets and thus eliminate the potential returns on bank equity. The bank is also subject to a regulatory leverage $\varphi \leq \varphi^R$, where $\varphi^R \in [1, +\infty)$ denotes the regulatory maximum leverage.

Using equation (15) and the equilibrium condition (6) in subsection 2.6, we can express the maximum leverage $\varphi_m^L(\psi)$ guaranteeing liquidity of the banker, using model primitives, i.e., it holds that

$$\varphi_m^L(\psi) = \frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}[A_{s,m}^L]}. \tag{16}$$

The banker uses the returns on bank equity $[1 + r_{s,m}^E(\varphi)]E^b$ to purchase consumption good C_s^B at the nominal price $P > 0$. The banker is maximizing the expected utility, which we assume to be linearly increasing in consumption. Accordingly, the optimization problem of the banker is given in real terms by

$$\max_{\substack{\varphi \in [1, \overline{\varphi}_m(\theta)],\\ m \in \{0,1\}}} \{1 + \mathbb{E}[r_{s,m}^E(\varphi)] - m\kappa\varphi\} qE,$$

where we made use of the definitions $E^b = QE$ and $\varphi = L^b/E^b$ to obtain $m\kappa L^b = m\kappa\varphi QE$. As in subsection 2.6, we apply the notation $\overline{\varphi}_m(\theta) = \min\{\varphi^R, \varphi_m^L(\psi)\}$, where $\theta = (\varphi^R, \psi)$ represents the policy measures imposed by the bank regulator and the central bank.

We now outline the banker's optimal choice in equilibrium. First, we focus on the banker's optimal choice of the leverage or, in other words, the optimal loan supply and deposit issuance. Based on assumption 5, we know that the expected productivity of a loan-financed firm is higher than the productivity of a bond-financed firm, even without monitoring by the matched banker ($\mathbb{E}[A_{s,0}^L] > A^B$). Interest rates on loans and deposits are directly linked to firm productivity in equilibrium, namely, it holds that $r_{s,m}^L = A_{s,m}^L/q - 1$ for all s and $r^D = r^B = A^B/q - 1$. Accordingly, the expected loan repayment is larger than the interest payment on deposits, incentivizing the banker to attain the maximum leverage, i.e., $\varphi = \overline{\varphi}_m(\theta)$.

Next, we turn to the banker's monitoring decision, which generally depends on three factors: (i) the monitoring-induced increase of loan repayment for a negative idiosyncratic productivity shock of the financed firm, to which we refer to as the *return channel* of monitoring, (ii) the monitoring-induced increase of collateral capacity, allowing any liquidity-constrained bank to expand deposit issuance and loan supply, to which we refer to as the *collateral leverage channel* of monitoring, and (iii) the monitoring costs. If, independent of the monitoring decision, the banker is not exposed to a solvency risk (case (I) in lemma 7), the banker internalizes all the expected benefits $(1-\eta)\triangle$ from higher loan repayment due to monitoring in the presence of a negative idiosyncratic shock. In turn, if the banker is exposed to a solvency risk (cases (II) and (III) in lemma 7), the banker defaults for a low productivity of the financed firm and thus expects no benefits from higher loan repayment due to monitoring. In other words, the return channel is not active. Solvency risk thus reduces the banker's incentives to monitor and ultimately may even induce the banker to shirk. However, if the bank is liquidity-constrained, monitoring also increases the valuation of bank loans and thereby the collateral capacity, allowing the bank to expand deposit issuance and loan supply, which increases the expected profits of the bank. This collateral leverage channel is only active if the banker is liquidity-constrained at least without monitoring, i.e., $\overline{\varphi}_0(\theta) = \varphi_0^L(\psi) < \overline{\varphi}_1(\theta) \leq \varphi^R$. In contrast, if, independent of the monitoring decision, the banker is only constrained by capital, i.e., $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, the banker's decision about monitoring only involves the benefits following from the return channel and the monitoring costs. The following lemma summarizes the previous explanations on the banker's optimal choice.

Lemma 7 (Optimal Choice of the Banker)
In equilibrium, the banker's optimal choice of leverage is given by $\varphi = \overline{\varphi}_m(\theta)$ and the banker's optimal monitoring decision is given by $m = 1$ if and only if

(I) without solvency risk, i.e., $\overline{\varphi}_m(\theta) \leq \varphi_m^S$ for all m, it holds that $\mathcal{M}_N(\theta) \geq 0$, where

$$\mathcal{M}_N(\theta) := (1-\eta)\triangle + (\mathbb{E}[A_{s,0}^L] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q,$$

(II) with partial solvency risk, i.e., $\overline{\varphi}_0(\theta) > \varphi_0^S$ and $\overline{\varphi}_1(\theta) \leq \varphi_1^S$, it holds that $\mathcal{M}_P(\theta) \geq 0$, where

$$\mathcal{M}_P(\theta) := -(1-\eta)\left[A^B - A_{l,1}^L - \frac{A^B}{\overline{\varphi}_1(\theta)}\right] + \eta(A_{h,0}^L - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q,$$

(III) with full solvency risk, i.e., $\overline{\varphi}_m(\theta) > \varphi_m^S$ for all m, it holds that $\mathcal{M}_F(\theta) \geq 0$, where

$$\mathcal{M}_F(\theta) := \eta(A_{h,0}^L - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q.$$

B.3 Equilibrium properties

We first provide necessary conditions for the existence of a competitive equilibrium and the bank's exposure to a solvency risk. Then, we characterize welfare, using economic fundamentals, and provide further details on the monitoring decision of the banker.

Existence and solvency risk. The existence of an equilibrium crucially depends on the clearing of the capital good market. Specifically, an equilibrium only exists if loan-financed firms do not receive more funds from banks than needed to purchase the entire capital good in the economy, i.e. $L^b = QK^L = \overline{\varphi}_m(\theta)E \leq K + E$ or, with the notation $\varphi^M := 1 + K/E$, equivalently, $\overline{\varphi}_m(\theta) \leq \varphi^M$. From the latter inequality, we can derive a condition on the capital requirements or the collateral requirements, depending which ones are binding. First, if the banker is constrained by capital, i.e., $\varphi^R \leq \varphi_m^L(\psi)$, it must hold that $\varphi^R \leq \varphi^M$. In turn, if the banker is constrained by liquidity, i.e., $\varphi_m^L(\psi) \leq \varphi^R$, the collateral requirements in the form of the haircut must be such that $\varphi_m^L(\psi) \leq \varphi^M$. From the latter condition, we can derive a smallest feasible haircut ψ_m^M, which, if implemented, allows bankers to provide as much loan financing as needed to allow loan-financed firms to acquire the entire capital good in the economy. Any haircut lower than ψ_m^M conflicts with the clearing condition for the capital good market and thus does not permit an equilibrium, whereas any haircut larger than ψ_m^M restricts the bank leverage below the maximum feasible, i.e. $\varphi_m^L(\psi) < \varphi^M$, but guarantees the existence of an equilibrium.

If an equilibrium exists, i.e., $\varphi^R \leq \varphi^M$ or $\psi \geq \psi_m^M$, the banker is exposed to a solvency risk if the attained leverage is sufficiently large to exceed the leverage guaranteeing solvency in all states, i.e., $\overline{\varphi}_m(\theta) > \varphi_m^S$. Clearly, this is only possible if the capital requirements, leading to the regulatory maximum leverage, are sufficiently loose, i.e., $\varphi^R > \varphi_m^S$, and the haircut set by the central bank is sufficiently small to achieve $\varphi_m^L(\psi) > \varphi_m^S$. We can use the condition $\varphi_m^L(\psi) > \varphi^S$ to derive the smallest possible haircut ψ_m^S guaranteeing solvency of the bank in all states: For any haircut ψ satisfying $\psi < \psi_m^S$, the banker is exposed to a solvency risk, assuming that capital requirements are sufficiently loose and it holds $\varphi^R > \varphi_m^S$. Proposition 5 provides the details.

Proposition 5 (Existence and Solvency Risk)
A competitive equilibrium exists only if $\varphi^R \leq \varphi^M$ or $\varphi_m^L(\psi) \leq \varphi^M$, where the latter inequality is equivalent to

$$\psi \geq \psi_m^M := 1 - \frac{\alpha A^B}{\mathbb{E}[A_{s,m}^L](1 + E/K)},$$

where the banker is exposed to a solvency risk only if $\varphi^R > \varphi_m^S$ and $\varphi_m^L(\psi) > \varphi_m^S$, where the latter inequality is equivalent to

$$\psi < \psi_m^S := 1 - \frac{\alpha A_{l,m}^L}{\mathbb{E}[A_{s,m}^L]}.$$

The banker's monitoring decision m follows from lemma 7.

The smallest feasible haircut ψ_m^M and the smallest possible haircut ψ_m^S guaranteeing solvency of banks both depend on the monitoring activity m. Note that bank monitoring increases productivity in the presence of negative idiosyncratic shock, i.e., $A_{h,1}^L = A_{h,0}^L$ and $A_{l,1}^L = A_{l,0}^L + \triangle$, and thereby also increases the expected loan repayment, i.e., $\mathbb{E}[A_{s,1}^L] = \mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle$. The smallest feasible haircut ψ_m^M increases with monitoring, i.e., $\psi_1^M > \psi_0^M$, as monitoring increases the collateral value of bank loans, but leaves the maximum feasible bank leverage φ^M unchanged. In contrast, the smallest possible haircut ψ_m^S guaranteeing solvency of banks decreases with monitoring, i.e.,

$$\psi_0^S = 1 - \frac{\alpha A_{l,0}^L}{\mathbb{E}[A_{s,0}^L]} > \psi_1^S = 1 - \frac{\alpha A_{l,1}^L}{\mathbb{E}[A_{s,1}^L]} = 1 - \frac{\alpha (A_{l,0}^L + \triangle)}{\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle}.$$

Monitoring increases the expected value of bank loans and would lead on its own to a higher critical haircut. However, bank monitoring also increases the necessary leverage for which the bank defaults, i.e., $\varphi_1^S > \varphi_0^S$, which by itself would lead to a lower critical haircut. It turns out that the second effect of monitoring dominates the first and the smallest possible haircut guaranteeing solvency of banks is actually decreasing with bank monitoring, i.e., it holds that $\psi_0^S > \psi_1^S$. This result contrasts the one obtained with the monitoring technology used in section 2.

Welfare. The following lemma provides a characterization of utilitarian welfare using economic fundamentals. Due to our assumption of linear utility, utilitarian welfare comprises aggregate consumption as well as utility losses due to monitoring by bankers, i.e., welfare, denoted by W, satisfies $W = C^H + C^B - m\kappa q\varphi E$, where $C^B = \mathbb{E}_m[C_s^B] = (1 + \mathbb{E}[r_{s,m}^E(\varphi)])qE$ denotes aggregate consumption by bankers.[14] Welfare is generally affected by three factors: the regulatory maximum leverage φ^R and the haircut ψ, both limiting bank leverage and thus the capital allocation between loan-financed and bond-financed firms, as well as the monitoring activity of bankers m, influencing the productivity of loan-financed firms. Note that the monitoring decision of the banker may also be influenced by the policy measures θ, the regulatory maximum leverage φ^R and the haircut ψ (see lemma 7).

Lemma 8 (Welfare)
In equilibrium, welfare is given by $W_m(\theta) = (\mathbb{E}[A_{s,m}^L] - A^B - m\kappa q)\overline{\varphi}_m(\theta)E + A^B(K + E)$.

