Credit Market Competition and Capital Regulation*

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Abstract

Market discipline for financial institutions can be imposed from the asset side as well as the liability side. This occurs if there is a shortfall of good lending opportunities, so banks have to compete for projects. The optimal contract ensures that banks commit to monitoring by requiring that they hold capital. Incentives to monitor can also be provided through loan rates. Since banks' cost of capital is not fully internalized, the market capital level can be above or equal to the regulatory level. This implies that banks can keep capital above regulatory limits, in line with recent evidence.

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1 Introduction

A common justification for capital regulation for banks is the reduction of bank moral hazard. The presence of deposit insurance implies that banks have easy access to deposit funds. If they hold a low level of capital, there is an incentive for them to take on excessive risk. Given the widely accepted view that equity capital is more costly for banks than other forms of funds, the common result in many analyses of bank regulation is that capital adequacy standards are binding as banks attempt to economize on the use of this costly input.

In practice, however, it appears that banks often hold levels of capital well above those required by regulation and that capital holdings have varied substantially over time in a way that is difficult to explain as a function of regulatory changes. For example, Berger et al. (1995) report that the ratios of equity to assets of US banks fell from around 40-50 percent in the 1840's and 1850's to 6-8 percent in the 1940's, where they stayed until the 1980's. Comparing actual capital holdings to regulatory requirements, Flannery and Rangan (2004) suggest that banks' capital ratios have increased substantially in the last decade, with banks in the U.S. now holding capital that is 75% in excess of the regulatory minimum. Similar cross-country evidence is provided in Barth et al. (2005) (see Figure 3.8, p. 119).[1] In search of an explanation of the capital buildup in the US throughout the 1980's, Ashcraft (2001) finds little evidence that tougher capital requirements were responsible. Barrios and Blanco (2003) argue that Spanish banks' capital ratios over the period 1985-1991 were primarily driven by the pressure of market forces rather than regulatory constraints. Also, Alfon et al. (2004) report that UK banks increased their capital ratios in the last decade despite a reduction in their individual capital requirements, and operate now with an average capital buffer of 35-40 percent.

In this paper we develop a model of bank capital consistent with the observation that banks hold high levels of capital which may change independently of regulation. Our model

[1] A recent study by Citigroup Global Markets (2005) finds that "... most European banks have and generate excess capital", with Tier 1 ratios significantly above target.

is based on two standard assumptions. First, banks' capital structures may have implications for their ability to attract borrowers. Second, banks perform a special role as monitors. With these two features, we show that costly capital is not sufficient to guarantee that banks will minimize how much capital they hold so that capital requirements need not be binding.

In our one-period model of bank lending, firms need external financing to make productive investments. Banks grant loans to firms and monitor them, which helps improve firms' performance. Specifically, we assume that the more monitoring effort a bank exerts, the greater is the probability that a firm's investment is successful. Given that monitoring is costly and banks have limited liability, banks are subject to a moral hazard problem in the choice of monitoring effort and need to be provided with incentives. One way of doing this is through the amount of equity capital a bank has. Capital forces banks to internalize the costs of their default, thus ameliorating the limited liability problem banks face due to their extensive reliance on deposit-based financing.[2] A second instrument to improve banks' incentives is embodied in the interest rate on the loan. A marginal increase in the loan rate gives banks a greater incentive to monitor in order to receive the higher payoff if the project succeeds. Thus, capital and loan rates are alternative ways to improve banks' monitoring incentives, but entail different costs. Holding capital implies a direct private cost for the banks, whereas increasing the loan rate has a negative impact only for borrowers in terms of a lower return from the investment. Which incentive instrument (or combination of instruments) is used in equilibrium will depend on how surplus is allocated between borrowers and banks, which in turn depends on the quantity of funds relative to good projects that are available.

We consider two distinct cases. In the first, we assume that there is a shortage of bank funds relative to good projects so that borrowers must compete for funds. In the second, there is a shortage of good projects relative to the funds available so that banks must compete

[2] Following the rest of the literature on capital regulation, in the first part of the paper we take it as given that there is deposit insurance. We relax this assumption in the later part of the paper to show that our results are not driven by the existence of deposit insurance.

for firms' business.

When there is a shortage of bank funds available, banks optimally choose to hold no capital and raise the loan rates to the highest level that is consistent with firms being willing to borrow. This combination of capital and loan rates allows banks to maximize their surplus since capital is more costly than deposits. Given that banks have limited liability and do not internalize the costs to the deposit insurance fund, the market solution may be inefficient. Thus, there may be scope for capital regulation when there is a shortage of funds. In particular, we show that when the cost of deposits is high enough, a regulator interested in maximizing social welfare would impose a requirement that banks hold a positive amount of capital. This capital requirement leads to improved monitoring and reduces the cost to the deposit insurance fund.

The case where there is a shortage of good projects is more complex. In equilibrium, competition to attract borrowers forces banks to hold a positive amount of capital. Capital acts as a commitment device for banks to monitor, which in turn increases borrowers' surplus. Loan rates are lower than in the case of a shortage of funds, but are still used to provide banks with incentives to monitor. Since borrowers' surplus is maximized, banks hold as much capital as is consistent with their participation constraint and the loan rate is set at the level where the positive incentive effect of a higher loan rate equals the negative direct effect on borrowers' surplus.

These findings suggest that market discipline can be imposed not only from the liability side, as has been stressed in the literature on the use of subordinated debt (for a review, see Flannery and Nikolova, 2004), but also from the asset side of banks' balance sheets. Given capital and loan rates are alternative instruments for improving banks' monitoring incentives, we find that in equilibrium there is a negative relationship between them. These results are consistent with the empirical finding in Hubbard et al. (2002) and Kim et al. (2005) of higher loan rates on loans from less-capitalized banks.

In this setting, we show that a social welfare maximizing regulator will choose an amount of capital either below or equal to the market level. The regulator chooses a level of capital below that in the market equilibrium when the cost of equity capital is high relative to the cost of deposits. The reason is that the regulator ignores distributional issues and simply trades off from a social welfare perspective the cost of raising capital against the benefit in terms of improved monitoring. In the other case, when the cost of equity capital is low relative to the cost of deposits, the regulator requires banks to hold the same amount of capital as in the market equilibrium. Requiring banks to hold high levels of capital so as to improve their monitoring incentives is now desirable. However, the regulator cannot require banks to hold more capital than in the market solution, as banks' participation constraint is already binding. The regulator therefore cannot improve on the market equilibrium and the market is constrained efficient.

We extend our model in a number of directions. First, we consider the case without deposit insurance and show that our main qualitative results remain valid. The only difference is that banks hold a positive amount of capital in the market equilibrium even when there is a shortage of funds. This is because without deposit insurance banks internalize the cost of their default and choose the same level of capital as a social welfare maximizing regulator.

Second, we analyze the case where banks can choose between relationship and transactional lending. The first refers to the monitored loan we have considered so far, and the second to a loan with a lower probability of success but a higher payoff in case of success. We show that capital regulation increases the attractiveness of relationship loans relative to transactional loans. This is because capital improves banks' monitoring incentives when they are engaged in relationship lending but it represents a pure cost in the case of transactional lending.

Finally, we study the case where banks have a franchise value from remaining in business to introduce some simple dynamic considerations. We find that franchise value and capital are substitute ways to provide banks with monitoring incentives. There is thus less need of capital regulation when banks enjoy a large franchise value from remaining in business.

The paper has a number of empirical implications. First, the model suggests that banks keep high levels of capital when they have limited good projects to invest in. This implies that there should be an empirical correlation between capital holdings and holdings of other investments, such as government bonds and other marketable securities. Second, our analysis predicts that increased capital regulatory requirements implies a shift in banks' portfolios away from transactional lending toward more relationship lending. Third, the analysis suggests that capital and franchise values are substitute ways to improve banks' monitoring incentives. Finally, our model offers some cross-sectional implications concerning banks' capital holdings and firms' sources of borrowing. Banks engaged in monitoring-intensive lending should be more capitalized than banks operating in more transactional lending. To the extent that small banks are more involved in more monitored lending to small and medium firms, the model predicts that small banks should be better capitalized than larger banks, in line with the empirical findings in Alfon et al. (2004) and Heider and Gropp (2006). Similarly, firms for which monitoring adds the most value should prefer to borrow from banks with high capital. Billett et al. (1995) finds that lender "identity," in the sense of the lender's credit rating, is an important determinant of the market's reaction to the announcement of a loan. To the extent that capitalization improves a lender's rating and reputation, these results are in line with the predictions of our model.

Recent research on the role of bank capital has studied a variety of issues. Gale (2003, 2004) and Gale and Özgür (2005) consider the risk sharing function of bank capital and the implications for regulation. Less risk averse equity holders share risk with more risk averse depositors. In contrast, in our model agents are risk neutral so risk sharing plays no role in determining banks' capital holdings.

