Minimum Capital Requirements, Bank Supervision and Special Resolution Schemes. Consequences for Bank Risk-Taking

Uwe Vollmer*, Harald Wiese†

November 2011

Abstract

This paper analyzes the incentive effects of special resolution schemes which were introduced in some countries during the recent fincial crisis. These schemes allow regulators to take control over a systemically important financial institution before bankruptcy. We ask how special resolution schemes influence banks' risk-taking and whether regulators should combine them with minimum capital requirements. We model a single bank which is supervised by a regulator who receives an imperfect signal about the bank's probability of success. We obtain the following results: (i) Capital requirements are better than closure policies from a welfare point of view, if the signal is relatively bad and/or if it is difficult for the bank to attract deposits and/or if the project's rate of return is relatively low. (ii) In the presence of systemic costs, a capital requirement of 100% may not be sufficient to thwart the bank's project plan.

Keywords: Financial crisis, minimum capital requirements, bank resolution, bank supervision, deposit insurance

JEL classification: G21 · G28 · G33 · F22 · F36

*University of Leipzig, Economics Department, Institute for Theoretical Economics, Grimmaische Straße 12, D-04109 Leipzig, Germany (E-Mail address: vollmer@wifa.uni-leipzig.de).

†University of Leipzig, Economics Department, Institute for Theoretical Economics, Grimmaische Straße 12, D-04109 Leipzig, Germany (E-Mail address: wiese@wifa.uni-leipzig.de).

1. Introduction

A major lesson learnt from the recent financial crisis was that the existing regulatory frameworks were inadequate for preventing banks from excessive risk taking. Pre-crisis prudential bank regulation basically allowed regulators to set minimum capital requirements for banks and to engage in bank supervision. While these provisions made banks more risilient against losses and helped reducing bank owners' incentives for risk-taking, they provided only inadequate safeguards against failures of systemically important financial institutions (SIFIs) (Dewatripont et al., 2010).

Without proper bank resolution tools, authorities were confined to two costly alternatives: to open corporate bankruptcy procedures or to bail-out failing banks. For SIFIs, a sudden and disorderly bankruptcy, as in the case of Lehman Brothers, can result in disruptions of the payment system, in contagion, and in sharp increases in interbank interest rates with systemic consequences. Ordinary bankruptcy procedures may also result in disturbing results because authorities loose control over actions taken by courts which often tend to maximize creditors' claims. When bankruptcy procedures become too costly for authorities, public bail-outs are the only alternative. With bankruptcy beeing an incredible threat, banks are "too big (too interconnected) to fail" which creates moral hazard and impairs market discipline (Čihak, Nier, 2010).[1]

To make the existing regulatory framework more effective, both the Basel Committee on Bank Supervision and the Financial Stability Board made recommendations how to handle SIFIs. They proposed procedures providing authorities with the power to implement resolution measures in order to tackle effectively the too-big-to-fail problem (Basel Committee on Bank Supervision, 2010; Financial Stability Board, 2010). The European Commission prepared a possible EU framework for bank recovery and resolution (European Union, 2010), and legislators in several EU member countries amended existing banking laws and allowed supervisors to transfer all or some of financial institutions' assets (and liabilities) to an existing legal entity if the stability of the financial system is in danger (Deutsche Bundesbank, 2011).[2]

[1] There is some evidence showing that banks receiving public support have smaller capital ratios. See Nier, Baumann (2006).

[2] For a survey of current bank resolution schemes in EU Countries see Čihak, Nier (2010). Japan had already introduced a resolution scheme in 1998 (Nakaso, 2002). In the US, the Federal Deposit Insurance Corporation Improvement Act introduced prompt corrective actions for undercapitalized banks in 1991. See Dewatripont et al. (2010).

Although the particular designs of special resolution schemes differ between countries, they share some common features: Authorities may (i) take control over a bank already at an early stage of its financial difficulties and may (ii) rapidely take a wide range of actions to deal with the failing institution without prior agreement of shareholders and creditors. If necessary, the financial institution may be liquidated or sold to an assuming bank. Special resolution schemes differ from both ordinary bankruptcy procedures and from bank bail-outs since they offer authorities more control over the failing bank. During ordinary bankruptcy procedures, courts often disregard the bank's systemic relevance, while authorities may take into account wider financial stability considerations. After a bail-out, on the other hand, the incumbent management often keeps its position and authorities loose control over the actions taken unless they exert considerable pressure on banks' CEOs; this kind of 'moral suasion', however, is not always very effective (Čihak, Nier, 2010).