Monitoring. We proceed as in section 2 by contrasting two situations: In the first, the banker is solely constrained by capital, as collateral requirements set by the central bank are sufficiently loose, i.e., it holds that $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$. In the second situation, the banker is constrained by liquidity at least without monitoring, i.e., it holds that $\overline{\varphi}_0(\theta) < \overline{\varphi}_1(\theta) \leq \varphi^R$. In the first (second) situation, the haircut ψ set on bank loans used as collateral must be sufficiently small (large), so that it holds that $\overline{\varphi}_0(\theta) = \varphi_0^L(\psi) \geq (<)\varphi^R$ or, equivalently,

$$\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}[A_{s,0}^L]} \geq (<)\varphi^R \qquad \Leftrightarrow \qquad \psi \leq (>)\tilde{\psi}_0(\varphi^R) := 1 - \frac{\alpha A^B}{\mathbb{E}[A_{s,0}^L]}\frac{\varphi^R - 1}{\varphi^R},$$

where we exploited equation (16) to represent $\varphi_m^L(\psi)$ using model primitives. Note that the banker is constrained by liquidity with monitoring whenever the collateral requirements are sufficiently tight, i.e., it holds that $\overline{\varphi}_1(\theta) = \varphi_1^L(\psi) < \varphi^R$ or, equivalently,

$$\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}[A_{s,1}^L]} < \varphi^R \qquad \Leftrightarrow \qquad \psi > \tilde{\psi}_1(\varphi^R) := 1 - \frac{\alpha A^B}{\mathbb{E}[A_{s,1}^L]}\frac{\varphi^R - 1}{\varphi^R},$$

where we again used the representation of the leverage $\varphi_m^L(\psi)$, following from equation (16). Bank monitoring increases the collateral value of bank loans and allows the bank to borrow more reserves from the central bank. Thus, when the bank is liquidity-constrained with monitoring, it is also liquidity-constrained without monitoring. Formally, it holds that $\tilde{\psi}_1^S(\varphi^R) > \tilde{\psi}_0^S(\varphi^R)$.

Next, we describe the banker's monitoring decision in the presence of sufficiently loose collateral requirements set by the central bank, so that the banker is never constrained by liquidity but only by capital. In other words, the haircut set by the central bank is sufficiently small, so

[14] Note that the idiosyncratic productivity shocks are i.i.d. across firms, and banks and firms exist each in a continuum, and as they are matched one-to-one. Thus, by the law of large numbers, the expected consumption by the banker equals the aggregate consumption of bankers.

that it satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$.

Corollary 3 (Monitoring Decision without Liquidity Constraints)
Suppose the collateral requirements set by the central bank are sufficiently loose, so that the bank is never liquidity-constrained, i.e., $\psi \leq \tilde{\psi}_0(\varphi^R)$. Then, it holds that $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$ and the banker optimally monitors (i.e., $m = 1$), if and only if

(I) without solvency risk, i.e., $\varphi^R \leq \varphi_0^S$, it holds that $\tilde{\mathcal{M}}_N \geq 0$ where

$$\tilde{\mathcal{M}}_N := (1-\eta)\triangle - \kappa q,$$

(II) with partial solvency risk, i.e., $\varphi_1^S \geq \varphi^R > \varphi_0^S$, it holds that $\tilde{\mathcal{M}}_P(\varphi^R) \geq 0$, where

$$\tilde{\mathcal{M}}_P(\varphi^R) := -(1-\eta)(A^B - A_{l,1}^L) + \frac{(1-\eta)A^B}{\varphi^R} - \kappa q,$$

(III) with full solvency risk, i.e., $\varphi^R > \varphi_1^S$, it holds that $\tilde{\mathcal{M}}_F \geq 0$, where

$$\tilde{\mathcal{M}}_F := -\kappa q.$$

Furthermore, it holds that $\lim_{\varphi^R \searrow \varphi_0^S} \tilde{\mathcal{M}}_P(\varphi^R) = \tilde{\mathcal{M}}_N$ and $\lim_{\varphi^R \nearrow \varphi_1^S} \tilde{\mathcal{M}}_P(\varphi^R) = \tilde{\mathcal{M}}_F$.

Note that without a solvency risk or with full exposure to a solvency risk, the banker's monitoring decision is not affected by the capital requirements in the presence of loose collateral requirements. Without solvency risk, the banker monitors whenever the benefits following from the return channel are sufficient to cover the monitoring costs, i.e., whenever it holds that $(1-\eta)\triangle \geq \kappa q$. With a full exposure to solvency risk, in turn, the banker does not enjoy any benefits from the increased productivity of the financed firm, but only incurs costs when monitoring. Accordingly, the banker monitors in this case only if there are no monitoring costs, i.e., whenever it holds that $\kappa = 0$. Finally, with partial exposure to a solvency risk, the banker's incentives depend on the regulatory maximum leverage following from the capital requirements. Specifically, a loosening of capital requirements decreases the banker's incentives to monitor, i.e., it holds that

$$\frac{\partial \mathcal{M}_P(\theta)}{\partial \varphi^R} = -\frac{(1-\eta)A^B}{(\varphi^R)^2} < 0.$$

From the latter result and the fact that $\lim_{\varphi^R \searrow \varphi_0^S} \tilde{\mathcal{M}}_P(\varphi^R) = \tilde{\mathcal{M}}_N$, we know that in the presence of partial solvency risk, the banker is never monitoring if $(1-\eta)\triangle \leq \kappa q$, and is always monitoring if $(1-\eta)\triangle > \kappa q$ and $\varphi^R \leq \varphi^*$, where

$$\tilde{\mathcal{M}}_P(\varphi^*) = -(1-\eta)(A^B - A_{l,1}^L) + \frac{(1-\eta)A^B}{\varphi^*} - \kappa q = 0 \quad \Leftrightarrow \quad \varphi^* = \frac{(1-\eta)A^B}{\kappa q + (1-\eta)(A^B - A_{l,1}^L)}.$$

We are particularly interested in situations where monitoring is socially optimal but the costs associated with monitoring and the exposure to a solvency risk induce the banker to shirk in the absence of the collateral leverage channel. From lemma 5, we know that the condition $(1-\eta)\triangle \geq \kappa q$ guarantees that monitoring is socially optimal.

Assumption 6 (Monitoring Costs)
$(1-\eta)\triangle \geq \kappa q.$

We now want to analyze the banker's monitoring decision in the presence of sufficiently loose capital requirements, such that the banker is never constrained by capital but only by liquidity, i.e. it holds that $\varphi^R \geq \varphi^L_m(\psi)$ for all m. We thereby again focus on the three situations, differing in the banker's exposure to a solvency risk; see cases (I)-(III) in lemma 7. First, we can show that under assumption 6, the banker always monitors without solvency risk, even without taking the benefits following from the collateral leverage channel into account. The reason is that the expected benefits of a higher loan repayment are sufficient to exceed the monitoring costs ($(1-\eta)\triangle \geq \kappa q$). Second, these direct effects of monitoring are not internalized by the banker if there is a solvency risk. In the cases with partial and full exposure to solvency risk, lemma 9 thus provides the conditions on the haircut ψ, so that the monitoring benefits following from the collateral leverage channel are sufficient to incentivize the banker to monitor.

Lemma 9 (Monitoring Decision without Capital Constraints)
Suppose that the capital requirements set by the bank regulator are sufficiently loose, so that the banker is never constrained by capital, i.e., $\varphi^R \geq \varphi^L_m(\psi)$. Then, it holds that $\overline{\varphi}_m(\theta) = \varphi^L_m(\psi)$ for all m and

(I) with no solvency risk, i.e., $\psi \geq \psi^S_0$, the banker always monitors,

(II) with partial solvency risk, i.e., $\psi^S_0 > \psi \geq \psi^S_1$, there exists a critical haircut $\psi^{**} = \min\left\{\psi^S_0 \geq \psi \geq \psi^S_1 : \mathcal{M}_P(\theta) \geq 0\right\}$, so that the banker monitors if and only if $\psi \geq \psi^{**}$,

(III) with full solvency risk, i.e., $\psi^S_1 > \psi$, the banker monitors if and only if

$$\psi \leq \hat{\psi} := 1 - \frac{\chi \alpha A^B}{\chi \mathbb{E}[A^L_{s,0}] + (1-\eta)\triangle}, \qquad \text{where} \qquad \chi := \frac{\kappa q}{\eta(A^L_{h,0} - A^B)}.$$

We are particularly interested in case (III) of lemma 7 and lemma 9, where independent of the monitoring decision, the banker is exposed to a solvency risk, i.e., it holds that $\psi^S_1 > \psi$. Note that, in the presence of monitoring, the banker can only be exposed to a solvency risk if it holds that

$$\psi^M_1 < \psi^S_1 \qquad \Leftrightarrow \qquad \frac{E}{K} < \frac{A^B - A^L_{l,1}}{A^L_{l,1}}.$$

We now further detail when the critical haircut $\hat{\psi}$, which in the presence of a full exposure to a solvency risk induces the banker to monitor, can be achieved indeed, as it weakly exceeds the smallest feasible haircut ψ_1^M, and when the condition $\psi \leq \hat{\psi}$ does not constitute an additional condition, as it holds that $\hat{\psi} \geq \psi_1^S$.

Lemma 10 (Collateral Leverage Channel of Monitoring)
It holds that $\psi_1^M \leq \hat{\psi}$ if and only if

$$\frac{E}{K} \leq \frac{1-\chi}{\chi} \frac{(1-\eta)\triangle}{\mathbb{E}[A_{s,1}^L]},$$

and $\hat{\psi} \geq \psi_1^S$ if and only if

$$\chi \leq \frac{(1-\eta)\triangle A_{l,1}^L}{A^B \mathbb{E}[A_{s,1}^L] - A_{l,1}^L \mathbb{E}[A_{s,0}^L]}.$$

The parameter χ follows from lemma 9.

B.4 Optimal bank regulation and optimal monetary policy

As in section 2, the government aims at maximizing welfare by setting the appropriate bank regulation and monetary policy. Also with the alternative technology, the neutrality of money applies, so that the optimization problem of the government is formally given by

$$\max_{\theta \in \Theta_m} W_m(\theta) = \max_{\theta \in \Theta_m} (\mathbb{E}[A_{s,m}^L] - A^B - m\kappa q)\overline{\varphi}_m(\theta)E + A^B(K+E),$$

where we used lemma 8 to express welfare $W_m(\theta)$ and again applied the notation $\Theta_m := [1, +\infty) \times [\psi_m^M, 1]$ to represent the set of feasible policy measures, which itself depends on the monitoring activity m of the banker. In particular, not only is the monitoring activity m influenced by the policy measures, but also the central bank's set of feasible haircuts $[\psi_m^M, 1]$ is affected by the monitoring activity m. As outlined before, the smallest feasible haircut increases with monitoring ($\psi_1^M > \psi_0^M$). Thus, if bankers monitor ($m = 1$), the central bank finds itself unable to set any haircut ψ lower than ψ_1^M.

We first discuss the optimal bank regulation in the presence of sufficiently loose collateral requirements set by the central bank, i.e., the haircut satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$, so that the banker is only constrained by capital. The logic of the optimal bank regulation exactly follows the one in section 2.

Proposition 6 (Optimal Bank Regulation without Liquidity Constraints)
Suppose the central bank sets sufficiently loose collateral requirements, so that the banker is never constrained by liquidity, i.e., the haircut satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$.

Then, the bank regulator optimally sets capital requirements leading to the regulatory maximum leverage $\varphi^R = \varphi^M$ whenever (i) $\varphi^M \leq \varphi^*$, such that bank lending is maximized and the banker monitors, or (ii) $\varphi^M > \varphi^*$, such that bank lending is maximized and the banker does not *monitor, but reducing bank leverage to induce monitoring does not yield a welfare gain, i.e.,*

$$\frac{\varphi^M}{\varphi^*} \geq 1 + \frac{(1-\eta)\triangle}{\mathbb{E}[A^L_{s,0}] - A^B}, \tag{17}$$

Otherwise, the bank regulator optimally implements capital requirements leading to the regulatory maximum leverage $\varphi^R = \varphi^*$, restricting bank leverage below the maximum feasible one and thereby inducing monitoring.

We now discuss the optimal monetary policy, assuming that the banker is only constrained by liquidity. In other words, capital requirements set by the bank regulator are sufficiently loose, i.e., the regulatory maximum leverage satisfies $\varphi^R \geq \varphi^L_m(\psi)$. For what follows, we use the notation $\hat{\varphi} = \varphi^L_0(\hat{\psi})$.

Proposition 7 (Optimal Monetary Policy without Capital Constraints)
Suppose that the bank regulator sets sufficiently loose capital requirements, so that the banker is never constrained by capital, i.e., $\varphi^R \geq \varphi^L_m(\psi)$.