Diamond and Rajan (2000) have considered the interaction between the role of capital as a buffer against shocks to asset values and banks' role in the creation of liquidity. Closer to our work, Holmstrom and Tirole (1997) study the role of capital in determining banks' lending capacities and providing incentives to monitor. Other studies such as Hellmann et al. (2000), Repullo (2004) and Morrison and White (2005) analyze the role of capital in reducing risk-taking. In contrast to these papers, our approach focuses on the relationship between unconstrained markets and regulatory requirements and shows the circumstances where the market equilibrium is constrained efficient.

A possible explanation for excess capital based on dynamic considerations is suggested by Blum and Hellwig (1995), Bolton and Freixas (2006), Peura and Keppo (2006), and Van den Heuvel (2005). Banks choose a buffer above the regulatory requirement as a way to ensure they do not violate the regulatory constraint. In these models banks' capital holdings would still be altered by regulatory changes, but we do not observe this in the data. Our model provides in a static framework an explanation for why capital holdings may be significantly above regulatory requirements and are not driven by regulatory changes.

Section 2 outlines the model. Section 3 considers banks' choice of monitoring taking the loan rates and capital amounts as given. The case where there is a shortage of bank funds is considered in Section 4, while the opposite case is analyzed in Section 5. Section 6 extends the analysis in various directions. Section 7 contains concluding remarks.

2 Model

Consider a simple one-period economy, with M firms and N banks. Firms have access to risky investment projects, and need external funds to finance them. Each bank lends to one firm only and monitors it.

Borrowers: Each firm needs 1 unit of funds to invest in a risky project with total payoff of R when successful and 0 when not. Firms raise the funds needed through bank loans in exchange for a promised total repayment r_L, and choose to invest in the project as long as they obtain an expected return at least equal to that on the next best alternative, $r_B \geq 0$.

Banks: Banks finance themselves with an amount of capital k at a total cost r_E per unit, and an amount of deposits $1 - k$ at a total per unit cost r_D. For the moment we consider the case where deposits are fully insured so that the deposit rate r_D does not depend on the risk of bank portfolios (we analyze the case with no deposit insurance in Section 6.1.), and assume $r_E \geq r_D$. This assumption captures the idea that bank capital is a particularly expensive form of financing, as is typically assumed in the literature.[3]

Bank monitoring: The function of banks in the economy is to provide monitoring and thus increase the success probability of firms. Specifically, each bank chooses a monitoring effort q that for simplicity represents the success probability of the firm it finances.[4] Exerting monitoring carries a cost of cq^2 for the bank. Our modelling of bank monitoring captures the idea that firms and banks have complementary skills. Firm managers have an expertise in running the firm. This consists of operating the plant, managing the employees, and so forth. Banks provide complementary financial expertise and can thus help firms and increase their expected value.[5]

Market structure: The loan rate r_L and the amount of capital k are determined endogenously, and can be set in one of two ways. They can either both be determined by the bank or the amount of capital can be set by a regulator who maximizes social welfare. The market is competitive, but the solution will depend on the division of surplus between banks and borrowers. We will distinguish between two cases for the allocation of surplus: first, the case where there is a shortage of funds available to lend ($N < M$), and, second, the case where there is a shortage of firms with good investment projects ($N > M$).

Timing: The model can be divided into 4 stages. First, the level of bank capital k is determined, either by the bank or by a regulator. Second, banks set the loan rate r_L. Third, borrowers choose the loan that is most attractive to them. Finally, banks choose their monitoring effort q once the terms of the loan have been set and they have raised capital

[3] See Berger et al. (1995) for a discussion of this issue; and Hellmann et al. (2000) and Repullo (2004) for a similar assumption.

[4] An alternative interpretation is that the effect of monitoring is to increase the return R in the case of success, holding the probability of success constant.

[5] See, e.g., Besanko and Kanatas (1993), Holmstrom and Tirole (1997), Carletti (2004), and Dell'Ariccia and Marquez (2006), for studies with related monitoring technologies. This is also consistent with the idea of relationship lending in Boot and Thakor (2000).

and deposits. Note that, in the absence of regulation, this timing structure is equivalent to assuming that k and r_L are set simultaneously.

3 Equilibrium bank monitoring

As usual we solve the model by backward induction, and begin with banks' optimal choice of monitoring at the final stage for a given amount of capital k and loan rate r_L. Each bank chooses its monitoring effort so as to maximize expected profits as given by

$$\max_q \ \Pi = q(r_L - (1-k)r_D) - kr_E - cq^2. \tag{1}$$

The first term, $q(r_L - (1-k)r_D)$, represents the return to the bank in case the project succeeds net of the repayment to depositors. The second term, kr_E, is the opportunity cost of providing k units of capital, and the last term is the cost of monitoring.

The solution to this problem yields

$$q^* = \min\left\{\frac{r_L - (1-k)r_D}{2c}, 1\right\} \tag{2}$$

as the optimal level of monitoring for each bank. Note that, when $q^* < 1$, bank monitoring effort is increasing in the return from lending r_L as well as in the level of capital k the bank holds, but is decreasing in the deposit rate r_D and in the marginal cost of monitoring c. Thus loan rates and capital are two alternative ways to improve banks' monitoring incentives.

This framework implies a moral hazard problem in the choice of monitoring when banks raise a positive amount of deposits. Since banks repay depositors only when their portfolios succeed, they do not internalize the full cost of default on depositors. This limited liability biases bank monitoring downwards. Capital forces banks to bear some of the burden associated with non-performing loans, and therefore provides an incentive for banks to monitor. Thus, a possible rationale for capital regulation is to limit moral hazard and raise the level of monitoring. This is illustrated by noting that, in the absence of limited liability, the equilibrium level of monitoring would be $\widehat{q} = \min\left\{\frac{r_L}{2c}, 1\right\} \geq q^*$, with the inequality strict whenever $q^* < 1$.

4 Shortage of funds

We now turn to the determination of the amount of capital k banks hold and the loan rate r_L, and begin with the case where there is a shortage of loanable funds relative to the supply of projects $(N < M)$. This case reflects the situation where borrowers compete away their returns on the projects in order to attract funding and banks obtain their preferred terms.

Banks set k and r_L so as to maximize their expected profits, taking into account their subsequent monitoring choice and the fact that borrowers accept the loans only if they have a non-negative surplus. Thus, the profit-maximizing contract solves the following problem:

$$\max_{k, r_L} \Pi = q(r_L - (1-k)r_D) - kr_E - cq^2 \tag{3}$$

subject to

$$\begin{aligned} q &= \min\left\{\frac{r_L - (1-k)r_D}{2c}, 1\right\}; \\ BS &= q\left(R - r_L\right) \geq r_B; \\ 0 &\leq k \leq 1. \end{aligned}$$

The first constraint represents the monitoring effort that banks choose in order to maximize expected profits after lending to borrowers, which was obtained above. The second constraint is the participation constraint of borrowers, labelled as borrower surplus BS. It states that a borrower will be willing to accept a loan only if he can earn an expected return at least equal to his reservation value r_B. The last constraint is simply a physical constraint on the level of capital, in that banks can choose between raising only deposits, a mixture of deposits and capital, or being entirely equity financed. We assume that the payoff R is sufficiently large that banks obtain non-negative profits and are therefore willing to participate.

The solution to this maximization problem yields the following result.

Proposition 1 *When there is a shortage of funds, banks maximize expected profits by holding no capital and offering a loan rate equal to the maximum possible return on the project, taking into account firms' participation constraint, $r_L = R - \frac{r_B}{q}$. Banks exert monitoring effort $q = \min\left\{\frac{R-r_D}{2c}, 1\right\}$ and earn positive expected profits.*

Proof: See the appendix. □

The intuition behind Proposition 1 is simple. When there is a shortage of funds, banks retain all the surplus from investment projects as borrowers compete away their returns in order to attract funds. Since equity is more costly to banks, they choose to finance themselves entirely with deposits. A high loan rate benefits banks in two ways. First, it provides them with a large return, all things equal. Second, a high loan rate also provide banks with incentives to monitor. Banks therefore offer to lend at the highest rate that borrowers are willing to accept so that in equilibrium the loan rate keeps borrowers indifferent between taking the loan and not.

Given that banks minimize their holdings of capital, there may be scope for capital regulation in this context. Because of limited liability and full deposit insurance, banks do not internalize the full cost of default and simply choose their level of capital and loan prices so as to maximize their expected profits. By contrast, a regulator interested in maximizing social welfare considers the cost borne by the deposit insurance fund in case of bank default and solves the following problem:

$$\begin{aligned} \max_k \; SW &= \Pi + BS - (1-q)(1-k)r_D \\ &= qR - (1-k)r_D - kr_E - cq^2 \end{aligned} \tag{4}$$

subject to

$$
\begin{aligned}
q &= \min\left\{\frac{r_L-(1-k)r_D}{2c},1\right\}; \\
r_L &= \arg\max_r \Pi(r); \\
BS &= q\,(R-r_L) \geq r_B; \\
0 &\leq k \leq 1.
\end{aligned}
$$

The optimization problem is similar to before, with the important difference that the regulator chooses only the level of capital, and that it does so in order to maximize social welfare. The loan rate is still set as part of the market solution, as given in Proposition 1, and this becomes the second constraint in the problem above.