While authorities introduced special resolution schemes primarily to contain externalities from contagion effects (the ex-post point of view), they may also have consequences for banks' risk taking and for the prevention of future banking crises (the ex-ante point of view). In this paper, we deal with the ex-ante problem of risk taking and ask whether regulators should be able to resolve banks or to set, in addition, minimum capital requirements. Bank resolution regimes may perfectly contain banks' excessive risk-taking only if the information used by the regulator is perfect; in this case, no other form of prudential regulation is needed. In practice, however, bank supervision is imperfect and a regulator may take a wrong decision, i.e., he may leave open a bank which should be closed ('type I' mistake or 'excessive forbearance'), or he may close a bank that should be left open ('type II' mistake or 'excessive intervention'). Knowing that the supervisor may be wrong, the bank manager may take excessive risks. In this situation, setting minimum capital requirements may be helpful only if the quality of bank supervision is low since they reduce risk taking by banks and hence counterbalance regulator's excessive forbearance.

We specify a model of a risk-neutral bank which is endowed with a given amount of equity capital, raises deposits from the market and invests funds in a risky project. The bank maximizes expected profits and is regulated and supervised by a public regulator who cares about social welfare. The bank "misbehaves" for two reasons. Firstly, since deposits are insured by a deposit insurer, the bank has an incentive to accept a higher leverage than socially optimal (because of the implicit subsidy on deposits). Secondly, we assume the bank to be systemically relevant and hence, bankcrupty causes systemic costs. In response to both problems, the regulator may either introduce a ceiling on deposits, i.e., the bank has to hold a minimum amount of (uninsured) equity capital, or supervise and eventually resolve the bank. We model riskiness of the bank by the project's success probabilities. While the bank learns the true probability, the regulator receives an imperfect signal about the true probability, only. We assume the bank has no possibility to inform the regulator about the true success probability in a verifiable manner.

Our model reproduces standard results found in the literature: Banks tend to realize risky projects at the expense of welfare for two reasons. First, a deposit insurance allows the bank to externalize the risk borne by the depositors. Second, systemic banks do not bear the systemic cost brought about by bankruptcy. The main contribution of the paper is to show how capital requirements and bank resolution may help to alleviate the welfare problems caused by excessive risk taking. We obtain the following results:

- Minimum capital requirements use the bank's information about the project, but deleverage the bank's project. In contrast, bank-closure policies do not use the bank's information and do not deleverage the project.

- Assume the project's success probability is sufficiently high. Then, we obtain a trade-off between the use of the bank's information about the project and the size of the bank's project. Since capital requirements and closure policies have opposing advantages, capital requirements are better than closure policies from a welfare point of view if (i) the signal quality is relatively bad and / or if (ii) it is difficult for the bank to attract deposits and / or if (iii) the project's rate of return is relatively low. The last case may also imply that a regulator should apply more stringent capital requirements during macro-economic downswings.

- In the presence of systemic costs, a capital requirement of even 100 per cent may not be sufficient to thwart the bank's project plan. In that case, the optimal capital requirement is 100 per cent in order to minimize the systemic cost that are a function of both equity capital and deposits (that equal zero with capital requirement 100 per cent).

Since we restrict our analysis to a single bank, we neither consider macroeconomic effects of special resolution schemes nor discuss the merits of an international harmonization of special bankruptcy regimes for banks. Furthermore, we take the advantageousness of a bank resolution mechanism as given and do not compare it with either ordinary bankruptcy procedures or public bank bail-outs. Finally, we abstract from other regulatory measures introduced in many countries together with resolution schemes, such as a bank levy.

The paper is organized as follows: Section 2 briefly reviews the relevant literature. Section 3 describes the model setting and compares minimum capital adequacy ratios with resolution policy under symmetric information. Section 4 deals with asymmetric information without the regulator receiving any signals while section 5 discusses signals obtained by the regulator. Section 6 describes the effect of systemic risk for the symmetric-information case, only. Section 7 concludes the paper.