Then, the central bank optimally chooses the smallest feasible haircut $\psi = \psi^M_1$ whenever (i) $\psi^M_1 \geq \psi^{**}$, or (ii) $\psi^S_1 > \psi^M_1$ and $\hat{\psi} \geq \psi^M_1$, such that bank lending is maximized and the banker monitors.

The central bank optimally chooses the haircut $\psi = \psi^M_0$ whenever (i) $\psi^{**} > \psi^M_1$ and $\psi^M_0 > \hat{\psi}$, such that the banker does not monitor, but reducing the bank leverage to induce monitoring does not yield a welfare gain, i.e.,

$$\frac{\varphi^M}{\varphi^{**}} \geq \ 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A^L_{s,0}] - A^B}.$$

The central bank optimally chooses the haircut $\psi = \hat{\psi}$ whenever $\psi^{**} > \psi^M_1$, $\psi^S_1 > \psi^M_0$ and $\hat{\psi} \geq \psi^M_0$, such that the banker does not monitor, but reducing the bank leverage to induce monitoring does not yield a welfare gain, i.e.,

$$\frac{\hat{\varphi}}{\varphi^{**}} \geq \ 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A^L_{s,0}] - A^B}.$$

Otherwise, the central bank optimally chooses the haircut $\psi = \psi^{**}$ to limit the bank leverage below the maximum feasible and thereby inducing monitoring.

We now outline the optimal mix of bank regulation and monetary policy.

Corollary 4 (Optimal Bank Regulation and Optimal Monetary Policy)
It is optimal to set capital requirements and collateral requirements such that

(i) $\varphi^R \geq \varphi^L_1(\psi)$ and $\psi = \psi^M_1$ whenever $\psi^M_1 \geq \psi^{**}$, or $\psi^S_1 > \psi^M_1$ and $\hat{\psi} \geq \psi^M_1$,

(ii) $\varphi^R \geq \varphi_0^L(\psi)$ *and* $\psi = \psi_0^M$ *whenever* $\psi^{**} > \psi_1^M$, $\psi_1^S > \psi_0^M > \hat{\psi}$, *and*

$$\frac{\varphi^M}{\varphi^{**}} \geq \ 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A_{s,0}^L] - A^B},$$

(iii) $\varphi^R = \varphi^M$ *and* $\psi \leq \tilde{\psi}_0(\varphi^R)$ *whenever* $\psi^{**} > \psi_1^M$, $\psi_1^S > \psi_0^M$, $\hat{\psi} \geq \psi_0^M$, *and*

$$\frac{\varphi^M}{\varphi^{**}} \geq \ 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A_{s,0}^L] - A^B},$$

(iv) $\varphi^R \geq \varphi_1^L(\psi)$ *and* $\psi = \psi^{**}$ *otherwise.*

C Proofs

Proof of Lemma 1. Firms are penniless and operate under limited liability, so that they are fully protected from losses. Accordingly, if the loan-financed firm is facing excess returns in one of the states, i.e., $A_s^L > (1 + r_s^L)q$ for some s, the expected profits are increasing with the input K^L of capital good to production. Thus, there exists no optimal, finite demand for the capital good by the loan-financed firm, which we denote by $K^L = +\infty$. In contrast, without excess returns, i.e., $A_s^L \leq (1 + r_s^L)q$ for all s, the loan-financed firm is making zero profits for any production input due to limited liability. Accordingly, the firm is indifferent between any amount of capital good put into production, and the optimal demand is given by $K^L \in [0, +\infty)$.

Similarly, there exists no optimal, finite demand of capital good by the bond-financed firm if it holds that $A^B > (1 + r^B)q$, which we denote by $K^B = +\infty$. In turn, if it holds that $A^B \leq (1 + r^B)q$, the bond-financed firm is indifferent between any input of capital good to production, i.e., $K^B \in [0, +\infty)$. ■

Proof of Lemma 2. Due to our assumption of linear utility, the household maximizes consumption $C^H = [\gamma(1 + r^D) + (1 - \gamma)(1 + r^B)]qK + \tau + \pi$. The optimal choice of the household is thus of knife-edge type, i.e., the household invests the revenues from capital good sales in the asset which yields the highest return. In other words, the household maximizes utility by only holding deposits ($\gamma = 1$) if the deposit rate exceeds the bond rate ($r^D > r^B$), and by only investing into bonds ($\gamma = 0$) if the bond rate exceeds the deposit rate ($r^D < r^B$). Otherwise ($r^D = r^B$), the household is indifferent between deposits and bonds ($\gamma \in [0, 1]$). ■

Proof of Lemma 3. Note that reserves can be borrowed from the central bank at an interest rate r_{CB}^L and can be deposited at the central bank at an interest rate r_{CB}^D. The interest rate for interbank loans is given by $r_{IB}^L > 0$, whereas the interest rate on interbank deposits is given by r_{IB}^D. We assume that the bank cannot differentiate between deposits held by other banks and deposits from households and firms, so that it holds that $r_{IB}^D = r^D$. Interbank loans are only demanded if $r_{IB}^L \leq r_{CB}^L$, whereas interbank deposits are only attractive to the bank if $r^D \geq r_{CB}^D$. Otherwise, the bank would only deposit at the central bank. The liquidity provided on the interbank market through loans L^{IB} to other banks is matched by interbank deposits D^{IB} held by the borrowing banks. Thus, it holds that $L^{IB} = D^{IB}$. Interbank deposits are fully withdrawn by the borrowing banks if these banks must settle deposit outflows due to transactions on the capital good market. The lending bank must settle the outflow of interbank deposits by using reserves in the amount $D^{CB} = D^{IB}$, which this bank must borrow from the central bank by demanding loans L^{CB}. The revenues from interbank lending are given by $r_{IB}^L L^{IB}$, whereas the costs of interbank lending are given by $r^D D^{IB} + L^{CB} - r_{CB}^D D^{CB}$. Using $L^{IB} = D^{IB}$ and $L^{CB} = D^{CB} = D^{IB}$, the bank only offers interbank loans and deposits if

$$r_{IB}^L \geq r^D + r_{CB}^L - r_{CB}^D \qquad \Leftrightarrow \qquad r_{IB}^L \geq r^D,$$

where we used the equality of central bank rates ($r_{CB}^L = r_{CB}^D$), following from assumption 2. Since the interbank market is active only if $r^D \geq r_{CB}^D$ and $r_{IB}^L \leq r_{CB}^L$, we can conclude that the interest rates satisfy $r^L_{IB} = r^D = r^D_{CB}$. ■

Proof of Lemma 4. First, we focus on the banker's optimal choice of the leverage. The banker's expected utility is given by

$$\begin{aligned}\{1 + \mathbb{E}_m[r^E_s(\varphi)] - m\kappa\varphi\}qE &= \{\mathbb{E}_m[\{(A^L_s - A^B)\varphi + A^B\}^+] - m\kappa q\varphi\}E \\ &= \eta_m[(A^L_h - A^B)\varphi + A^B]E \\ &\qquad + \mathbb{1}\{\varphi \leq \varphi^S\}(1-\eta_m)[(A^L_l - A^B)\varphi + A^B]E - m\kappa q\varphi E.\end{aligned}$$

Based on assumption 1, even without monitoring, the expected productivity of a loan-financed firm exceeds the productivity of a bond-financed firm, i.e., it holds that $\mathbb{E}_0[A^L_s] > A^B$. Accordingly, for any monitoring decision m, the banker maximizes the expected return from banking operations by choosing the maximum possible leverage, i.e., $\varphi = \overline{\varphi}_m(\theta)$.

Second, we focus on the banker's optimal monitoring decision. This monitoring decision crucially depends on whether there is solvency risk or not. First, let us focus on the case where, independent of the monitoring decision, the banker is not exposed to a solvency risk, i.e., it holds that $\overline{\varphi}_m(\theta) \leq \varphi^S$ for all m. Then, the banker monitors (i.e., $m = 1$) if and only if

$$\begin{aligned} & \{\mathbb{E}_1[(A^L_s - A^B)\overline{\varphi}_1(\theta) + A^B] - \kappa q\overline{\varphi}_1(\theta)\}E \geq \{\mathbb{E}_0[(A^L_s - A^B)\overline{\varphi}_0(\theta) + A^B]\}E \\ \Leftrightarrow \qquad & (\mathbb{E}_1[A^L_s] - A^B)\overline{\varphi}_1(\theta) - (\mathbb{E}_0[A^L_s] - A^B)\overline{\varphi}_0(\theta) \geq \kappa q\overline{\varphi}_1(\theta),\end{aligned}$$

which can be further rearranged to

$$\begin{aligned} & (\mathbb{E}_1[A^L_s] - \mathbb{E}_0[A^L_s])\overline{\varphi}_1(\theta) + (\mathbb{E}_0[A^L_s] - A^B)[\overline{\varphi}_1(\theta) - \overline{\varphi}_0(\theta)] \geq \kappa q\overline{\varphi}_1(\theta) \\ \Leftrightarrow \qquad & \mathcal{M}_N(\theta) := \triangle(A^L_h - A^L_l) + (\mathbb{E}_0[A^L_s] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q \geq 0.\end{aligned}$$

Second, we focus on the case where the banker is exposed to a solvency risk only with monitoring, i.e., it holds that $\overline{\varphi}_1(\theta) > \varphi^S \geq \overline{\varphi}_0(\theta)$. Then, the banker monitors (i.e., $m = 1$) if and only if

$$\{\eta_1[(A_h^L - A^B)\overline{\varphi}_1(\theta) + A^B] - \kappa q\overline{\varphi}_1(\theta)\}E \geq \{(\mathbb{E}_0[A_s^L] - A^B)\overline{\varphi}_0(\theta) + A^B\}E$$

$$\Leftrightarrow \quad \eta_1[(A_h^L - A^B)\overline{\varphi}_1(\theta) + A^B] - (\mathbb{E}_0[A_s^L] - A^B)\overline{\varphi}_0(\theta) - A^B \geq \kappa q\overline{\varphi}_1(\theta)$$

$$\Leftrightarrow \quad (\eta_1 - \eta_0)(A_h^L - A^B)\overline{\varphi}_1(\theta) + (\mathbb{E}_0[A_s^L] - A^B)[\overline{\varphi}_1(\theta) - \overline{\varphi}_0(\theta)]$$

$$- (1-\eta_0)(A_l^L - A^B)\overline{\varphi}_1(\theta) - (1-\eta_1)A^B \geq \kappa q\overline{\varphi}_1(\theta)$$

$$\Leftrightarrow \quad \mathcal{M}_P(\theta) := \triangle(A_h^L - A^B) + (\mathbb{E}_0[A_s^L] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right]$$

$$+ (1-\eta_0)(A^B - A_l^L) - \frac{(1-\eta_1)A^B}{\overline{\varphi}_1(\theta)} - \kappa q \geq 0.$$

Third, we focus on the case where, independent of the monitoring decision, the banker is exposed to a solvency risk, i.e., it holds that $\overline{\varphi}_m(\theta) > \varphi^S$ for all m. Then, the banker monitors (i.e., $m = 1$) if and only if

$$\{\eta_1[(A_h^L - A^B)\overline{\varphi}_1(\theta) + A^B] - \kappa q\overline{\varphi}_1(\theta)\}E \geq \eta_0[(A_h^L - A^B)\overline{\varphi}_0(\theta) + A^B]E$$

$$\Leftrightarrow \quad \eta_1[(A_h^L - A^B)\overline{\varphi}_1(\theta) + A^B] - \eta_0[(A_h^L - A^B)\overline{\varphi}_0(\theta) + A^B] \geq \kappa q\overline{\varphi}_1(\theta)$$

$$\Leftrightarrow \quad \eta_1(A_h^L - A^B)\overline{\varphi}_1(\theta) - \eta_0(A_h^L - A^B)\overline{\varphi}_0(\theta) + \triangle A^B \geq \kappa q\overline{\varphi}_1(\theta)$$

$$\Leftrightarrow \quad (\eta_1 - \eta_0)(A_h^L - A^B)\overline{\varphi}_1(\theta) + \eta_0(A_h^L - A^B)[\overline{\varphi}_1(\theta) - \overline{\varphi}_0(\theta)] + \triangle A^B \geq \kappa q\overline{\varphi}_1(\theta)$$

$$\Leftrightarrow \quad \mathcal{M}_F(\theta) := \triangle(A_h^L - A^B) + \eta_0(A_h^L - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] + \frac{\triangle A^B}{\overline{\varphi}_1(\theta)} - \kappa q \geq 0.$$