Proposition 2 *When there is a shortage of funds, capital regulation that maximizes social welfare requires banks to hold capital equal to* $k^{reg} = \max\{1-\frac{2c}{r_D^2}(r_E-r_D), 0\}$*, which is positive as long as* $r_D > \max\left\{R-2c, \sqrt{c(c+2r_E)}-c\right\}$ *and 0 otherwise. Banks exert monitoring effort* $q = \frac{R-r_D}{2c} < 1$ *and earn positive expected profits.*

Proof: See the appendix. □

Proposition 2 shows that welfare-maximizing capital regulation may require a positive −but always less than 1− level of capital because of its positive incentive effect on bank monitoring. This occurs when the required return for depositors r_D is sufficiently high that banks would not monitor fully when they have no capital (i.e., when $r_D > R-2c$ so that $q < 1$), and also high enough that the positive incentive effect on social welfare of raising capital outweighs the cost r_E (i.e., when $r_D > \sqrt{c(c+2r_E)}-c$). While banks internalize the value of their monitoring, they do not fully internalize the cost associated with the failure of the project and the consequent burden imposed on the deposit insurance fund. Capital regulation is therefore a second best solution to the distortion of deposit insurance. When deposits are fully insured, banks can reduce monitoring without having to pay more to depositors. Banks are thus more likely to default, with the deposit insurance fund left to make up the difference. By forcing banks to hold a positive amount of capital, regulation improves banks' monitoring incentives and reduces the disbursement of the deposit insurance fund, as in, for example, Hellmann et al. (2000), Repullo (2004) and Morrison and White (2005).

Comparing Propositions 1 and 2 leads to the following immediate result.

Proposition 3 *When there is a shortage of funds, capital regulation requires banks to hold a higher amount of capital than the market for* $r_D > \max\left\{R - 2c, \sqrt{c(c+2r_E)} - c\right\}$.

This result establishes that in our framework a regulator requires a higher amount of capital than the amount that maximizes banks' profits when the deposit rate is sufficiently high. Regulation can thus be beneficial as it increases social welfare relative to what would be obtained under the market solution. In these instances, there is a rationale for capital regulation as a way of providing banks with incentives to monitor. This is entirely due to the presence of full deposit insurance which allows banks to take advantage of the implicit subsidy it provides. As we will show in Section 6.1, in the absence of deposit insurance the market is instead constrained efficient and maximizes social welfare when there is a shortage of funds.

5 Shortage of projects

We now turn to the case where there is a shortage of good lending opportunities for banks relative to the funds the banking system has available to lend ($N > M$). In this case, banks will have to set contract terms competitively in order to attract borrowers, who will generally be able to appropriate most, if not all, of the surplus associated with their projects.

The levels of capital and loan rates that maximize borrower surplus solve the following problem:

$$\max_{k,r_L} BS = q\left(R - r_L\right) \tag{5}$$

subject to

$$
\begin{aligned}
q &= \min\left\{\frac{r_L-(1-k)r_D}{2c}, 1\right\}; \\
\Pi &= q(r_L-(1-k)r_D) - kr_E - cq^2 \geq 0; \\
0 &\leq k \leq 1; \\
1 &\leq r_L \leq R.
\end{aligned}
$$

As before, Π represents banks' expected profits, q is the monitoring effort that each bank chooses as a function of r_L and k, and BS represents borrower surplus. Note that, in contrast to the previous section, we now impose a participation constraint for banks, in that they must earn non-negative profits, and a constraint that the loan rate not be higher than the maximum return from the project. We will assume throughout that there is enough surplus generated from lending that the borrowers' participation constraint is always satisfied when borrower surplus is being maximized.

We can now state the following result, which focuses on the case of an interior solution for bank monitoring. The more general case is relegated to the appendix.

Proposition 4 *Assume that $R < 4c$. When there is a shortage of projects, borrower surplus is maximized by setting a loan rate of $r_L = \frac{R+(1-k^{BS})r_D}{2}$ and having banks hold capital equal to $k^{BS} = \min\left\{\frac{8cr_E - Rr_D + r_D^2 - 4\sqrt{r_E c\left(4cr_E - Rr_D + r_D^2\right)}}{r_D^2}, 1\right\}$, which is less than 1 for $r_E > \frac{R^2}{16c}$ and equal to 1 otherwise. Banks exert monitoring effort $q = \frac{R-(1-k^{BS})r_D}{4c} < 1$; and earn zero expected profits for $r_E > \frac{R^2}{16c}$ and positive expected profits otherwise.*

Proof: See the appendix, which contains a full characterization of the equilibrium. $\square$

The results in Proposition 4 highlight the incentive mechanisms for bank monitoring provided by a competitive credit market. As already mentioned, there are two ways of providing banks with incentives to monitor: by requiring that they hold a minimum amount of capital and by setting the loan rate so as to compensate them for their monitoring when the project is successful and the loan is repaid. These two instruments differ in terms of their costs and effects on borrower surplus and bank profits. Borrowers prefer that banks hold large amounts of capital so as to commit to exert a high level of monitoring, since borrowers' returns increase with q and they do not fully internalize the costs of capital and of monitoring. By contrast, since capital is a costly input (i.e., $r_E \geq r_D$), banks would prefer to minimize its use and rather receive incentives through a higher loan rate r_L. However, while increasing r_L is good for incentive purposes, its direct effect is to reduce the surplus to the borrowers. Given that borrower surplus is maximized, the equilibrium in the case of a shortage of projects involves the maximum level of capital consistent with banks' participation constraint and a level of loan rates up to the point where the positive incentive effect of a higher loan rate on bank monitoring is dominated by the negative direct effect on borrower surplus, $R - r_L$. In this sense, market discipline can be imposed from the asset side as both the loan rate and banks' capital holdings are used to provide banks with monitoring incentives.[6]

The exact amounts of monitoring and capital in equilibrium depend on the return of investment projects R, the cost of capital r_E, and the cost of monitoring c. When monitoring is costly ($c > \frac{R}{4}$) but capital is not too expensive ($r_E < \frac{R^2}{16c}$), banks raise the highest level of capital, but do not monitor fully since the cost of doing so would be too high. If capital is relatively costly ($r_E > \frac{R^2}{16c}$), however, market incentives lead banks to choose a lower level of capital ($k^{BS} < 1$), less monitoring ($q < 1$), or both. The participation constraint of banks prevents them from raising the highest level of capital in this case, thus leading to a lower level of monitoring.

In the appendix, we also present the case where projects are highly profitable or, equivalently, monitoring is cheap ($c \leq \frac{R}{4}$), and show that, when capital is not too costly ($r_E < c$), banks raise the highest level of capital, $k^{BS} = 1$, and exert the maximum effort, $q = 1$.

[6] A related issue is studied in Chemmanur and Fulghieri (1994), who analyze how banks can develop a reputation for committing to devote resources to evaluating firms in financial distress and thus make the correct renegotiation versus liquidation decisions. Borrowers who anticipate running into difficulties may therefore prefer to borrow from banks with a reputation for flexibility in dealing with firms in financial distress. Reputation thus serves as a commitment device for banks similarly to capital in our model.

Borrowers want banks to monitor fully as projects are very profitable, and can induce banks to do so by raising a large amount of capital, as long as this is not too costly and banks' profits are positive. When capital is costly, however, banks will again choose a lower level of capital and/or less monitoring.

Interestingly, the results in Proposition 4 suggest that the loan rate r_L plays the dual role of allocating the surplus and determining the incentives of banks to monitor. Borrowers are willing to give up some of the return on the loans to the banks as long as they benefit from increased monitoring. They accomplish this by allowing the rate on the loan to reflect the return of the project, and to be increasing in such return as long as there are incentive effects from doing so (i.e., $\frac{\partial r_L}{\partial R} > 0$ as long as $q < 1$). Thus, the loan rate need not be set only to compensate banks for the credit risk associated with granting the loan, but also to induce them to exert effort in monitoring the projects and thus improve the expected returns of the loans. Furthermore, since capital and loan rates are alternative instruments for providing banks with an incentive to monitor and thus provide market-based discipline for the banks, we note that in equilibrium r_L is negatively correlated with banks' capital holdings k. This implies that these are substitute instruments from the point of view of borrowers, who only trade off their relative costs from the perspective of reducing borrower surplus. This result finds support in the findings in Hubbard et al. (2002) and Kim et al. (2005) of higher interest rates on loans from less-capitalized banks.

Following the same structure as before, we now turn to analyze the optimal choice of capital from a social welfare perspective when there is a shortage of projects, and rates are set as part of a market solution to maximize the return to borrowers. Formally, a regulator solves the following problem:

$$\begin{aligned} \max_k SW &= \Pi + BS - (1-q)(1-k)r_D \\ &= qR - (1-k)r_D - kr_E - cq^2 \end{aligned} \tag{6}$$

subject to

$$
\begin{aligned}
q &= \min\left\{\frac{r_L-(1-k)r_D}{2c},1\right\}; \\
r_L &= \arg\max_r BS = q(R-r); \\
\Pi &= q(r_L-(1-k)r_D)-kr_E-cq^2 \geq 0; \\
0 &\leq k \leq 1.
\end{aligned}
$$

The constraints have the usual meaning; and again we focus here on the case of an interior solution for the monitoring effort, and leave the description of the other cases, which are qualitatively similar, to the appendix.