2. Literature

Our paper is related to other studies that analyze the impact of different regulatory instruments on risk-taking by banks which enjoy a flat-rate deposit insurance. One branch of the literature follows Hart and Jaffee (1974) and applies the mean-variance (or portfolio) framework to a bank which is assumed to be risk-averse. Most authors contributing to this line of research consider capital requirements and argue that uniform adequacy requirements increase (rather than decrease) risk-taking by banks which have an incentive to invest in more risky asset portfolios (Kahane, 1977; Koehn and Santomero, 1980; Kim and Santomero, 1988; Gennotte and Pyle, 1991). This view is challenged by Furlong and Keeley (1989), Keeley and Furlong (1990) and Rochet (1992) who claim the opposite relationship, thereby backing the purpose of capital requirements. Other authors also use the portfolio approach and analyze the impact of bank closure policies on risk-taking. They assume that regulators close a bank if its (observable) net worth is below a critical level and find that increasing this critical capital level can either increase or decrease the banks' risk taking (Davies and McManus, 1991). Finally, Kahane (1977) analyzes constraints on the composition of the bank's asset portfolio and shows that a combination of different regulatory instruments may reach the desired results.

As in the portfolio approach, we also analyze the combination of different instruments for prudential regulation; yet, we consider bank resolution in addition to capital requirements. Since there are no informational asymmetries between bank and regulator, the mean-variance framework does not offer any room for bank supervision. In fact, there the regulator sets an upper bound on the probability of default and the bank chooses an asset portfolio which is observed by the regulator. In our model, the probability of default is exogenously given, but not known by the regulator who, by supervision, improves his knowledge about the bank's investment decision. Besides, our paper does not assume risk-aversion on the side of the bank, an assumption which is plausible for small, closely-held manager-owned banks, but not for large, publicly-held banking institutions which are able to diversify their asset risks (Freixas and Rochet, 2008).

A second branch of the literature applies the principal-agent framework to prudential supervision and assumes that the bank is better informed than the regulator about its risks (Giammarino, Lewis and Sappington, 1993; Freixas and Gabillon, 1999). These models consider an economy with a large number of banks that invest their funds in a loan portfolio with a random return. The quality of the loan is known to the bank but not to the regulator who - by supervision - is informed about the characteristics of the loan quality's density function. The regulator cares about social welfare and maximizes the sum of expected payments to all agents. Under symmetric information, all banks would have to pay actuarial deposit premiums and would not be subject to capital requirements. This first-best-solution is not feasible, however, under asymmetric information since it would result in adverse selection. Under asymmetric information, hence, the regulator would offer two kinds of regulatory regimes and banks would have to choose one of these regimes: One regime with no capital requirement but a constant deposit insurance premium and another regime with positive capital requirement and a deposit insurance premium which decreases in the quality of the loan portfolio.

We also use informational asymmetries between the bank and the regulator and assume that the regulator pursues bank supervision and learns something about the quality of the bank's assets. The main point of departure is that we consider a single bank so that there is no room for adverse selection in our model; besides, we assume a flat deposit insurance premium which is not differentiated between banks. A major drawback of the principal-agent framework is that the bank is implicitely assumed to be managed by a person who also owns the bank; in reality, however, bank managers do not provide much equity capital to the bank and it should be more fruitful to concentrate on an incentive scheme for managers rather than for stockholders (Freixas and Rochet, 2008).

Closest to our paper is the third strand of the literature which applies the incomplete contracts approach to financial contracting (Aghion and Bolton, 1992) to prudential bank regulation (Dewatripont and Tirole, 1993, 1994; Tirole, 1994). Crucial for this approach is the assumption that a public regulator - through supervision - receives an imperfect and non-verifiable signal about the solvency of a bank with a given balance sheet. The regulator may withdraw property rights away from the bank owners and assign them to depositors (or the deposit insurance). This action is noncontractable. If property rights remain with bank owners, they will pursue the bank's project in any case (if their stake is not too large); on the contrary, depositors would close down the bank in any case if property rights are allocted to them. Since the signal is imperfect, the regulator is subject to either type I or type II mistake which result in ex post inefficiencies. Under these assumptions, the ex ante efficiency of bank supervision depends on the capital ratio specified by the regulator.[3]