Note that the banker cannot face situations where there is solvency risk only without monitoring, i.e., where it holds that $\overline{\varphi}_0(\theta) > \varphi^S \geq \overline{\varphi}_1(\theta)$. The reason is that the maximum possible leverage $\varphi_m^L(\psi)$ increases with monitoring (i.e., $\overline{\varphi}_0(\theta) \leq \overline{\varphi}_1(\theta)$), while the leverage threshold for solvency φ^S is unaffected by monitoring. ■

Proof of Proposition 1. First, note that in any competitive equilibrium, the capital good market must clear. Accordingly, bank lending cannot exceed the funds needed to purchase the entire endowment in the economy, i.e., it must holds that $QK^L = L^b = \overline{\varphi}_m(\theta)QE \leq Q(K+E)$ or, equivalently, $\overline{\varphi}_m(\theta) \leq 1 + K/E := \varphi^M$. By definition, $\overline{\varphi}_m(\theta) = \min\{\varphi^R, \varphi_m^L(\psi)\}$, so that the latter inequality implies $\varphi^R \leq \varphi^M$ or $\varphi_m^L(\psi) \leq \varphi^M$. Using the structure of $\varphi_m^L(\psi)$, as provided in equation (7), the latter inequality can be rewritten as

$$\begin{aligned}
&\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}_m[A_s^L]} \leq 1 + K/E \\
\Leftrightarrow \quad &\alpha A^B \leq \{\alpha A^B - (1-\psi)\mathbb{E}_m[A_s^L]\}(1 + K/E) \\
\Leftrightarrow \quad &(1-\psi)\mathbb{E}_m[A_s^L](1 + K/E) \leq \alpha A^B K/E,
\end{aligned}$$

which further simplifies to

$$(1-\psi) \leq \frac{\alpha A^B}{\mathbb{E}_m[A_s^L](1+E/K)} \qquad \Leftrightarrow \qquad \psi \geq \psi_m^M := 1 - \frac{\alpha A^B}{\mathbb{E}_m[A_s^L](1+E/K)}.$$

Thus, ψ_m^M represents the smallest feasible haircut the central bank can choose.

Again using $\overline{\varphi}_m(\theta) = \min\{\varphi^R, \varphi_m^L(\psi)\}$, the banker can only be exposed to a solvency risk if $\varphi^R > \varphi^S$ and $\varphi_m^L(\psi) > \varphi^S$. Using the structure of φ^S and $\varphi_m^L(\psi)$, as provided in equation (4) and equation (7), respectively, the latter inequality can be rewritten as

$$\begin{aligned}
&\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}_m[A_s^L]} > \frac{A^B}{A^B - A_l^L} \\
\Leftrightarrow \quad &\alpha(A^B - A_l^L) > \alpha A^B - (1-\psi)\mathbb{E}_m[A_s^L] \\
\Leftrightarrow \quad &(1-\psi)\mathbb{E}_m[A_s^L] > \alpha A_l^L \\
\Leftrightarrow \quad &\psi < \psi_m^S := 1 - \frac{\alpha A_l^L}{\mathbb{E}_m[A_s^L]}.
\end{aligned}$$

■

Proof of Lemma 5. Due to our assumption of linear utility for households and bankers, utilitarian welfare comprises aggregate consumption and utility losses due to monitoring, i.e.,

$$W = [\gamma(1+r^D) + (1-\gamma)(1+r^B)]qK + \tau + \pi + (1 + \mathbb{E}_m[r_s^E(\varphi)] - m\kappa\varphi)qE.$$

In equilibrium, the interest rates on bonds and deposits satisfy $r^D = r^B = A^B/q - 1$ (for a derivation see subsections 2.4 and 2.3), so that firms make zero profits, i.e., $\pi = 0$, and welfare translates into

$$W = A^B K + \tau + \mathbb{E}_m[\{(A_s^L - A^B)\varphi + A^B\}^+]E - m\kappa\varphi qE,$$

where we used equation (3) in subsection 2.6, stating that the rate of return on bank equity is given by $r_s^E(\varphi) = \{(A_s^L - A^B)\varphi + A^B\}^+/q - 1$. The government uses taxes to cover central bank losses and bank losses in the case of default, while it distributes central bank profits through transfers, i.e., it holds that $T = \Pi^{b,-} + \Pi^{CB}$. Note that as we focus on a representative bank, deposit outflows match deposit inflows. Together with the equal interest rates on reserves deposits and reserve loans (see assumption 2), we can then conclude that the central bank makes neither profits nor losses, i.e., $\Pi^{CB} = 0$. Then, taxes must only cover bank losses in the case of default, so that government taxes satisfy in real terms

$$\tau = \pi^{b,-} = \mathbb{1}\{\varphi > \varphi^S\}(1 - \eta_m)[(A_l^L - A^B)\varphi + A^B]E$$
$$= \mathbb{E}_m[\{(A_s^L - A^B)\varphi + A^B\}^-]E,$$

where we make use of the notation $\{X\}^- = \min\{X, 0\}$. Welfare then simplifies to

$$W = A^B K + \mathbb{E}_m[(A_s^L - A^B)\varphi + A^B]E - m\kappa\varphi qE,$$

which, using the bank's optimal leverage choice $\varphi = \overline{\varphi}_m(\theta)$ (see lemma 4), finally reads as

$$W_m(\theta) = (\mathbb{E}_m[A_s^L] - A^B - m\kappa q)\overline{\varphi}_m(\theta)E + A^B(K + E).$$

■

Proof of Corollary 1. The results follow directly from lemma 4 by using $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, which follows from the assumption that the central bank implements sufficiently loose collateral requirements, i.e., $\psi \leq \tilde{\psi}_0(\varphi^R)$. Note that in any such situation, case (II) in lemma 4 cannot arise, where there is partial solvency risk, namely where banker is exposed to a solvency risk only with monitoring. Either the banker faces a solvency risk or not, so that we are left with the cases (I) and (III) of lemma 4.

We can then conclude that, if it holds $\psi \leq \tilde{\psi}_0(\varphi^R)$, so that $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, the banker optimally monitors (i.e., $m = 1$) if and only if

(I) without solvency risk, i.e., $\varphi^R \leq \varphi^S$, it holds $\tilde{\mathcal{M}}_N \geq 0$, where

$$\tilde{\mathcal{M}}_N := \triangle(A_h^L - A_l^L) - \kappa q,$$

(II) with full solvency risk, i.e., $\varphi^R > \varphi^S$, it holds $\tilde{\mathcal{M}}_F(\varphi^R) \geq 0$, where

$$\tilde{\mathcal{M}}_F(\varphi^R) := \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\varphi^R} - \kappa q.$$

Furthermore, it holds that $\lim_{\varphi^R \searrow \varphi^S} \tilde{\mathcal{M}}_F(\varphi^R) = \tilde{\mathcal{M}}_N$, as

$$\begin{aligned}
\lim_{\varphi^R \searrow \varphi^S} \tilde{\mathcal{M}}_F(\varphi^R) &= \lim_{\varphi^R \searrow \varphi^S} \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\varphi^R} - \kappa q \\
&= \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\varphi^S} - \kappa q \\
&= \triangle(A_h^L - A^B) + \triangle(A^B - A_l^L) - \kappa q \\
&= \triangle(A_h^L - A_l^L) - \kappa q,
\end{aligned}$$

where we made use of $\varphi^S = A^B/(A^B - A_l^L)$ which is provided by equation (4) in subsection 2.6. ■

Proof of Proposition 2. Based on assumption 3, the banker monitors in any case if there is no solvency risk, in particular no matter whether the leverage constraint stems from capital requirements or collateral requirements. Formally, this means that $\mathcal{M}_N(\theta) \geq 0$ for all $\theta = (\varphi^R, \psi)$ and $\tilde{\mathcal{M}}_N \geq 0$. However, whenever the banker is exposed to a solvency risk, it matters for the monitoring incentives if the banker is constrained by capital or liquidity, i.e.,

$$\mathcal{M}_F(\theta) - \tilde{\mathcal{M}}_F(\varphi^R) = \eta_0(A_h^L - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] + \triangle A^B \left[\frac{1}{\overline{\varphi}_1(\theta)} - \frac{1}{\varphi^R}\right].$$

Note that we assume $\tilde{\psi}_0(\varphi^R) < \psi$, so that $\overline{\varphi}_0(\theta) = \varphi_0^L(\psi) < \varphi^R$ and thus

$$\mathcal{M}_F(\theta) - \tilde{\mathcal{M}}_F(\varphi^R) = \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi)}{\overline{\varphi}_1(\theta)}\right] + \triangle A^B \left[\frac{1}{\overline{\varphi}_1(\theta)} - \frac{1}{\varphi^R}\right].$$

Moreover, note that for $\psi \leq \tilde{\psi}_1(\varphi^R)$ it holds that $\overline{\varphi}_1(\theta) = \varphi^R$ and otherwise $\overline{\varphi}_1(\theta) = \varphi_1^L(\psi) < \varphi^R$. Furthermore, note that

$$\lim_{\psi \searrow \tilde{\psi}_0(\varphi^R)} \mathcal{M}_F(\theta) - \tilde{\mathcal{M}}_F(\varphi^R) = \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi^R}{\varphi^R}\right] + \triangle A^B \left[\frac{1}{\varphi^R} - \frac{1}{\varphi^R}\right] = 0,$$

as it holds that $\lim_{\psi \searrow \tilde{\psi}_0(\varphi^R)} \varphi_0^L(\psi) = \varphi^R$. ■

Proof of Proposition 3. As the central bank implements sufficiently loose collateral requirements, i.e., the haircut satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$, so that $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, we know, using lemma 5, that welfare is given by

$$W_m(\varphi^R) = (\mathbb{E}_m[A_s^L] - A^B - m\kappa q)\varphi^R E + A^B(K + E),$$

where the banker's monitoring decision is described by corollary 1. From corollary 1 and assumption 6, we know that the banker monitors whenever it holds that $\varphi^R \leq \varphi^*$, where φ^* is described by equation (9). Then, the bank regulator maximizes welfare by implementing the regulatory maximum leverage $\varphi^R = \varphi^M$ if it holds (i) $\varphi^M \leq \varphi^*$, so that bank lending is maximized and the banker monitors, or (ii) $\varphi^M > \varphi^*$, so that bank lending is maximized and the banker does not monitor, but reducing the bank leverage to induce monitoring does not yield a welfare gain, i.e., $W_0(\varphi^M) \geq W_1(\varphi^*)$ or, equivalently,

$$
\begin{aligned}
& (\mathbb{E}_0[A_s^L] - A^B)\varphi^M E + A^B(K+E) \geq (\mathbb{E}_1[A_s^L] - A^B - \kappa q)\varphi^* E + A^B(K+E) \\
\Leftrightarrow \quad & (\mathbb{E}_0[A_s^L] - A^B)\varphi^M \geq (\mathbb{E}_1[A_s^L] - A^B - \kappa q)\varphi^* \\
\Leftrightarrow \quad & \frac{\varphi^M}{\varphi^*} \geq \frac{\mathbb{E}_1[A_s^L] - A^B - \kappa q}{\mathbb{E}_0[A_s^L] - A^B}.
\end{aligned}
$$

Using $\mathbb{E}_1[A_s^L] = \mathbb{E}_0[A_s^L] + \triangle(A_h^L - A_l^L)$, the latter inequality further simplifies to

$$
\frac{\varphi^M}{\varphi^*} \geq 1 + \frac{\triangle(A_h^L - A_h^L) - \kappa q}{\mathbb{E}_0[A_s^L] - A^B}.
$$

Note that, based on assumption 1, even without monitoring by the matched banker, a loan-financed firm is more productive than a bond-financed firm, i.e., it holds that $\mathbb{E}_0[A_s^L] > A^B$. Accordingly, under the assumption that $\varphi^M > \varphi^*$, the bank regulator maximizes welfare without monitoring by setting the capital requirements such that $\varphi^R = \varphi^M$. Similarly, welfare with monitoring is maximized by setting the capital requirements such that $\varphi^R = \varphi^*$. Hence, we only need to compare welfare $W_0(\varphi^M)$ and $W_1(\varphi^*)$.