Proposition 5 *Assume that* $R < 2c\frac{2r_E-r_D}{r_D}$. *When there is a shortage of projects, capital regulation that maximizes social welfare requires banks to hold capital equal to* $k^{reg} = \min\left\{\frac{Rr_D+r_D^2-8c(r_E-r_D)}{r_D^2}, k^{BS}\right\}$, *which is less than 1 for* $r_E > r_D\frac{(R+8c)}{8c}$ *and equal to 1 otherwise. Banks exert monitoring effort* $q = \frac{R-(1-k^{reg})r_D}{4c} < 1$; *and earn zero expected profits for* $r_E > r_D\frac{(R+8c)}{8c}$ *and positive expected profits otherwise.*

Proof: See the appendix, which contains a full characterization of the equilibrium. □

While the interest rate on the loan is determined in a competitive market setting and is not subject to regulatory intervention, a regulator may want to impose a capital requirement for banks in order to ensure they have sufficient incentives to monitor and increase social welfare. In contrast to Proposition 2, the regulator now requires that banks hold an amount of capital greater than in the case where there is a shortage of funds. The reason is that the market sets a lower loan rate when borrowers obtain the surplus than when banks obtain it and, therefore, the regulator has to use more capital to provide banks with incentives to monitor. Optimal regulation, however, does not necessarily call for having entirely equity financed banks, but rather allows for a mix between capital and deposit-based financing. This will generally be true when the cost of capital is high relative to the cost of deposits or when the aggregate return from encouraging greater monitoring is relatively low.

We now turn to one of the main results in the paper, which is whether a pure market-based system is likely to provide sufficient incentives for bank discipline and monitoring, and whether capital regulation can be an effective tool for providing such incentives. For that, we have the following:

Proposition 6 *Define $\rho_E = \frac{r_E}{r_D}$ as the cost of capital relative to deposits. When there is a shortage of projects, for all R, r_E, and c there exists a value $\widetilde{\rho}_E(R, r_E, c) > 0$ such that $k^{reg} < k^{BS}$ for $\rho_E > \widetilde{\rho}_E$, and $k^{reg} = k^{BS}$ for $\rho_E \leq \widetilde{\rho}_E$.*

Proof: See the appendix. □

While the exact expressions for $\widetilde{\rho}_E$ are provided in the proof, the interpretation of this result can be stated quite generally for all parameter values as follows. When capital is significantly more expensive than deposits (i.e., when ρ_E is large), it is socially optimal to economize on capital and instead rely more heavily on deposits for financing the bank. Since the regulator ignores distributional issues between borrowers and banks, this solution is more efficient from a welfare perspective than requiring that banks hold large amounts of capital in order to improve monitoring. The market solution, by contrast, maximizes borrower surplus and does not fully internalize the cost of raising capital. Thus, when raising capital is expensive relative to raising deposits, the market solution is inefficient from a welfare perspective as it requires banks to keep an excessive level of capital.

At the other extreme, when bank capital is not significantly more costly than deposits, it is socially optimal to use relatively more capital to improve monitoring incentives. However, given that the market solution is already requiring banks to hold the highest level of capital consistent with their participation constraint, the regulator cannot improve on the market equilibrium and will require the same amount of capital as the market. In this sense the market equilibrium is constrained efficient.

6 Extensions

In this section we look at a few important extensions. First, we consider the case where there is no deposit insurance, so that banks must internalize the cost imposed on depositors of their inability to repay deposits when their projects fail. Second, we analyze the case where banks can also engage in a classic asset substitution problem by choosing a project with a lower probability of success but with a higher payoff in case of success. Finally, we study the case where banks have a franchise value from continuing to operate, which introduces some simple dynamic considerations.

6.1 The case without deposit insurance

Up to now we have considered only the case where deposits are fully insured, so that the interest rate paid on deposits is determined entirely by depositors' opportunity cost, given by r_D. In this section we analyze the case where deposits are not insured, so that the promised repayment must compensate depositors for the risk they face when placing their money in banks that may not repay. This introduces a liability-side disciplining force on bank behavior since banks have to bear the cost of their risk-taking through a higher promised deposit rate.

We modify the timing of the model slightly. First, banks choose how much to raise in deposits, $1-k$, and capital, k; and the promised repayment on deposits (i.e., the deposit rate) c_D is set. Second, the loan rate r_L is determined. Third, borrowers choose the loan that is most attractive to them. Fourth, banks choose their monitoring effort q. Note that the only change is the introduction of the setting of the deposit rate c_D in stage 1. Since deposits are uninsured, the expected value of their promised payment c_D must be equal to depositors' opportunity cost r_D. Given the level of capital k, depositors conjecture a level of monitoring for the bank, q^c, and set the deposit rate to meet their reservation return, which is given by r_D. This implies that $q^c c_D = r_D$, or that $c_D = \frac{r_D}{q^c}$.

We now solve the model by backward induction. For a given c_D, banks choose monitoring to maximize their expected profits given by

$$\max_{q} \ \Pi = q(r_L - (1-k)c_D) - kr_E - cq^2. \tag{7}$$

For an interior solution, this problem yields $q^* = \frac{r_L-(1-k)c_D}{2c}$. In equilibrium, depositors' conjecture about monitoring must be correct, so that $q^c = q^*$. We can therefore substitute $c_D = \frac{r_D}{q^*}$ into the solution above for q and solve for the equilibrium value of monitoring. There are two solutions, $q_1 = \frac{1}{4c}\left(r_L + \sqrt{r_L^2 - 8cr_D\,(1-k)}\right)$ and $q_2 = \frac{1}{4c}\left(r_L - \sqrt{r_L^2 - 8cr_D\,(1-k)}\right)$, with $q_1 > q_2$. However, it can be shown that both banks and borrowers are better off with the higher level of monitoring. To see this, note that, in equilibrium, bank profits are given by

$$\Pi(q) = q(r_L - (1-k)\frac{r_D}{q}) - kr_E - cq^2 = qr_L - (1-k)r_D - kr_E - cq^2, \tag{8}$$

which is strictly increasing in q for $q \leq \frac{r_L}{2c}$. Since $q_2 < q_1 < \frac{r_L}{2c}$, banks prefer the equilibrium with the higher level of monitoring. The equilibrium return for firms is either equal to r_B when borrowers compete for funds or it is just $BS(q) = q(R - r_L)$ when banks compete for borrowers. In the former case, firms are indifferent to the choice of q, whereas in the latter case, substituting for the equilibrium interest rate $r_L = \frac{R+(1-k)c_D}{2}$, we have

$$BS(q) = q\left(R - \frac{R + (1-k)\frac{r_D}{q}}{2}\right) = \frac{1}{2}\left(qR - (1-k)r_D\right), \tag{9}$$

which again is strictly increasing in q. Since depositors are indifferent between the two levels of monitoring, the higher level of monitoring, q_1, yields a Pareto-superior equilibrium. We focus on this equilibrium in what follows.

Having solved the last stage, we can then turn to the determination of the loan rate and capital holding along the lines of the previous sections. The rate on the loan, r_L, is given either by the maximum rate that is consistent with borrowers' participation constraints when there is a shortage of funds, or by the rate that maximizes the return to borrowers,

$\frac{R+(1-k)c_D}{2}$, when there is a shortage of projects. Solving the first stage, where either banks or the regulator choose the level of capital, we have the following result for the case where there is a shortage of funds.

Proposition 7 *When there is a shortage of funds and no deposit insurance, banks hold a positive amount of capital for r_D sufficiently large.*

Proof: See the appendix. □

The intuition for this result is as follows. When the deposit rate is constant, banks have no incentive to hold any capital since capital is a costly form of financing. In the absence of deposit insurance, however, capital signals a commitment to monitor on the part of the bank. Depositors recognize this greater incentive to monitor by banks and reduce the interest payment they demand on their deposits. Thus, in contrast to Proposition 1, banks may now have an incentive to hold capital as a way of reducing their cost of funding, and this incentive is greatest when the cost of deposits is sufficiently high. Also, since borrowers compete away their surplus, banks wind up internalizing the full value of their monitoring effort, and the market problem becomes equivalent to the regulator's maximization problem. There is thus no additional role for regulation in the case of a shortage of funds when deposits are not insured as the market is constrained efficient.