In this paper, we adopt the incomplete contracts framework but resume the assumption that the size of the bank's balance sheet is given; instead, the bank manager chooses how many deposits he accepts and invests all funds in his loan portfolio. This allows us to model the impact of prudential bank regulation on bank size. We further assume that the regulator nationalizes and resumes the bank after receiving a bad signal, instead of transfering property rights to depositors and dissolving the bank. Under these assumptions, the new owner maximizes expected payments from the bank instead of minimizing expected payments to depositors. This assumption seems to fit better with empirical evidence at least during the recent financial crisis when regulators did not liquidate supervised banks but nationalized them and continued their business.

To our best knowledge, only few papers discuss the consequences of bank resolution schemes for bank behavior. Some authors, e.g., Jacques and Aggarwal (1999), Aggarwal and Jacques (2001), Shim (2006), Freixas and Parigi (2007), and Kocherlakota and Shim (2007), consider prompt corrective action (PCA) which was introduced in the USA after the financial crisis of the 1980s. Under PCA, banks are classified according to their capitalization into five categories, and the regulator may mandate restrictions on the bank's activities if the capital ratio falls below certain levels; in extreme cases, the bank may be placed under conservatorship or receivership if capital falls below two per cent of tangible assets (Weinstock, 2009). In consequence, the bank can trade-off lower capital ratios against larger interventions. Under special resolution schemes as analyzed in this

[3] Repullo (2000) and Kahn and Santos (2005, 2006) also use the incomplete contracts approach but discuss the optimal allocation of regulatory powers among different regulators, the central bank and a deposit insurer. They consider two policy instruments, lending of last resort and bank supervision, and ask whether bank regulatory competences should be concentrated on a single authority or whether different regulatory institutions should be involved.

paper, however, such a trade-off is not possible since the regulator's decision is not necessarily based upon fulfillment of capital requirements but depends on the regulator's perception of the bank's future profitability.

Finally, some authors ask whether international differences in bank regulation are feasible and a convergence of regulatory standards is desirable if international financial markets are integrated and banks offer financial services across borders. Acharya (2003), Holthausen and Ronde (2005) and Dell'Ariccia and Marquez (2006) argue that with internationally active banks competition among regulators may lead to a 'race to the bottom' and to a 'competition in laxity', if national regulators set their banking policies non-cooperatively. Therefore, an international regulator should set uniform standards for all banks. While Holthausen and Ronde (2005) and Dell'Ariccia and Marquez (2006) assume that the national regulator has only one instrument at hands - capital requirements and closure policies, respectively - Acharya (2003) considers the case of two national regulators who can set both capital requirements or closure policies. With uniform capital ratios, domestic banks with less forbearing regimes compete on domestic markets with foreign banks from more forbearing regimes which can take greater risks. This reduces domestic banks' profits and, to prevent market exit, domestic regulators have to adopt greater forbearance. In consequence, regulators in different countries converge to the highest level of forbearance or apply different capital adequacy ratios to compensate for differences in laxity. Uniform capital requirements across nations are hence only desirable if supervisors maintain different closure policies. An incomplete harmonization of regulatory policies may therefore be more harmful than no international harmonization at all. Our paper builds upon this strand of the literature as we also analyze the optimal mix between capital requirements and closure policies from a welfare point of view; the main point of departure of our study is that we restrict our analysis to a closed economy with only one regulator who has two instruments available.

3. Symmetric information

3.1. Basic model

A bank plans to invest its funds in a risky project with constant returns to scale. The (gross) rate of return of the project is either $R > 1$ (the success case) or zero. In all our models, we assume that the bank learns the true probability of success, $p > 0$. However, this information is non-verifiable. In this section, we assume that p is known to the regulator, too, and we focus on the bank's behavior.

The bank is endowed with a given amount of equity capital $E = 1$ and can, in addition, raise deposits D from households. We assume a deposit supply function $D(r) = d(r-1)$, with $d > 0$ and $r \geq 1$, where r is the (gross) rate of return offered to depositors by the bank. Deposits are assumed to be insured by a public deposit insurance agency with the deposit insurance premium normalized to zero. All agents are assumed to be risk neutral and the risk-free interest rate is zero.