In all other situations, the bank regulator optimally sets capital requirements such that the regulatory maximum leverage is given by $\varphi^R = \varphi^*$, restricting bank leverage below the maximum feasible and thereby inducing the banker to monitor. ■

Proof of Proposition 4. As the bank regulator implements sufficiently loose capital requirements, i.e., $\varphi^R \geq \varphi_m^L(\psi)$, so that $\overline{\varphi}_m(\theta) = \varphi_m^L(\psi)$ for all m, we know, using lemma 5, that welfare is given by

$$
W_m(\psi) = (\mathbb{E}_m[A_s^L] - A^B - m\kappa q)\varphi_m^L(\psi)E + A^B(K+E),
$$

where the banker's monitoring decision is described by lemma 4. First, note that based on assumption 3, there exists a critical haircut ψ^{**} such that for $\theta^{**} = (\varphi^R, \psi^{**})$ it holds that

$$
\mathcal{M}_F(\theta^{**}) = \triangle(A_h^L - A^B) + \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi^{**})}{\varphi_1^L(\psi^{**})}\right] + \frac{\triangle A^B}{\varphi_1^L(\psi^{**})} - \kappa q = 0,
$$

where we used $\overline{\varphi}_m(\theta) = \varphi_m^L(\psi)$ for all m, as it holds that $\varphi^R \geq \varphi_m^L(\psi)$. For what follows, we will make use of the notation $\varphi^{**} = \varphi_1^L(\psi^{**})$.

Furthermore, note that it holds that $\lim_{\psi \nearrow \psi_1^S(\varphi^R)} \mathcal{M}_F(\theta) = \mathcal{M}_N(\theta_1^S) > 0$, with $\theta_1 = (\varphi^R, \psi_1^S)$, where, based on lemma 4, for sufficiently loose collateral requirements implying $\varphi^R \geq \varphi_m^L(\psi)$ for all m, it holds that

$$
\mathcal{M}_N(\theta_1^S) = \triangle(A_h^L - A_l^L) + (\mathbb{E}_0[A_s^L] - A^B)\left[1 - \frac{\varphi_0^L(\psi_1^S)}{\varphi^S}\right] - \kappa q,
$$

where we used the fact that $\varphi_1^L(\psi_1^S) = \varphi^S$. Now observe that it holds that

$$\begin{aligned}
\lim_{\psi \nearrow \psi_1^S(\varphi^R)} \mathcal{M}_F(\theta) &= \triangle(A_h^L - A^B) + \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi_1^S)}{\varphi_1^L(\psi_1^S)}\right] + \frac{\triangle A^B}{\varphi_1^L(\psi_1^S)} - \kappa q \\
&= \triangle(A_h^L - A^B) + \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi_1^S)}{\varphi^S}\right] + \frac{\triangle A^B}{\varphi^S} - \kappa q \\
&= \triangle(A_h^L - A^B) + \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi_1^S)}{\varphi^S}\right] + \triangle(A^B - A_l^L) - \kappa q \\
&= \triangle(A_h^L - A_l^L) + \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi_1^S)}{\varphi^S}\right] - \kappa q \\
&= \mathcal{M}_N(\theta_1^S),
\end{aligned}$$

where we made use of $\varphi_1^L(\psi_1^S) = \varphi^S$ and $\varphi^S = A^B/(A^B - A_l^L)$, the latter following from equation (4) in subsection 2.6.

We can then conclude that the banker always monitors if it holds that $\varphi < \varphi^{**}$ and it is optimal for the central bank to set $\psi = \psi_1^M$ whenever $\varphi^M \leq \varphi^{**}$, so that bank lending is maximized and the banker monitors. Moreover, it is optimal for the central bank to set $\psi = \psi_0^M$ whenever $\varphi^M > \varphi^{**}$, so that bank lending is maximized and the banker does not monitor, and reducing the bank leverage to induce monitoring does not yield a welfare gain, i.e., it holds that $W_0(\psi_0^M) \geq W_1(\psi^{**})$ or, equivalently,

$$\begin{aligned}
& (\mathbb{E}_0[A_s^L] - A^B)\varphi^M E + A^B(K+E) \geq (\mathbb{E}_1[A_s^L] - A^B - \kappa q)\varphi^{**} E + A^B(K+E) \\
\Leftrightarrow \quad & (\mathbb{E}_0[A_s^L] - A^B)\varphi^M \geq (\mathbb{E}_1[A_s^L] - A^B - \kappa q)\varphi^{**} \\
\Leftrightarrow \quad & \frac{\varphi^M}{\varphi^{**}} \geq \frac{\mathbb{E}_1[A_s^L] - A^B - \kappa q}{\mathbb{E}_0[A_s^L] - A^B} \\
\Leftrightarrow \quad & \frac{\varphi^M}{\varphi^{**}} \geq 1 + \frac{\triangle(A_h^L - A_l^L) - \kappa q}{\mathbb{E}_0[A_s^L] - A^B},
\end{aligned}$$

where we made use of $\mathbb{E}_1[A_s^L] = \mathbb{E}_0[A_s^L] + \triangle(A_h^L - A_l^L)$. Note that, based on assumption 1, even without monitoring by the matched banker, a loan-financed firm is more productive than a bond-financed firm, i.e., it holds that $\mathbb{E}_0[A_s^L] > A^B$. Accordingly, under the assumption that $\varphi^M > \varphi^{**}$, the central bank maximizes welfare without monitoring by setting the haircut $\psi = \psi_0^M$. Similarly, welfare with monitoring is maximized by setting the haircut such that $\psi = \psi^{**}$. Hence, we only need to compare welfare $W_0(\psi_0^M)$ and $W_1(\psi^{**})$.

In all other situations, the central bank optimally sets the haircut $\psi = \psi^{**}$ to reduce bank leverage below the maximum feasible and thereby inducing the banker to monitor. ■

Proof of Corollary 2. We start by showing that it holds that $\varphi^{**} = \varphi_1^L(\psi^{**}) > \varphi^*$. Note that by the definition of φ^{**} and φ^{*}, we obtain

$$\mathcal{M}_F(\theta^{**}) = 0 = \tilde{\mathcal{M}}_F(\varphi^{*}),$$

where $\theta^{**} = (\varphi^R, \psi^{**})$. The latter equation reads as

$$\triangle(A_h^L - A^B) + \eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi^{**})}{\varphi_1^L(\psi^{**})}\right] + \frac{\triangle A^B}{\varphi_1^L(\psi^{**})} - \kappa q = \triangle(A_h^L - A^B) + \frac{\triangle A^B}{\varphi^{*}} - \kappa q$$

and can be further simplified to

$$\eta_0(A_h^L - A^B)\left[1 - \frac{\varphi_0^L(\psi^{**})}{\varphi_1^L(\psi^{**})}\right] = \triangle A^B\left[\frac{1}{\varphi^{*}} - \frac{1}{\varphi_1^L(\psi^{**})}\right].$$

The left-hand side of the latter condition is strictly positive, so that we can conclude that it holds that $\varphi^{*} < \varphi_1^L(\psi^{**}) = \varphi^{**}$. Note that the difference between the two critical leverage ratios φ^{*} and φ^{**} originates from the collateral leverage channel of monitoring.

A liquidity-constrained banker monitors under higher leverage ratios than a capital-constrained banker. Based on assumption 1 and assumption 3, we know that more loan financing and monitoring by the banker both increase welfare. Accordingly, it is optimal to only constrain the bank by liquidity, through the implementation of sufficiently tight collateral requirements, while capital requirements set by the bank regulator should be sufficiently loose not to constrain the banker. Specifically, the capital requirements should lead to a regulatory maximum leverage $\varphi^R \geq \varphi_m^L(\psi)$ (e.g., $\varphi^R = \varphi^M$), where the haircut ψ should be set according to proposition 4. ■

Proof of Lemma 6. Firms are penniless and operate under limited liability, so that they are fully protected from losses. Accordingly, if the loan-financed firm is facing excess returns in one of the states, i.e., $A_{s,m}^L > (1 + r_{s,m}^L)q$ for some s, the expected profits are increasing with the input K^L of capital good to production. Thus, there exists no optimal, finite demand for capital good by the loan-financed firm, which we denote by $K^L = +\infty$. In contrast, without excess returns, i.e., $A_{s,m}^L \leq (1 + r_{s,m}^L)q$ for all s, the loan-financed firm is making zero profits for any production input due to limited liability. Accordingly, the firm is indifferent between any amount of capital good put into production and the optimal demand is given by $K^L \in [0, +\infty)$. ■

Proof of Lemma 7. The expected utility of the banker is given by

$$\begin{aligned}\{1 + \mathbb{E}[r_{s,m}^E(\varphi)] - m\kappa\varphi\}qE &= \mathbb{E}[\{(A_{s,m}^L - A^B)\varphi + A^B\}^+]E - m\kappa\varphi qE \\ &= \eta[(A_{h,m}^L - A^B)\varphi + A^B]E \\ &\qquad + \mathbb{1}\{\varphi \leq \varphi_m^S\}(1-\eta)[(A_{l,m}^L - A^B)\varphi + A^B]E - m\kappa q\varphi E.\end{aligned}$$

First, we focus on the banker's choice of leverage φ or, in other words, the decision about deposit issuance and loan supply. From assumption 5, we know that, even without monitoring by the banker, the loan-financed firm is more productive on average than the bond-financed firm, i.e., it holds that $\mathbb{E}[A^L_{s,0}] > A^B$. Thus, the banker optimally always leverages as much as possible, i.e., $\varphi = \overline{\varphi}_m(\theta)$.

Next, we focus on the banker's monitoring decision. The banker's incentives crucially depend on the exposure to a solvency risk, so that we must differentiate three situations. First, in any situation where, independent of the monitoring decision, the banker is not exposed to a solvency risk, i.e., it holds for all m that $\overline{\varphi}_m(\theta) \leq \varphi^S_m$, the banker decides to monitor (i.e., $m = 1$) if and only if

$$
\begin{aligned}
& \{(\mathbb{E}[A^L_{s,1}] - A^B)\overline{\varphi}_1(\theta) + A^B - \kappa q\overline{\varphi}_1(\theta)\}E \geq \{(\mathbb{E}[A^L_{s,0}] - A^B)\overline{\varphi}_0(\theta) + A^B\}E \\
\Leftrightarrow \quad & (\mathbb{E}[A^L_{s,1}] - A^B)\overline{\varphi}_1(\theta) - (\mathbb{E}[A^L_{s,0}] - A^B)\overline{\varphi}_0(\theta) \geq \kappa q\overline{\varphi}_1(\theta) \\
\Leftrightarrow \quad & \mathbb{E}[A^L_{s,1}] - A^B - (\mathbb{E}[A^L_{s,0}] - A^B)\frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)} \geq \kappa q.
\end{aligned}
$$

The latter inequality can be further rearranged to

$$
\begin{aligned}
& \mathbb{E}[A^L_{s,1}] - A^B - (\mathbb{E}[A^L_{s,0}] - A^B) - (\mathbb{E}[A^L_{s,0}] - A^B)\left[\frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)} - 1\right] \geq \kappa q \\
\Leftrightarrow \quad & \mathbb{E}[A^L_{s,1}] - \mathbb{E}[A^L_{s,0}] + (\mathbb{E}[A^L_{s,0}] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] \geq \kappa q \\
\Leftrightarrow \quad & \mathcal{M}_N(\theta) := (1-\eta)\triangle + (\mathbb{E}[A^L_{s,0}] - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q \geq 0,
\end{aligned}
$$

where we used $A^L_{h,1} = A^L_{h,0}$ and $A^L_{l,1} = A^L_{l,0} + \triangle$.