We now turn to the case where there is a shortage of projects. We have the following:

Proposition 8 *Define $\rho_E = \frac{r_E}{r_D}$ as the cost of capital relative to deposits. When there is a shortage of projects and no deposit insurance, there exists a value $\widehat{\rho}_E(R, r_E, c) > 0$ such that $k^{reg} < k^{BS}$ for $\rho_E > \widehat{\rho}_E$ and $k^{reg} = k^{BS}$ otherwise.*

Proof: See the appendix. □

The proposition establishes that one of our main results, that market competition induces banks to keep high levels of capital, continues to hold even for the case where deposits are not insured. As before, the market is inefficient from a social welfare perspective when the cost of capital is high relative to the cost of deposits, and it is constrained efficient otherwise. The intuition is similar to that in the previous section, in that the market solution does not fully internalize all the costs and benefits associated with holding capital while social welfare maximization abstracts from distributional issues. More specifically, when there is a shortage of projects, borrowers try to extract all the surplus from banks by requiring them to hold high levels of capital so as to improve their monitoring incentives. However, when capital is costly relative to deposits, from a social welfare perspective requiring that banks hold large amounts of capital implies a significant reduction of bank profits which may more than offset any gains to borrowers from increased monitoring. Because the social welfare maximization ignores distributional issues while the market solution aims at maximizing borrower surplus, the market solution may end up requiring that banks hold inefficiently high levels of capital. Differently, when capital is not so costly relative to deposits, it is socially optimal to use more capital and improve monitoring incentives. Given the market equilibrium already requires banks to keep the highest level of capital consistent with their participation constraint, a welfare maximizing regulator cannot require banks to hold even higher levels of capital without violating their participation constraint and cannot thus improve on the market equilibrium. The market is constrained efficient.

6.2 Relationship and transactional lending

In the analysis above, we have assumed throughout that banks can finance only projects that benefit from monitoring. In that context, we have shown that capital plays a role as a commitment device for banks to monitor and thus attract borrowers. We now modify this basic framework slightly and, similarly to Boot and Thakor (2000), we consider the case where banks can choose between investing in a project much as before, and an alternative project with a fixed success probability p_T of returning a payoff R_T. We will refer to the first kind of loan as a "relationship" loan since it benefits from the interaction with the bank, and the latter project as a "transactional" loan (or project). The crucial difference is that bank monitoring affects only the success probability of the relationship loan, given as before by q. As a consequence, the bank's capital holdings will now affect the relative attractiveness of the two projects and will play the additional role of affecting the distribution of bank funds across projects.

Assume that $p_T < q(0)$, $R_T > R$, and $p_T R_T < q(0)R$, where $q(k)$ is the level of monitoring for a relationship loan when the bank has capital k. The transactional project has a lower probability of success than a relationship loan even with no capital ($k = 0$), a higher payoff in case of success, but a lower expected payoff. For a given level of capital k and loan rate r_L, the expected profit for the bank is

$$\Pi_R = q(r_L - (1-k)r_D) - kr_E - cq^2,$$

when it invests in a relationship loan, and

$$\Pi_T = p_T(r_L - (1-k)r_D) - kr_E,$$

when it invests in a transactional loan. The bank's choice crucially depends on the level of capital k it holds and on the return r_L it obtains when the project is successful. We notice immediately that $\frac{\partial \Pi_T}{\partial k} = p_T r_D - r_E < 0$, so that capital decreases the attractiveness of the transactional loan and the bank would not want to hold any capital when investing in this project.

To analyze the bank's choice in more detail, assume for the moment that both types of loans yield the same promised repayment r_L and recall that maximizing the bank's expected profit from a relationship loan with respect to the level of monitoring effort gives $q^* = \min\left\{\frac{r_L-(1-k)r_D}{2c}, 1\right\}$. Then, we can rewrite the bank's expected profits in equilibrium as

$$\Pi_R = c(q^*)^2 - kr_E,$$

$$\Pi_T = 2cq^* p_T - kr_E,$$

with the relationship loan and the transactional loan, respectively. Comparing now the two expressions, relationship lending will be preferred if and only if

$$\Pi_R > \Pi_T \Leftrightarrow cq^* \left(q^* - 2p_T\right) > 0.$$

For low enough values of p_T, this condition will be satisfied if either k or r_L is large enough, or some combination of both. Putting it differently, a sufficiently high regulatory capital requirement increases the likelihood that the bank will choose the relationship (i.e., monitored) loan. Note as well that, since q is increasing in r_L, relationship lending is more likely to be optimal the higher is the interest rate on the loan.

The analysis so far assumes that there is a fixed sharing rule described by the loan rate r_L, which is independent of the type of project chosen. Suppose now instead that banks receive different returns when investing in the two projects and the returns are determined from the competition in the credit market, as in our basic model. Then the distribution of funds across projects will depend on the allocation of surplus in the economy. Consider first the case where there is a shortage of funds so that banks can extract all the surplus and have expected profits equal to

$$\Pi_R = q(R - (1-k)r_D) - kr_E - cq^2,$$

$$\Pi_T = p_T(R_T - (1-k)r_D) - kr_E,$$

from the relationship and the transactional loans, respectively. Since $R_T > R$, it is more likely that $\Pi_R > \Pi_T$ the greater is R_T and r_D, and the smaller is k. As in our basic model, there may be scope for regulation to solve the distortion introduced by deposit insurance and increase the likelihood that the bank invests in the relationship loan. Given $R_T > R$, the minimum capital requirement such that $\Pi_R > \Pi_T$ will have to be higher than in the case where both projects return r_L to the bank.

The case where there is a shortage of relationship projects also generates similar implications. Assume that banks obtain a fixed interest rate of r_T on the transactional loan, but that the rate r_R on the relationship loan is set in the market, as in our basic model. To induce banks to invest in the relationship loans, it is now necessary that banks earn on the relationship loan at least as much as they could earn on the transactional loan, which is equal to $\Pi_T = p_T(r_T - (1-k)r_D) - kr_E$. Define $\underline{\pi} = p_T(r_T - (1-k)r_D) - kr_E$ as the bank's reservation profit. We can then solve the market equilibrium and notice that the solution in the market for relationship loans must now solve the same problem as in Section 5, but with the additional constraint that $\Pi_R \geq \underline{\pi}$. Again, it must be that an increase in the bank's capital holdings increases the bank's revenue qr_L relative to that for a transactional loan, $p_T r_T$. While in the end the bank is indifferent between the two kinds of loans (because borrowers are able to capture any additional surplus), an increase in the required capital raises the relative attractiveness of a relationship loan and increases the surplus generated from lending.

To sum up, in all cases considered, capital regulation increases the attractiveness of relationship lending relative to transactional lending. This would be particularly true if higher capital requirements applied to riskier types of loans. The intuition is that whereas capital increases the expected return of a relationship loan through its effect on bank monitoring incentives, it represents only a pure cost in the case the bank invests in a transactional loan.

6.3 Bank franchise value

Recent discussion on bank behavior has focused on the role of franchise value as a possible way to reduce risk-taking (see, e.g., Keeley, 1990). To analyze the role of bank franchise value in our framework, suppose that, as in the previous section, there are two kinds of projects in which the bank can invest: a "transactional" project, and a "relationship" loan that benefits from bank monitoring. The bank has a franchise value associated with remaining in business, which we denote by FV. This value is the same independently of which project is chosen in the current period since the bank faces the same problem in following periods and will choose optimally in each period.

For a given level of capital k and loan rate r_L, the bank's expected long term values from making the relationship and the transaction loan are given, respectively, by

$$V_R = q(r_L - (1-k)r_D) - kr_E - cq^2 + qFV,$$

$$V_T = p_T(r_L - (1-k)r_D) - kr_E + p_T FV.$$

The bank's return from the relationship loan is maximized by choosing the level of monitoring $q^* = \min\left\{\frac{r_L - (1-k)r_D + FV}{2c}, 1\right\}$. We can now write the bank's equilibrium value when it makes the relationship loan as

$$V_R = c\left(q^*\right)^2 - kr_E.$$

Comparing the two expressions, and assuming that both types of loans have the same promised repayment r_L, relationship lending will be preferred if and only if

$$V_R > V_T \Leftrightarrow cq^*\left(q^* - 2p_T\right) > 0,$$

which is the same condition as in the previous section. The only difference is that once one accounts for the franchise value FV, we have that q^* is additionally increasing in FV. Franchise value acts therefore as an additional instrument providing a commitment to monitor, and pushes the bank toward relationship lending. The intuition is simply that a greater franchise value means that the bank has a larger incentive to remain viable and in business, which leads it to dedicate more resources to monitor its borrowers so as to increase the probability of success of its projects. As a consequence, there is ceteris paribus a lower need for capital regulation relative to the static case where banks do not enjoy any franchise value from remaining in business.

7 Concluding remarks

A standard view of capital regulation is that it offsets the risk-taking incentives provided by deposit insurance. A common approach in the study of bank regulation has been to assume that any capital requirements will be binding, since equity capital is generally believed to be more costly than other forms of finance. However, in many cases banks hold large levels of capital and regulatory requirements appear not to be binding. Moreover, banks' capital holdings seem to have varied substantially over time also independently of regulatory changes. In this paper we have developed an alternative view of capital that is consistent with the observation that banks may hold high levels of capital even above the levels required by regulation.

An issue that we have not explored is the possible negative effect of raising capital, which may arise for example when there is an agency problem between managers and owners of the bank. For instance, Besanko and Kanatas (1996) show that, under some circumstances, raising equity dilutes current owners' and current managers' stakes, reducing their incentives to curb risk-taking. As a result, an increase in equity resulting from a stock issue may actually lead to increased risk-taking. While we abstract from such considerations, the analysis of other effects associated with stock issues constitutes an interesting avenue for further research.

In our model we assume that all banks are the same and operate in perfectly competitive markets. Differently, Boot and Marinč (2006) consider heterogeneous banks with a fixed cost of monitoring operating in markets with different degrees of competition. Incorporating these elements into our framework is another interesting topic for future research.

A Proofs

Proof of Proposition 1: Assume that each bank chooses the level of monitoring q simultaneously with k and r_L. The solution to this problem is the same as that for the sequential problem discussed in the text, since it is a single agent maximization problem.

Banks set q, k and r_L so as to maximize their expected profits. Thus, the profit-maximizing contract, net of the opportunity cost associated with bank capital, solves the following problem:

$$\max_{q,r_L,k} \Pi = q(r_L - (1-k)r_D) - kr_E - cq^2 \tag{10}$$

subject to

$$\begin{aligned} BS &= q\left(R - r_L\right) \geq r_B; \\ 0 &\leq k \leq 1; \\ 0 &\leq q \leq 1. \end{aligned}$$

Ignoring for now the second and third constraints, we explicitly incorporate the first constraint, assuming that it is satisfied with equality. The Lagrangean for this problem can be written as

$$\max_{q,r_L,k} \mathcal{L} = q(r_L - (1-k)r_D) - kr_E - cq^2 + \lambda\left(q\left(R - r_L\right) - r_B\right). \tag{11}$$

The first order conditions are:

$$\begin{aligned} &\tfrac{\partial \mathcal{L}}{\partial q} = r_L - (1-k)r_D - 2cq + \lambda\left(R - r_L\right) = 0; \\ &\tfrac{\partial \mathcal{L}}{\partial r_L} = q - \lambda q = q\left(1 - \lambda\right) = 0; \\ &\tfrac{\partial \mathcal{L}}{\partial k} = qr_D - r_E = 0; \\ &\tfrac{\partial \mathcal{L}}{\partial \lambda} = q\left(R - r_L\right) - r_B = 0. \end{aligned}$$

Since it must be that $0 \leq q \leq 1$, and $r_D \leq r_E$, from the third expression we see that $k = 0$ is optimal. We can also use the last expression to solve for r_L as $r_L = R - \frac{r_B}{q}$. From the second expression we derive that $\lambda = 1$. Therefore, we are left with just one condition with one unknown, which is the first expression:

$$r_L - (1-k)r_D - 2cq + (R - r_L) = 0.$$

Rearranging,

$$R - (1-k)r_D - 2cq = 0.$$

Solving now for q, we obtain

$$q = \frac{R - (1-k)r_D}{2c} = \frac{R - r_D}{2c},$$

for $k = 0$, as in the proposition.

Note that, if this value of q is less than 1, the upper bound on bank monitoring, $q \leq 1$, will be satisfied. Suppose instead that $\frac{R-r_D}{2c} > 1$. Then we hit the boundary and q must be equal to 1, but the solution is otherwise exactly the same. Finally, note that since $R > r_D$, $\frac{R-r_D}{2c} > 0$, so that the lower bound on bank monitoring is always satisfied: $q > 0$.

To check that the BS constraint must always be binding, assume to the contrary that it is not, so that $BS = q(R - r_L) > r_B$ in equilibrium. Since this implies that $r_L < R$, the bank can fix q and raise r_L a slight amount such that the constraint is still satisfied. However, such a higher r_L yields strictly higher expected profits for the bank, contradicting the assumption that BS is slack in equilibrium. $\square$

Proof of Proposition 2: Substituting $r_L = R - \frac{r_B}{q}$ and $k = 0$ in the expression for q gives

$$q = \min\left\{\frac{R - r_D}{2c}, 1\right\}.$$

Thus, $q = 1$ if $R - r_D \geq 2c$, and $q < 1$ if $R - r_D < 2c$.

Substituting $r_L = R - \frac{r_B}{q}$ and keeping $k > 0$, social welfare becomes

$$SW = \frac{(R-(1-k)r_D)^2}{4c} - kr_E - [1 - \frac{(R-(1-k)r_D)}{2c}](1-k)r_D.$$

Differentiating SW with respect to k, we have

$$\begin{aligned} \frac{dSW}{dk} &= \frac{(R-(1-k)r_D)r_D}{2c} - r_E - [-\frac{(1-k)r_D^2}{2c} - r_D + \frac{(R-(1-k)r_D)r_D}{2c}] = 0 \\ &= \frac{(1-k)r_D^2}{2c} + r_D - r_E = 0. \end{aligned}$$

Calculating this expression at the two extreme levels of capital gives

$$\left.\frac{dSW}{dk}\right|_{k=1} = r_D - r_E \leq 0,$$

and

$$\left.\frac{dSW}{dk}\right|_{k=0} = \frac{r_D^2}{2c} + r_D - r_E \gtreqless 0,$$

implying that the welfare-maximizing level of capital is $k^{reg} \in (0,1)$ if $r_D > \sqrt{c(c+2r_E)} - c$, and is given by

$$k^{reg} = 1 - \frac{2c}{r_D^2}(r_E - r_D) < 1,$$

thus establishing the proposition. □

Proposition 4B *When there is an excess supply of funds, maximizing borrower surplus yields the following equilibrium:*

1) For $R \geq 4c$, monitoring is $q = 1$. The loan rate is $r_L = (1-k^{BS})r_D + 2c$, and banks are required to hold capital equal to $k^{BS} = \min\left\{\frac{c}{r_E}, 1\right\}$. For $k^{BS} = 1$ (i.e., if $r_E < c$), banks earn profits $\Pi = c - r_E > 0$, otherwise $\Pi = 0$.

2) For $R < 4c$, monitoring is $q = \frac{R-(1-k^{BS})r_D}{4c} < 1$. The loan rate is $r_L = \frac{R+(1-k^{BS})r_D}{2}$, and banks hold capital equal to $k^{BS} = \min\left\{\frac{8cr_E - Rr_D + r_D^2 - 4\sqrt{r_E c\left(4cr_E - Rr_D + r_D^2\right)}}{r_D^2}, 1\right\}$, which is less than 1 for $r_E > \frac{R^2}{16c}$ and equal to one otherwise. For $k^{BS} = 1$, $\Pi = \frac{R^2}{16c} - r_E > 0$, and

$\Pi = 0$ *for* $k^{BS} < 1$.

Proof: Start by noting that, since $q = \min\left\{\frac{r_L-(1-k)r_D}{2c}, 1\right\}$, if $r_L < (1-k)r_D + 2c$ then $q = \frac{r_L-(1-k)r_D}{2c} < 1$. Since $BS = q(R - r_L)$, we have that $\frac{\partial BS}{\partial k} = \frac{\partial q}{\partial k}(R - r_L) = \frac{r_D}{2c}(R - r_L) > 0$ for $q < 1$. Therefore, more capital increases borrower surplus.

We proceed in two stages. We start by maximizing BS with respect to the loan rate, r_L, for a fixed k, which yields

$$\frac{\partial BS}{\partial r_L} = \frac{\partial q}{\partial r_L}(R - r_L) - q = \frac{R - 2r_L + (1-k)r_D}{2c} = 0.$$

Solving the FOC yields $r_L = \frac{R+(1-k)r_D}{2}$.

We can now maximize BS with respect to the choice of capital, k. However, we know from above that the combination of $r_L = \frac{R+(1-k)r_D}{2}$ and the highest possible k will be optimal for borrowers. We therefore introduce the participation constraint for the bank, that $\Pi = q(r_L - (1-k)r_D) - kr_E - cq^2 \geq 0$. Substituting for $q = \frac{r_L-(1-k)r_D}{2c}$ as well as for r_L, we obtain

$$\Pi = \frac{(R - (1-k)r_D)^2}{16c} - kr_E \geq 0, \quad k \leq 1. \tag{12}$$

We can solve this for the value of k that satisfies the constraint with equality ($\Pi = 0$). Since Π is strictly convex in k, $0 \leq k \leq 1$, and borrower surplus is increasing in k, the relevant solution must be either the smaller root or a corner solution at $k = 1$. The solution is then

$$k^{BS} = \min\left\{\frac{8cr_E - Rr_D + r_D^2 - 4\sqrt{r_E c\left(4cr_E - Rr_D + r_D^2\right)}}{r_D^2}, 1\right\}.$$

Note that if $k^{BS} = 1$, then $r_L = \frac{R}{2}$. Substituting $k^{BS} = 1$ into (12), we obtain $\Pi = \frac{R^2}{16c} - r_E \geq 0$, which is positive only for $r_E < \frac{R^2}{16c}$. It follows that for $r_E > \frac{R^2}{16c}$, it must be that $k^{BS} < 1$ and $\Pi = 0$.