Second, in any situation where the banker is exposed to a solvency risk only without monitoring, i.e., it holds that $\overline{\varphi}_0(\theta) > \varphi^S_0$ and $\overline{\varphi}_1(\theta) \leq \varphi^S_1$, the banker decides to monitor (i.e., $m = 1$) if and only if

$$
\begin{aligned}
& \{(\mathbb{E}[A^L_{s,1}] - A^B)\overline{\varphi}_1(\theta) + A^B - \kappa q\overline{\varphi}_1(\theta)\}E \geq \eta[(A^L_{h,0} - A^B)\overline{\varphi}_0(\theta) + A^B]E \\
\Leftrightarrow \quad & (\mathbb{E}[A^L_{s,1}] - A^B)\overline{\varphi}_1(\theta) - \eta(A^L_{h,0} - A^B)\overline{\varphi}_0(\theta) + (1-\eta)A^B \geq \kappa q\overline{\varphi}_1(\theta) \\
\Leftrightarrow \quad & (\mathbb{E}[A^L_{s,1}] - A^B) - \eta(A^L_{h,0} - A^B)\frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)} + \frac{(1-\eta)A^B}{\overline{\varphi}_1(\theta)} \geq \kappa q.
\end{aligned}
$$

The latter inequality can be rewritten to

$$
\begin{aligned}
& (\mathbb{E}[A^L_{s,1}] - A^B) + (1-\eta)(A^B - A^L_{l,0}) - \eta(A^L_{h,0} - A^B)\frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)} \\
& \qquad + \frac{(1-\eta)A^B}{\overline{\varphi}_1(\theta)} \geq \kappa q + (1-\eta)(A^B - A^L_{l,0})
\end{aligned}
$$

which, using $(1-\eta)(A^B - A^L_{l,0}) = \eta(A^L_{h,0} - A^B) - (\mathbb{E}[A^L_{s,0}] - A^B)$, translates into

$$(\mathbb{E}[A^L_{s,1}] - A^B) - (\mathbb{E}[A^L_{s,0}] - A^B) + \eta(A^L_{h,0} - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] + \frac{(1-\eta)A^B}{\overline{\varphi}_1(\theta)} \geq \kappa q + (1-\eta)(A^B - A^L_{l,0}).$$

With $\mathbb{E}[A^L_{s,1}] = \mathbb{E}[A^L_{s,0}] + (1-\eta)\triangle$, and $A^L_{l,1} = A^L_{l,0} + \triangle$, the latter inequality simplifies to

$$\mathcal{M}_P(\theta) := \eta(A^L_{h,0} - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - (1-\eta)\left[A^B - A^L_{l,1} - \frac{A^B}{\overline{\varphi}_1(\theta)}\right] - \kappa q \geq 0.$$

Third, in any situation where, independent of the monitoring decision, the banker is exposed to a solvency risk, i.e., $\overline{\varphi}_m(\theta) > \varphi^S_m$ for all m, the banker monitors, i.e., $m = 1$, if and only if

$$\begin{aligned} & \{\eta[(A^L_{h,1} - A^B)\overline{\varphi}_1(\theta) + A^B] - \kappa q\overline{\varphi}_1(\theta)\}E \geq \eta[(A^L_{h,0} - A^B)\overline{\varphi}_0(\theta) + A^B]E \\ \Leftrightarrow \quad & \eta(A^L_{h,1} - A^B)\overline{\varphi}_1(\theta) - \eta(A^L_{h,0} - A^B)\overline{\varphi}_0(\theta) \geq \kappa q\overline{\varphi}_1(\theta) \\ \Leftrightarrow \quad & \eta(A^L_{h,1} - A^B) - \eta(A^L_{h,0} - A^B)\frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)} \geq \kappa q. \end{aligned}$$

Using $A^L_{h,1} = A^L_{h,0}$, the latter inequality further simplifies to

$$\mathcal{M}_F(\theta) := \eta(A^L_{h,0} - A^B)\left[1 - \frac{\overline{\varphi}_0(\theta)}{\overline{\varphi}_1(\theta)}\right] - \kappa q \geq 0.$$

Note that the banker can never face a situation where solvency risk only exists with monitoring, i.e., where it holds that $\overline{\varphi}_0(\theta) \leq \varphi^S_0$ and $\overline{\varphi}_1(\theta) > \varphi^S_1$. This is straightforward if, independent of the monitoring decision, the banker is always constrained by capital, i.e., $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, as it can never hold that $\varphi^S_0 \geq \varphi^R > \varphi^S_1$ with $\varphi^S_1 > \varphi^S_0$. Next, we show that such a situation cannot arise either if the banker is constrained by liquidity only, i.e., when it holds that $\overline{\varphi}_m(\psi) = \varphi^L_m(\psi)$ for all m. Specifically, we show that it cannot hold that $\varphi^L_0(\psi) \leq \varphi^S_0$ and $\varphi^L_1(\psi) > \varphi^S_1$. On that account, note that

$$\begin{aligned} & \varphi^L_m(\psi) \leq \varphi^S_m \\ \Leftrightarrow \quad & \frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}[A^L_{s,m}]} \leq \frac{A^B}{A^B - A^L_{l,m}} \\ \Leftrightarrow \quad & \alpha(A^B - A^L_{l,m}) \leq \alpha A^B - (1-\psi)\mathbb{E}[A^L_{s,m}] \\ \Leftrightarrow \quad & (1-\psi)\mathbb{E}[A^L_{s,m}] \leq \alpha A^L_{l,m} \\ \Leftrightarrow \quad & \psi \geq \psi^S_m := 1 - \frac{\alpha A^L_{l,m}}{\mathbb{E}[A^L_{s,m}]}, \end{aligned}$$

where we made use of equations (14) and (16) to express the leverage ratios φ_m^S and $\varphi_m^L(\psi)$ in terms of the economic fundamentals. It thus holds that $\varphi_m^L(\psi) > \varphi_m^S$ if and only if $\psi < \psi_m^S$. Note further that

$$\psi_0^S = 1 - \frac{\alpha A_{l,0}^L}{\mathbb{E}[A_{s,0}^L]} > \psi_1^S = 1 - \frac{\alpha A_{l,1}^L}{\mathbb{E}[A_{s,1}^L]} = 1 - \frac{\alpha(A_{l,0}^L + \triangle)}{\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle},$$

where we used $A_{h,1}^L = A_{h,0}^L$ and $A_{l,1}^L = A_{l,0}^L + \triangle$. It thus follows that $\psi < \psi_1^S$ only if $\psi < \psi_0^S$, leading us to the conclusion that the banker can never face a situation where there is only solvency risk with monitoring. ■

Proof of Proposition 5. First, note that in any competitive equilibrium, the capital good market must clear. Accordingly, bank lending cannot exceed the funds needed to purchase the entire endowment in the economy, i.e., $QK^L = L^b = \overline{\varphi}_m(\theta)QE \leq Q(K+E)$ or, equivalently, $\overline{\varphi}_m(\theta) \leq 1 + K/E := \varphi^M$. As $\overline{\varphi}_m(\theta) = \min\{\varphi^R, \varphi_m^L(\psi)\}$, the latter inequality requires that $\varphi^R \leq \varphi^M$ or $\varphi_m^L(\psi) \leq \varphi^M$. Using the structure of $\varphi_m^L(\psi)$, as provided in (16), the latter inequality can be rewritten as

$$\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}[A_{s,m}^L]} \leq 1 + K/E$$

$$\Leftrightarrow \qquad \alpha A^B \leq \{\alpha A^B - (1-\psi)\mathbb{E}[A_{s,m}^L]\}(1 + K/E)$$

$$\Leftrightarrow \qquad (1-\psi)\mathbb{E}[A_{s,m}^L](1 + K/E) \leq \alpha A^B K/E,$$

which further simplifies to

$$(1-\psi) \leq \frac{\alpha A^B}{\mathbb{E}[A_{s,m}^L](1 + E/K)} \qquad \Leftrightarrow \qquad \psi \geq \psi_m^M := 1 - \frac{\alpha A^B}{\mathbb{E}[A_{s,m}^L](1 + E/K)}.$$

Thus, ψ_m^M represents the smallest feasible haircut the central bank can choose.

Again using $\overline{\varphi}_m(\theta) = \min\{\varphi^R, \varphi_m^L(\psi)\}$, the banker can only be exposed to a solvency risk if $\varphi^R > \varphi_m^S$ and $\varphi_m^L(\psi) > \varphi_m^S$. Using the structure of φ_m^S and $\varphi_m^L(\psi)$, as provided by equations (14) and (16), the latter inequality can be rewritten as

$$\frac{\alpha A^B}{\alpha A^B - (1-\psi)\mathbb{E}[A_{s,m}^L]} > \frac{A^B}{A^B - A_{l,m}^L}$$

$$\Leftrightarrow \qquad \alpha(A^B - A_{l,m}^L) > \alpha A^B - (1-\psi)\mathbb{E}[A_{s,m}^L]$$

$$\Leftrightarrow \qquad (1-\psi)\mathbb{E}[A_{s,m}^L] > \alpha A_{l,m}^L$$

$$\Leftrightarrow \qquad \psi < \psi_m^S := 1 - \frac{\alpha A_{l,m}^L}{\mathbb{E}[A_{s,m}^L]}.$$

■

Proof of Lemma 8. Due to our assumption of linear utility for households and bankers, utilitarian welfare comprises aggregate consumption and utility losses due to monitoring, i.e.,

$$W = [\gamma(1+r^D) + (1-\gamma)(1+r^B)]qK + \tau + \pi + (1 + \mathbb{E}[r^E_{s,m}(\varphi)] - m\kappa\varphi)qE.$$

In equilibrium, the interest rates on bonds and deposits satisfy $r^D = r^B = A^B/q - 1$, so that firms make zero profits, i.e., $\pi = 0$, and welfare translates into

$$W = A^B K + \tau + \mathbb{E}[\{(A^L_{s,m} - A^B)\varphi + A^B\}^+]E - m\kappa\varphi qE,$$

where we used equation (13) in subsection 2.6, stating that the rate of return on bank equity is given by $r^E_{s,m}(\varphi) = \{(A^L_{s,m} - A^B)\varphi + A^B\}^+/q - 1$. The government uses taxes to cover central bank losses and bank losses in the case of default, while it distributes central bank profits through transfers, i.e., $T = \Pi^{b,-} + \Pi^{CB}$. Note that as we focus on a representative bank, deposit outflows match deposit inflows. Moreover, the interest rates on reserves deposits and reserve loans equal (see assumption 2). Thus, the central bank makes neither profits nor losses, i.e., $\Pi^{CB} = 0$, and taxes must only cover bank losses in the case of default, so that in real terms, governmental taxes satisfy

$$\begin{aligned} \tau = \pi^{b,-} &= \mathbb{1}\{\varphi > \varphi^S\}(1-\eta)[(A^L_{l,m} - A^B)\varphi + A^B]E \\ &= \mathbb{E}[\{(A^L_{s,m} - A^B)\varphi + A^B\}^-]E, \end{aligned}$$

where we make use of the notation $\{X\}^- = \min\{X, 0\}$. Welfare then simplifies to

$$W = A^B K + \mathbb{E}[(A^L_{s,m} - A^B)\varphi + A^B]E - m\kappa\varphi qE,$$

which, using $\varphi = \overline{\varphi}_m(\theta)$ (see lemma 7), finally reads as

$$W_m(\theta) = (\mathbb{E}[A^L_{s,m}] - A^B - m\kappa q)\overline{\varphi}_m(\theta)E + A^B(K + E).$$

■

Proof of Corollary 3. The results follow directly from lemma 7 by using $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$, which follows from the assumption that the central bank implements sufficiently loose collateral requirements, i.e., the haircut set by the central bank satisfies $\psi \leq \tilde{\psi}_0(\varphi^R)$, so that $\overline{\varphi}_0(\theta) = \overline{\varphi}_1(\theta) = \varphi^R$. Using lemma 7, the banker then optimally monitors (i.e., $m = 1$) if and only if