We now check when in fact $q < 1$. From the definition of the optimal level of monitoring $q = \min\left\{\frac{r_L-(1-k)r_D}{2c}, 1\right\}$, we see that, for $r_L \geq (1-k)r_D + 2c$, $q = 1$. Substituting in the optimal value for r_L gives the following condition:

$$\frac{R + (1-k)r_D}{2} \geq (1-k)r_D + 2c.$$

The right hand side is maximized at $k = 0$. Thus, a sufficient condition for $q = 1$ is that $R - r_D - 4c \geq 0$. In this case, there is no benefit in terms of greater monitoring to having a higher interest rate on the loan, and so borrowers should just require the lowest possible interest rate consistent with $q = 1$, which is satisfied by $r_L = (1-k)r_D + 2c$. If we again substitute this value of r_L into the expression for bank profits we obtain

$$\Pi = \left(r_L - (1-k^{BS})r_D\right) - k^{BS}r_E - c = c - k^{BS}r_E,$$

which, after setting equal to zero, yields $k^{BS} = \frac{c}{r_E}$ as long as $r_E > c$. In this case, we have $r_L = (1 - \frac{c}{r_E})r_D + 2c = (\frac{r_E - c}{r_E})r_D + 2c$.

Otherwise, for $r_E < c$, $k^{BS} = 1$, which implies that $r_L = 2c$. Moreover, substituting this value of r_L into $q = \min\left\{\frac{r_L-(1-k^{BS})r_D}{2c}, 1\right\}$ and observing that $k^{BS} = 1$, we obtain that $\Pi > 0$ and $q = \min\left\{\frac{R}{4c}, 1\right\} = 1$ for $R \geq 4c$, and is less than 1 otherwise. All together, this implies that $q \geq 1$ for $R \geq 4c$, and $q < 1$ for $R < 4c$. $\square$

Proposition 5B *When there is an excess supply of funds, capital regulation that maximizes social welfare requires:*

1) For $R > 2c\frac{2r_E - r_D}{r_D}$, monitoring is $q = \min\left\{\frac{R}{4c}, 1\right\}$, and capital equals $k^{reg} = \min\left\{\frac{4c+r_D-R}{r_D}, k^{BS}\right\}$, which is less than 1 for $R > 4c$ and equal to 1 otherwise.

2) For $R < 2c\frac{2r_E - r_D}{r_D}$, monitoring is $q = \frac{R-(1-k^{reg})r_D}{4c} < 1$ and capital equals $k^{reg} = \min\left\{\frac{Rr_D + r_D^2 - 8c(r_E - r_D)}{r_D^2}, k^{BS}\right\}$, which is less than 1 for $r_E > r_D\frac{(R+8c)}{8c}$ and equal to 1 otherwise.

Proof: Start by maximizing social welfare with respect to k, assuming that the loan rate is set to maximize BS, i.e., that $r_L = \frac{R+(1-k)r_D}{2}$. Social welfare is given by

$$\max_k SW = \Pi + BS - (1-q)(1-k)r_D = qR - (1-k)r_D - kr_E - cq^2.$$

Ignoring for now the banks' participation constraint, we can now take the first order condition to get

$$\frac{\partial SW}{\partial k} = \frac{\partial q}{\partial k}\,(R - 2cq) - r_E + r_D.$$

We know that, for $q < 1$, the optimal level of monitoring is $q = \frac{r_L-(1-k)r_D}{2c}$. Substituting in the value of r_L above we get $q = \frac{R-(1-k)r_D}{4c}$. We therefore have that

$$\frac{\partial SW}{\partial k} = \frac{r_D}{4c}\left(\frac{R+(1-k)r_D}{2}\right) + r_D - r_E = 0.$$

The solution we obtain is

$$k^{reg} = \min\left\{\frac{Rr_D + r_D^2 - 8c\,(r_E - r_D)}{r_D^2}, 1\right\}.$$

Assuming that $k^{reg} \le k^{BS}$, from this expression we obtain that $k^{reg} < 1$ for $c > \frac{Rr_D}{8(r_E-r_D)} \Leftrightarrow r_E > r_D\frac{(R+8c)}{8c}$. Otherwise, for $r_E < r_D\frac{(R+8c)}{8c}$, we have that $k^{reg} = 1$. If, however, $k^{reg} > k^{BS}$, then bank profits would be negative if they were required to hold capital equal to k^{reg}. To see why, note that given the equilibrium value of $r_L = \frac{R+(1-k)r_D}{2}$, k^{BS} is obtained directly from the banks' participation constraint, $\Pi \ge 0$. Any higher level of capital, along with the lower loan interest rate it implies, would yield negative profits for the banks. In this case, the solution is just $k^{reg} = k^{BS}$.

The previous solution assumed that $q < 1$. To get the bounds on when $q = 1$, substitute the solution for k^{reg}, assuming $k^{reg} < 1$, into

$$q = \frac{R - (1-k^{reg})r_D}{4c} = \frac{Rr_D - 4c\,(r_E - r_D)}{2cr_D}.$$

From here, we see that for $c > \frac{Rr_D}{4r_E - 2r_D} \Leftrightarrow R < 2c\frac{2r_E - r_D}{r_D}$, $q < 1$. Otherwise, for $R > 2c\frac{2r_E - r_D}{r_D}$, $q = 1$ and k should be set such that $q(k) = 1 \Leftrightarrow k^{reg} = \frac{4c + r_D - R}{r_D}$, again assuming that $k^{reg} \leq k^{BS}$. Note, however, that for $R < 4c$ this solution would imply that $k^{reg} > 1$, which is not feasible. Therefore, for $R < 4c$, we obtain that $k^{reg} = 1$, which implies that $q = \frac{R}{4c} < 1$. For $k^{reg} > k^{BS}$, an argument similar to the above establishes that the banks' participation constraint must bind, implying that the solution must be $k^{reg} = k^{BS}$.

One final point that needs to be verified is that, for $R < 2c\frac{2r_E - r_D}{r_D}$, then $q = \frac{R - (1-k)r_D}{4c} < 1$, but that for $r_E < r_D\frac{(R+8c)}{8c}$ or, equivalently, $R > 8c\frac{(r_E - r_D)}{r_D}$, we have that $k^{reg} = 1$, which would imply that $q = \frac{R}{4c}$. Note, however, that for both of these conditions to be true at the same time requires that $8c\frac{(r_E - r_D)}{r_D} < 2c\frac{2r_E - r_D}{r_D}$. This will be satisfied if and only if $4\left(r_E - r_D\right) < 2r_E - r_D \Leftrightarrow r_E < \frac{3}{2}r_D$. We can now use this in the necessary condition for $q < 1$, which is $R < 2c\frac{2r_E - r_D}{r_D}$. Given the restriction on r_E and r_D, the right hand side must be less than $2c\frac{2\left(\frac{3}{2}r_D\right) - r_D}{r_D} = 4c$. Therefore, the joint assumption that $R < 2c\frac{2r_E - r_D}{r_D}$ and $R > 8c\frac{(r_E - r_D)}{r_D}$ implies that $R < 4c$, and consequently that $q = \frac{R}{4c} < 1$, as desired. $\square$

Proof of Proposition 6: We begin with the case of parameter values such that $q, k < 1$, and show that there exists a value $\widetilde{r}_D > 0$ such that $k^{reg} < k^{BS}$ if and only if $r_D < \widetilde{r}_D$. Consider the solution that maximizes borrower surplus, k^{BS}, and assume that $R < 4c$ and $c > \frac{R^2}{16r_E}$, which implies that $q, k^{BS} < 1$. From the condition defining k^{BS},

$$\Pi = \frac{\left(R - (1 - k^{BS})r_D\right)^2}{16c} - k^{BS}r_E = 0,$$

one can clearly see that, as $r_D \to 0$, $k^{BS} \to \frac{R^2}{16cr_E} < 1$ for $c > \frac{R^2}{16r_E}$.

By contrast, k^{reg} is defined by

$$\frac{\partial SW}{\partial k} = \frac{r_D}{4c}\left(\frac{R + (1 - k^{reg})r_D}{2}\right) + r_D - r_E = 0.$$

For $r_D \to 0$, we see that $k^{reg} \to 0$, since it is optimal to just have deposit-based finance.

These two results together imply that there is some threshold $\underline{r}_D$ such that, for $r_D < \underline{r}_D$, $k^{reg} < k^{BS}$.

At the other extreme, we consider the solutions as $r_D \to r_E$. For $c > \frac{R^2}{16r_E}$, $k^{BS} = \frac{8c-R+r_E-4\sqrt{(4c-R+r_E)c}}{r_E} < 1$. As in the proof of Proposition 5B, we ignore for now the banks' participation constraint and focus on the unconstrained solution to the problem of social welfare maximization. Here, we see that $k^{reg} \to 1$ as $r_D \to r_E$ for all parameter values. Therefore, we can also conclude that there must exist some threshold $\overline{r}_D$ such that, for $r_D > \overline{r}_D$, $k^{reg} > k^{BS}$.