(I) without solvency risk, i.e., $\varphi^R \leq \varphi^S_0$, it holds that $\tilde{\mathcal{M}}_N \geq 0$, where

$$\tilde{\mathcal{M}}_N := (1-\eta)\triangle - \kappa q,$$

(II) with partial solvency risk, i.e., $\varphi^S_1 \geq \varphi^R > \varphi^S_0$, it holds that $\tilde{\mathcal{M}}_P(\varphi^R) \geq 0$, where

$$\tilde{\mathcal{M}}_P(\varphi^R) := -(1-\eta)(A^B - A^L_{l,1}) + \frac{(1-\eta)A^B}{\varphi^R} - \kappa q,$$

(III) with full solvency risk, i.e., $\varphi^R > \varphi_1^S$, it holds that $\tilde{\mathcal{M}}_F \geq 0$, where

$$\tilde{\mathcal{M}}_F := -\kappa q.$$

Furthermore, it holds that $\lim_{\varphi^R \searrow \varphi_0^S} \tilde{\mathcal{M}}_P(\varphi^R) = \tilde{\mathcal{M}}_N$ and $\lim_{\varphi^R \nearrow \varphi_1^S} \tilde{\mathcal{M}}_P(\varphi^R) = \tilde{\mathcal{M}}_F$, as

$$\begin{aligned}
\lim_{\varphi^R \searrow \varphi_0^S} \tilde{\mathcal{M}}_P(\varphi^R) &= -(1-\eta)(A^B - A_{l,1}^L) + \frac{(1-\eta)A^B}{\varphi_0^S} - \kappa q \\
&= -(1-\eta)(A^B - A_{l,1}^L) + (1-\eta)(A^B - A_{l,0}^L) - \kappa q \\
&= (1-\eta)(A_{l,1}^L - A_{l,0}^L) - \kappa q \\
&= (1-\eta)\triangle - \kappa q \\
&= \tilde{\mathcal{M}}_N,
\end{aligned}$$

where we used $\varphi_0^S = A^B/(A^B - A_{l,0}^L)$, following from equation (14). ■

Proof of Lemma 9. Based on the assumption that the bank regulator sets sufficiently loose capital requirements, i.e. $\varphi^R \geq \varphi_m^L(\psi)$, we know that the maximum possible leverage satisfies $\overline{\varphi}_m(\theta) = \varphi_m^L(\psi)$ for all m. First, we focus on the case where no matter the monitoring decision, the banker is not exposed to a solvency risk, i.e., $\varphi_m^S \geq \varphi_m^L(\psi)$ for all m, or, equivalently, $\psi \geq \psi_m^S$ for all m. As we know that it holds that $\psi_0^S > \psi_1^S$, the inequality $\psi \geq \psi_m^S$ is satisfied for all m whenever $\psi \geq \psi_0^S$. We know from lemma 7 that in any such situation, the banker monitors (i.e., $m = 1$) if and only if $\mathcal{M}_N(\theta) \geq 0$, where

$$\mathcal{M}_N(\theta) = (1-\eta)\triangle + (\mathbb{E}[A_{s,0}^L] - A^B)\left[1 - \frac{\varphi_0^L(\psi)}{\varphi_1^L(\psi)}\right] - \kappa q.$$

Based on assumption 5, stating $\mathbb{E}[A_{s,0}^L] > A^B$, and assumption 6, stating that $(1-\eta)\triangle \geq \kappa q$, it follows that $\mathcal{M}_N(\theta) \geq 0$ for any ψ, so that without solvency risk, the banker always monitors.

Second, we focus on the situation where the banker is exposed to a solvency risk only without monitoring, i.e., $\varphi_0^L(\psi) > \varphi_0^S$ and $\varphi_1^L(\psi) \leq \varphi_1^S$, or, equivalently, $\psi_0^S > \psi \geq \psi_1^S$. We know from lemma 7 that in any such situation, the banker monitors (i.e., $m = 1$) if and only if $\mathcal{M}_P(\theta) \geq 0$, where

$$\mathcal{M}_P(\theta) = \eta(A_{h,0}^L - A^B)\left[1 - \frac{\varphi_0^L(\psi)}{\varphi_1^L(\psi)}\right] - (1-\eta)\left[A^B - A_{l,1}^L - \frac{A^B}{\varphi_1^L(\psi)}\right] - \kappa q.$$

Note that, using $A_{l,1}^L = A_{l,0}^L + \triangle$, we can rearrange the inequality $\mathcal{M}_P(\theta) \geq 0$ to

$$(1-\eta)\triangle + \eta(A_{h,0}^L - A^B)\left[1 - \frac{\varphi_0^L(\psi)}{\varphi_1^L(\psi)}\right] - (1-\eta)\left[A^B - A_{l,0}^L - \frac{A^B}{\varphi_1^L(\psi)}\right] \geq \kappa q.$$

With $\mathbb{E}[A_{s,0}^L] - A^B = \eta(A_{h,0}^L - A^B) + (1-\eta)(A_{l,0}^L - A^B)$, the latter inequality further simplifies to

$$(1-\eta)\triangle + (\mathbb{E}[A^L_{s,0}] - A^B)\left[1 - \frac{\varphi^L_0(\psi)}{\varphi^L_1(\psi)}\right] + (1-\eta)\frac{(A^L_{l,0} - A^B)\varphi^L_0(\psi) + A^B}{\varphi^L_1(\psi)} \geq \kappa q.$$

Note that

$$(\mathbb{E}[A^L_{s,0}] - A^B)\left[1 - \frac{\varphi^L_0(\psi)}{\varphi^L_1(\psi)}\right] + (1-\eta)\frac{(A^L_{l,0} - A^B)\varphi^L_0(\psi) + A^B}{\varphi^L_1(\psi)} \geq 0$$

$$\Leftrightarrow \qquad (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi) - \varphi^L_0(\psi)] + (1-\eta)[(A^L_{l,0} - A^B)\varphi^L_0(\psi) + A^B] \geq 0,$$

where the latter inequality is satisfied for any haircut ψ sufficiently close to ψ^S_0, i.e.,

$$\begin{aligned}
&\lim_{\psi \nearrow \psi^S_0} (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi) - \varphi^L_0(\psi)] + (1-\eta)[(A^L_{l,0} - A^B)\varphi^L_0(\psi) + A^B] \\
&= (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi^S_0) - \varphi^L_0(\psi^S_0)] + (1-\eta)[(A^L_{l,0} - A^B)\varphi^L_0(\psi^S_0) + A^B] \\
&= (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi^S_0) - \varphi^S_0] + (1-\eta)[(A^L_{l,0} - A^B)\varphi^S_0 + A^B] \\
&= (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi^S_0) - \varphi^S_0] + (1-\eta)[(A^L_{l,0} - A^B)\varphi^S_0 + A^B] \\
&= (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi^S_0) - \varphi^S_0] + (1-\eta)[-A^B + A^B] \\
&= (\mathbb{E}[A^L_{s,0}] - A^B)[\varphi^L_1(\psi^S_0) - \varphi^S_0] > 0,
\end{aligned}$$

where we used $\varphi^L_0(\psi^S_0) = \varphi^S_0$ and $\varphi^S_0 = A^B/(A^B - A^L_{l,0})$. Using assumption 6, stating $(1-\eta)\triangle \geq \kappa q$, we can then conclude that there exists a set of haircuts in the interval $(\psi^S_0, \psi^S_1]$ which induces the banker to monitor. Specifically, the banker monitors for any haircut $\psi \geq \psi^{**}$, where $\psi^{**} = \min\left\{\psi^S_0 \geq \psi \geq \psi^S_1 : \mathcal{M}_P(\theta) \geq 0\right\}$.

Third and last, we focus on the situation, where independent of the monitoring decision, the banker is exposed to a solvency risk, i.e., $\varphi^L_m(\psi) > \varphi^S_m$ for all m, or, equivalently, $\psi^S_m > \psi$ for all m. Since we know that it holds that $\psi^S_0 > \psi^S_1$, the inequality $\psi^S_m > \psi$ is satisfied for all m whenever $\psi^S_1 > \psi$. We then know from lemma 7 that the banker monitors (i.e., $m = 1$) if and only if $\mathcal{M}_F(\theta) \geq 0$, where

$$\mathcal{M}_F(\theta) = \eta(A^L_{h,0} - A^B)\left[1 - \frac{\varphi^L_0(\psi)}{\varphi^L_1(\psi)}\right] - \kappa q.$$

We know that for any haircut ψ sufficiently close to one, the banker does not monitor, as it holds that $\mathcal{M}_F(\theta) < 0$. However, if the haircut ψ is sufficiently small, the banker may decide to monitor, i.e., formally, it must hold that

$$\mathcal{M}_F(\theta) \geq 0 \qquad \Leftrightarrow \qquad 1 - \frac{\varphi^L_0(\psi)}{\varphi^L_1(\psi)} \geq \frac{\kappa q}{\eta(A_{h,0} - A^B)} := \chi \qquad \Leftrightarrow \qquad 1 - \chi \geq \frac{\varphi^L_0(\psi)}{\varphi^L_1(\psi)}.$$

Based on assumption 5, we know that $\chi > 0$. Using the structure of $\varphi^L_m(\psi)$, as outlined in equation (16), the latter inequality reads as

$$1-\chi \geq \frac{\dfrac{\alpha A^B}{\alpha A^B-(1-\psi)\mathbb{E}[A^L_{s,0}]}}{\dfrac{\alpha A^B}{\alpha A^B-(1-\psi)\mathbb{E}[A^L_{s,1}]}} \qquad \Leftrightarrow \qquad 1-\chi \geq \frac{\alpha A^B-(1-\psi)\mathbb{E}[A^L_{s,1}]}{\alpha A^B-(1-\psi)\mathbb{E}[A^L_{s,0}]}.$$

The latter inequality further simplifies to

$$\begin{aligned}
\Leftrightarrow \qquad & (1-\chi)\{\alpha A^B-(1-\psi)\mathbb{E}[A^L_{s,0}]\} \geq \alpha A^B-(1-\psi)\mathbb{E}[A^L_{s,1}] \\
\Leftrightarrow \qquad & (1-\psi)\{\mathbb{E}[A^L_{s,1}]-(1-\chi)\mathbb{E}[A^L_{s,0}]\} \geq \chi\alpha A^B \\
\Leftrightarrow \qquad & (1-\psi)\{\chi\mathbb{E}[A^L_{s,0}]+(1-\eta)\triangle\} \geq \chi\alpha A^B \\
\Leftrightarrow \qquad & 1-\frac{\chi\alpha A^B}{\chi\mathbb{E}[A^L_{s,0}]+(1-\eta)\triangle} := \hat{\psi} \geq \psi,
\end{aligned}$$

where we used $A^L_{h,1}=A^L_{h,0}$ and $A^L_{l,1}=A^L_{l,0}+\triangle$. ■

Proof of Lemma 10. From Lemma 9, we know that in the situation where the banker is fully exposed to a solvency risk, i.e., $\psi^S_1 > \psi$, the banker monitors if and only if

$$\psi \leq \hat{\psi} := 1-\frac{\chi\alpha A^B}{\chi\mathbb{E}[A^L_{s,0}]+(1-\eta)\triangle}, \qquad \text{with} \qquad \chi := \frac{\kappa q}{\eta(A^L_{h,0}-A^B)}.$$

First, we want to know under which conditions the smallest feasible haircut with monitoring by the banker ψ^M_1 is indeed smaller than the critical haircut $\hat{\psi}$. On that account, note that it holds that

$$\begin{aligned}
& \psi^M_1 \leq \hat{\psi} \\
\Leftrightarrow \qquad & 1-\frac{\alpha A^B}{\mathbb{E}[A^L_{s,1}](1+E/K)} \leq 1-\frac{\chi\alpha A^B}{\chi\mathbb{E}[A^L_{s,0}]+(1-\eta)\triangle} \\
\Leftrightarrow \qquad & \frac{\chi\alpha A^B}{\chi\mathbb{E}[A^L_{s,0}]+(1-\eta)\triangle} \leq \frac{\alpha A^B}{\mathbb{E}[A^L_{s,1}](1+E/K)},
\end{aligned}$$

which further simplifies to

$$
\begin{aligned}
& \chi\mathbb{E}[A_{s,1}^L](1+E/K) \leq \chi\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle \\
\Leftrightarrow \quad & \chi\{\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle\} + \chi\mathbb{E}[A_{s,1}^L]E/K \leq \chi\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle \\
\Leftrightarrow \quad & \chi\mathbb{E}[A_{s,1}^L]E/K \leq (1-\chi)(1-\eta)\triangle \\
\Leftrightarrow \quad & E/K \leq \frac{(1-\chi)(1-\eta)\triangle}{\chi\mathbb{E}[A_{s,1}^L]}.
\end{aligned}
$$

Second, we assess when the condition $\psi \leq \hat{\psi}$ is less restrictive than the condition $\psi_1^S > \psi$. On that account, note that it holds that

$$
\begin{aligned}
& \hat{\psi} \geq \psi_1^S \\
\Leftrightarrow \quad & 1 - \frac{\chi\alpha A^B}{\chi\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle} \geq 1 - \frac{\alpha A_{l,1}^L}{\mathbb{E}[A_{s,1}^L]} \\
\Leftrightarrow \quad & \frac{\alpha A_{l,1}^L}{\mathbb{E}[A_{s,1}^L]} \geq \frac{\chi\alpha A^B}{\chi\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle},
\end{aligned}
$$

which further simplifies to

$$
\begin{aligned}
& A_{l,1}^L\{\chi\mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle\} \geq \chi A^B\mathbb{E}[A_{s,1}^L] \\
\Leftrightarrow \quad & (1-\eta)\triangle A_{l,1}^L \geq \chi(A^B\mathbb{E}[A_{s,1}^L] - A_{l,1}^L\mathbb{E}[A_{s,0}^L]) \\
\Leftrightarrow \quad & \frac{(1-\eta)\triangle A_{l,1}^L}{A^B\mathbb{E}[A_{s,1}^L] - A_{l,1}^L\mathbb{E}[A_{s,0}^L]} \geq \chi.
\end{aligned}
$$

■

Proof of Proposition 6. Based on assumption 5, stating that even without monitoring, a loan-financed firm is in expectation more productive than a bond-financed firm, and based on assumption 6, ensuring that monitoring is socially optimal, welfare increases with loan financing and monitoring by the banker. The banker always monitors if $\varphi^R \leq \varphi^*$. Accordingly, it is optimal for the bank regulator to implement capital requirements, such that $\varphi^R = \varphi^M$ whenever (i) $\varphi^M \leq \varphi^*$, such that bank lending is maximized and the banker monitors, or (ii) $\varphi^M > \varphi^*$, so that bank lending is maximized and the banker does not monitor, but reducing bank leverage to induce monitoring does not yield a welfare gain, i.e., it holds that $W_0(\varphi^M) \geq W_1(\varphi^*)$ or, equivalently,

$$
\begin{aligned}
& (\mathbb{E}[A^L_{s,0}] - A^B)\varphi^M E + A^B(K+E) \geq (\mathbb{E}[A^L_{s,1}] - A^B - \kappa q)\varphi^* E + A^B(K+E) \\
\Leftrightarrow \quad & (\mathbb{E}[A^L_{s,0}] - A^B)\varphi^M \geq (\mathbb{E}[A^L_{s,1}] - A^B - \kappa q)\varphi^* \\
& \frac{\varphi^M}{\varphi^*} \geq \frac{\mathbb{E}[A^L_{s,1}] - A^B - \kappa q}{\mathbb{E}[A^L_{s,0}] - A^B} \\
& \frac{\varphi^M}{\varphi^*} \geq 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A^L_{s,0}] - A^B},
\end{aligned}
$$

where we used $A_{l,1} = A_{l,0} + \triangle$, implying $\mathbb{E}[A^L_{s,1}] = \mathbb{E}[A^L_{s,0}] + (1-\eta)\triangle$. Based on asssumption 1, a loan-financed firm is in expectation, independent of the banker's monitoring decision, more productive than a bond-financed firm. Accordingly, under the condition $\varphi^M > \varphi^*$, the welfare without monitoring by the banker is maximized for $\varphi^R = \varphi^M$, whereas welfare with monitoring is maximized for $\varphi^R = \varphi^*$. We therefore only need to compare welfare $W_0(\varphi^M)$ and $W_1(\varphi^*)$.

In all other situations, it is optimal for the bank regulator to implement capital requirements leading to the regulatory maximum leverage $\varphi^R = \varphi^*$, restricting bank leverage below the maximum feasible and thereby inducing the banker to monitor. ■

Proof of Proposition 7. Based on assumption 5, stating that even without monitoring, a loan-financed firm is in expectation more productive than a bond-financed firm, and based on assumption 6, ensuring that monitoring is socially optimal, we know that welfare increases with loan financing and monitoring by bankers. From lemma 9, it follows that the banker monitors whenever (i) $\psi \geq \psi^S_0$, (ii) $\psi^S_1 > \psi \geq \psi^S_1$ and $\psi \geq \psi^{**}$, where $\psi^{**} = \min\{\psi^S_0 > \psi \geq \psi^S_1 : \mathcal{M}_P(\theta) \geq 0\}$, and (iii) $\psi^S_1 > \psi$ and $\hat{\psi} \geq \psi$, where

$$
\hat{\psi} = 1 - \frac{\chi\alpha A^B}{\chi\mathbb{E}[A^L_{s,0}] + (1-\eta)\triangle}, \qquad \text{with} \qquad \chi := \frac{\kappa q}{\eta(A^L_{h,0} - A^B)}.
$$

Note that it holds that $\psi^S_0 > \psi^{**} \geq \psi^S_1$. Accordingly, we can state that the central bank optimally sets the haircut $\psi = \psi^M_1$ whenever (i) $\psi^M_1 \geq \psi^{**}$ or (ii) $\psi^S_1 > \psi^M_1$ and $\hat{\psi} \geq \psi^M_1$. Next, we study the alternative cases. First, focus on the situation where $\psi^{**} > \psi^M_1$. Then three situations can arise: Either it holds (iii) $\psi^M_0 \geq \psi^S_1$, or (iv) $\psi^S_1 > \psi^M_0$ and $\psi^M_0 > \hat{\psi}$, or (v) $\psi^S_0 > \psi^M_0$ and $\hat{\psi} \geq \psi^M_0$. In the cases (iii) and (iv), the banker does not monitor for any feasible haircut lower than ψ^{**}. Thus, the central bank has to decide between maximizing bank lending by setting the haircut $\psi = \psi^M_0$ but having bankers not monitoring, or reducing bank leverage below the maximum feasible by setting the haircut $\psi = \psi^{**}$ but having bankers monitoring. In the cases (iii) and (iv), the central bank implements the haircut $\psi = \psi^M_0$ whenever it holds that

$W_0(\psi_0^M) \geq W_1(\psi^{**})$ or, equivalently,

$$
\begin{aligned}
& (\mathbb{E}[A_{s,0}^L] - A^B)\varphi^M E + A^B(K+E) \geq (\mathbb{E}[A_{s,1}^L] - A^B - \kappa q)\varphi^{**} E + A^B(K+E) \\
\Leftrightarrow \quad & (\mathbb{E}[A_{s,0}^L] - A^B)\varphi^M \geq (\mathbb{E}[A_{s,1}^L] - A^B - \kappa q)\varphi^{**} \\
\Leftrightarrow \quad & \frac{\varphi^M}{\varphi^{**}} \geq \frac{\mathbb{E}[A_{s,1}^L] - A^B - \kappa q}{\mathbb{E}[A_{s,0}^L] - A^B} \\
\Leftrightarrow \quad & \frac{\varphi^M}{\varphi^{**}} \geq 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A_{s,0}^L] - A^B},
\end{aligned}
$$

where we used $\mathbb{E}[A_{s,1}^L] = \mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle$ and applied the notation $\varphi^{**} = \varphi_1^L(\psi^{**})$. In case (v), the central bank finds itself unable to set the smallest feasible haircut $\psi = \psi_0^M$, as it would actually induce monitoring, but with monitoring, the haircut $\psi = \psi_0^M$ would not permit clearing of the capital good market. Thus, the central bank can only set a haircut sufficiently close to, but above $\hat{\psi}$ in order to maximize bank lending and without inducing monitoring. In case (v), the central bank then decides to set the haircut $\psi = \hat{\psi} - \epsilon$ with $\epsilon \to 0$ whenever it holds that

$$
\begin{aligned}
& (\mathbb{E}[A_{s,0}^L] - A^B)\varphi_0^L(\hat{\psi}) E + A^B(K+E) \geq (\mathbb{E}[A_{s,1}^L] - A^B - \kappa q)\varphi^{**} E + A^B(K+E) \\
\Leftrightarrow \quad & (\mathbb{E}[A_{s,0}^L] - A^B)\varphi_0^L(\hat{\psi}) \geq (\mathbb{E}[A_{s,1}^L] - A^B - \kappa q)\varphi^{**} \\
\Leftrightarrow \quad & \frac{\hat{\varphi}}{\varphi^{**}} \geq \frac{\mathbb{E}[A_{s,1}^L] - A^B - \kappa q}{\mathbb{E}[A_{s,0}^L] - A^B} \\
\Leftrightarrow \quad & \frac{\hat{\varphi}}{\varphi^{**}} \geq 1 + \frac{(1-\eta)\triangle - \kappa q}{\mathbb{E}[A_{s,0}^L] - A^B},
\end{aligned}
$$

where we used $\mathbb{E}[A_{s,1}^L] = \mathbb{E}[A_{s,0}^L] + (1-\eta)\triangle$ and applied the notation $\hat{\varphi} = \varphi_0^L(\hat{\psi})$.

In all other cases, the central bank optimally sets the haircut $\psi = \psi^{**}$ to restrict bank leverage below the maximum feasible and thereby inducing the banker to monitor. ■

Proof of Corollary 4. We first show that a liquidity-constrained banker monitors under higher leverage ratios than a capital-constrained banker. Note that it holds that

$$\mathcal{M}_P(\theta^{**}) = 0 = \tilde{\mathcal{M}}(\varphi^*),$$

where $\theta^{**} = (\varphi^R, \psi^{**})$. The latter equation is equivalent to

$$
\begin{aligned}
& \eta(A_{h,0}^L - A^B)\left[1 - \frac{\varphi_0^L(\psi^{**})}{\varphi_1^L(\psi^{**})}\right] - (1-\eta)\left[A^B - A_{l,1}^L - \frac{A^B}{\varphi_1^L(\psi^{**})}\right] - \kappa q \\
& \qquad = -(1-\eta)(A^B - A_{l,1}^L) + \frac{(1-\eta)A^B}{\varphi^*} - \kappa q.
\end{aligned}
$$

Rearranging the latter equation yields

$$\eta(A_{h,0}^{L}-A^{B})\left[1-\frac{\varphi_0^L(\psi^{**})}{\varphi_1^L(\psi^{**})}\right]=(1-\eta)A^{B}\left[\frac{1}{\varphi^{*}}-\frac{1}{\varphi_1^L(\psi^{**})}\right].$$

Since the left-hand side of the this equality is always positive for $\psi \in [0,1)$, we can conclude that $\varphi^{**} = \varphi_1^L(\psi^{**}) > \varphi^{*}$. It thus follows that it is generally optimal to constrain the banker by liquidity rather than by capital. Accordingly, in most situations, the optimal bank regulation is characterized by sufficiently loose capital requirements, i.e., $\varphi^R \geq \varphi_m^L(\psi)$ (e.g., $\varphi = \varphi^M$), and collateral requirements in the form of the haircut that follow the monetary policy described in proposition 7. There is only one exception: If it holds that $\psi^{**} > \psi_1^M > \hat{\psi}$ and the central bank cannot implement the smallest feasible haircut $\psi = \psi_0^M$ with inducing monitoring, i.e., $\psi_1^S > \psi_0^M$ and $\hat{\psi} \geq \psi_0^M$, it follows that it is better to constrain the banker by capital rather than liquidity, as in the former case, bank lending can be maximized. In this particular case, the collateral requirements set by the central bank should satisfy $\psi \leq \tilde{\psi}_0(\varphi^R)$, while the capital requirements satisfy $\varphi^R = \varphi^M$. ■

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