Comparing the two values of k, $k^{reg} < k^{BS}$ if and only if

$$k^{reg} = \frac{Rr_D + r_D^2 - 8c\left(r_E - r_D\right)}{r_D^2} < \frac{8cr_E - Rr_D + r_D^2 - 4\sqrt{r_E c\left(4cr_E - Rr_D + r_D^2\right)}}{r_D^2} = k^{BS}.$$

Rearranging, we obtain the condition for $k^{reg} - k^{BS} < 0$ as:

$$\frac{2}{r_D^2}\left(Rr_D + 4cr_D - 8cr_E + 2\sqrt{cr_E\left(4cr_E - Rr_D + r_D^2\right)}\right) < 0.$$

Since we know that for low values of r_D this condition will be satisfied, but not for higher values, we can establish that there is a unique threshold where the inequality flips (i.e., that $\underline{r}_D = \overline{r}_D$) if the difference $k^{reg} - k^{BS}$ is either concave or convex in r_D. For this, we only need the second derivative of the term inside the parenthesis, which yields

$$\begin{aligned} &\frac{\partial^2}{\partial r_D^2}\left(Rr_D + 4cr_D - 8cr_E + 2\sqrt{cr_E\left(4cr_E - Rr_D + r_D^2\right)}\right) \\ = \;& \frac{\frac{1}{2}\left(16cr_E - R^2\right)\left(\sqrt{cr_E}\right)}{\left(4cr_E - Rr_D + r_D^2\right)\left(\sqrt{4cr_E - Rr_D + r_D^2}\right)} > 0, \end{aligned}$$

since by assumption $c > \frac{R^2}{16r_E}$.

The finding that the function $k^{reg} - k^{BS}$ is convex implies that $k^{reg} - k^{BS}$ can at most cross zero twice, the first time from above and the second from below. However, two crossings are inconsistent with the finding in the proposition above that for low values of r_D, $k^{reg} - k^{BS} < 0$, while for high values of r_D, $k^{reg} - k^{BS} > 0$. Therefore, $k^{reg} - k^{BS} = 0$ at one unique point, which implies that $\underline{r}_D = \overline{r}_D = \widetilde{r}_D$, and we have just one threshold, as desired. We can now introduce the banks' participation to note, as a final point, that since $k^{reg} > k^{BS}$ violates the banks' participation constraint, we must have that $k^{reg} = k^{BS}$ for $r_D > \widetilde{r}_D$.

We next proceed to the case where $q = 1$ in both cases, which is true for sufficiently large R, but that $k < 1$. Start with the case of borrower surplus maximization, where, for $R > 4c$, $q = 1$ and $k^{BS} = \frac{c}{r_E}$. For the case with regulation, we have that for $R > \max\{2c\frac{2r_E - r_D}{r_D}, 4c\}$, $q = 1$ and $k^{reg} = \frac{4c + r_D - R}{r_D}$. Therefore, $k^{reg} < k^{BS} \Leftrightarrow$

$$\frac{4c + r_D - R}{r_D} < \frac{c}{r_E}.$$

This last inequality can be solved for r_D to yield the condition

$$r_D < r_E \left(\frac{R - 4c}{r_E - c} \right),$$

which establishes that $k^{reg} - k^{BS} < 0$ only if $r_D < \widetilde{r}_D = r_E \left(\frac{R-4c}{r_E - c} \right)$. For $r_D > r_E \left(\frac{R-4c}{r_E - c} \right)$, $k^{reg} = k^{BS}$.

The last case is a possible "mixed" case, in which monitoring may be at a maximum for one solution but not the other. It is straightforward to show that the only case of relevance is where, with a slight abuse of notation, $q^{BS} = 1$ but $q^{req} < 1$. This occurs for $\frac{Rr_D}{2(2r_E - rD)} < c < \frac{R}{4}$, and in this range $k^{BS} = \frac{c}{r_E}$ and $k^{reg} = \frac{Rr_D + r_D^2 - 8c(r_E - r_D)}{r_D^2}$. The difference $k^{reg} - k^{BS}$ simplifies to

$$(r_E - c)r_D^2 + (R + 8c)r_E r_D - 8cr_E^2 = 0.$$

The relevant solution is

$$\widetilde{r}_D = \frac{r_E(R+8c) - \sqrt{32c^2 + R^2 + 16c(R + 2r_E)}}{2(c - r_E)},$$

which implies $k^{reg} < k^{BS}$ only if $r_D < \widetilde{r}_D$.

To complete the proof, define $\widetilde{\rho}_E = \frac{r_E}{\widetilde{r}_D}$ for all the cases described above. The condition on ρ_E described in the proposition then follows. □

Proof of Proposition 7: Note that bank profit maximization with respect to k yields the following FOC:

$$\begin{aligned} \frac{\partial \Pi}{\partial k} &= \frac{\partial q}{\partial k}(r_L - (1-k)c_D) + qc_D - q(1-k)\frac{\partial c_D}{\partial k} - r_E - 2cq\frac{\partial q}{\partial k} \\ &= qc_D - r_E - q(1-k)\frac{\partial c_D}{\partial k}. \end{aligned}$$

Since $qc_D = r_D$, $\frac{\partial c_D}{\partial q} = -\frac{r_D}{q^2}$, and, given $q = \frac{1}{4c}\left(R + \sqrt{R^2 - 8cr_D\,(1-k)}\right)$ when $r_L = R - \frac{r_B}{q}$, that $\frac{\partial q}{\partial k} = \frac{r_D}{\sqrt{R^2 - 8cr_D(1-k)}} > 0$, the FOC becomes :

$$r_D - r_E + (1-k)\frac{r_D}{q}\frac{r_D}{\sqrt{R^2 - 8cr_D\,(1-k)}} = 0.$$

Evaluating at $k = 0$, $\frac{\partial \Pi}{\partial k}$ is clearly positive for $r_D \to r_E$. Substituting in for q, we can find the limiting value of $\frac{\partial \Pi}{\partial k}$ explicitly as $r_D \to r_E$, which becomes

$$\lim_{r_D \to r_E}\left(r_D - r_E + \frac{r_D}{q}\frac{r_D}{\sqrt{R^2 - 8cr_D}}\right) = \frac{1}{4}r_E\frac{3R - \sqrt{R^2 - 8cr_E}}{\sqrt{R^2 - 8cr_E}} > \frac{1}{4}r_E\frac{2R}{\sqrt{R^2 - 8cr_E}} > 0.$$

Therefore, $k > 0$ even for the case where there is a shortage of funds relative to projects. □

Proof of Proposition 8: Assume that there is a shortage of projects relative to funds so that, as before, borrower surplus is maximized by setting

$$r_L = \frac{R + (1-k)c_D}{2}.$$

We can substitute this into the equation for q, recalling that $c_D = \frac{r_D}{q}$, and solve for q to obtain $q_1 = \frac{1}{8c}\left(R + \sqrt{R^2 - 16cr_D\,(1-k)}\right)$ and $q_2 = \frac{1}{8c}\left(R - \sqrt{R^2 - 16cr_D\,(1-k)}\right)$. We focus again on the Pareto dominant equilibrium with a higher level of monitoring (q_1).

We proceed by maximizing BS with respect to the choice of capital, k. However, we know from above that the combination of $r_L = \frac{R+(1-k)c_D}{2}$ and the highest possible k will be optimal for borrowers. We therefore introduce the participation constraint for the bank, that $\Pi = q(r_L - (1-k)c_D) - kr_E - cq^2 \geq 0$. Substituting for r_L gives $q = \frac{1}{8c}\left(R + \sqrt{R^2 - 16cr_D\,(1-k)}\right)$, and we obtain

$$\Pi = cq^2 - kr_E = c\left(\frac{1}{8c}\left(R + \sqrt{R^2 - 16cr_D\,(1-k)}\right)\right)^2 - kr_E = 0.$$

Focusing on parameter values for which there is an interior solution for k, the solution is

$$k^{BS} = \frac{1}{2c\,(4r_E - r_D)^2}\left(R^2 r_E + 2cr_D^2 - 8cr_D r_E - R\sqrt{r_E\,(R^2 r_E + 4cr_D^2 - 16r_E cr_D)}\right).$$

To maximize social welfare in the absence of deposit insurance, we need to solve

$$\max_k SW = \Pi + BS = qR - (1-k)\,r_D - kr_E - cq^2.$$

Ignoring the banks' participation constraint, the FOC yields

$$\frac{\partial SW}{\partial k} = \frac{\partial q}{\partial k}\,(R - 2cq) + r_D - r_E = 0.$$

Using $\frac{\partial q}{\partial k} = \frac{r_D}{\sqrt{16ckr_D - 16cr_D + R^2}}$, we can substitute into the FOC and solve for k, which yields

$$k^{reg} = \frac{1}{2}\frac{18cr_D^3 - 48cr_D^2 r_E + 32cr_D r_E^2 + 3R^2 r_D r_E - 2R^2 r_E^2}{cr_D\,(4r_E - 3r_D)^2}.$$

Comparing these two solutions, we note that as $r_D \to 0$, we have that, as before, $k^{BS} \to \frac{R^2}{16cr_E}$. By contrast, for the case of social welfare maximization it is easy to see from the FOC that as $r_D \to 0$, $k^{reg} \to 0$ as well. Therefore, for r_D sufficiently small, we have that $k^{reg} < k^{BS}$, as desired. This solution is valid since $k^{reg} < k^{BS}$, implying that banks' participation constraint will necessarily be satisfied.

To complete the proof, define $\widehat{\rho}_E = \frac{r_E}{r_D}$. The condition on ρ_E described in the proposition then follows. $\square$

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