Our basic banking model is one-stage. The bank learns p and chooses whether to pursue the project or not. If the project is not pursued, the game is over. Otherwise, the bank chooses r and employs equity E and deposits $D(r)$ for the project. If the project is realized, the bank's objective function equals expected profits paid out to equity holders

$$\begin{aligned} \Pi(p,r) &= p\left(R\left(E + D(r)\right) - E - rD(r)\right) + (1-p)(-E) \\ &= Rp - 1 + p(R-r)\,d(r-1), \end{aligned}$$

i.e., the bank looses its equity capital with probability $1-p$ but does not need to worry about the deposits in case of project failure. If the project is not realized, the bank's payoff is zero.

A benevolent (public) regulator cares about social welfare, i.e., maximizes expected payments to all agents. Since all deposits are insured, depositors with deposits $D(r)$ receive $(r-1)D(r)$ and the deposit insurance's expected payoff is $-(1-p)rD(r)$. Therefore, social welfare is given by

$$\begin{aligned} W(p,r) &= Rp - 1 + p(R-r)\,d(r-1) + (r-1)D(r) - (1-p)rD(r) \\ &= (Rp-1)(D(r)+E) \\ &= (Rp-1)(d(r-1)+1) \end{aligned}$$

if the project is pursued with rate of interest r, and 0, otherwise. We sometimes write $\Pi(r)$, $W(r)$ or simply Π or W. We assume that the bank will not pursue the project if the expected profit is zero.

Proposition 3.1. *Without prudential regulation, the bank pursues the project iff*

$$p > \frac{1}{R + \frac{1}{4}d(R-1)^2} =: p^B$$

holds. In this case, the bank sets the interest rate at

$$r^B = \frac{1}{2}(R+1).$$

and obtains the expected payoff

$$\Pi\left(r^B\right) = Rp - 1 + \frac{1}{4} dp \left(R-1\right)^2 .$$

The regulator's payoff is

$$W\left(r^B\right) = \left(Rp-1\right)\left(\frac{1}{2}d\left(R-1\right)+1\right). \tag{3.1}$$

From the point of view of welfare maximization, the project should be executed whenever $W\left(r^B\right) \geq 0$ *holds, i.e.,*

$$p \geq \frac{1}{R} =: p^W .$$

Optimal banking behavior is shown in the appendix.

As expected, the higher d or the higher R, the higher the chances that the project is realized. Note that a bank without deposits ($r = 1$ or $D = 0$, respectively) pursues the project iff the benevolent regulator likes to see it realized. However, by

$$p^B = \frac{1}{R + \frac{1}{4}d\left(R-1\right)^2} < \frac{1}{R} = p^W,$$

the bank may choose to go ahead with the project even if welfare is negative. In any case, the bank's decision on r is not welfare-maximizing unless p happens to equal $\frac{1}{R}$.

3.2. Capital requirements

To alleviate the bank's misbehavior, the public regulator can engage in capital regulation. Since $E = 1$ by assumption, a minimum capital requirement $\hat{k} = \frac{E}{E+D}$ entails a limit on deposits the bank is allowed to collect,

$$D \leq \frac{1-\hat{k}}{\hat{k}}E = \frac{1}{\hat{k}} - 1 =: \widehat{D},$$

or a limit on the interest offered to the bank's customers,

$$r \leq 1 + \frac{1}{d}\frac{1-\hat{k}}{\hat{k}} =: \hat{r}. \tag{3.2}$$

Assume that the bank plans to go ahead with its project. The capital requirement $\hat{k}$ is binding if the optimal interest rate r^B is disallowed, i.e., if $r^B > \hat{r}$ or, equivalently,

$$\hat{k} > \frac{2}{d\,(R-1)+2} =: \hat{k}^{\text{bind}}$$

holds.

We analyze bank behavior and assume this two-stage game: First, the regulator learns p and determines an capital ratio $\hat{k}$. Second, the bank also learns p and chooses whether to pursue the project or not. If the project is not pursued, the game is over. Otherwise (still within stage 2), the bank chooses $1 \leq r \leq \hat{r}$ and employs equity $E = 1$ and deposits $D\,(r) = d\,(r-1)\,, d > 0$, for the project. Payoff functions are the same as before.

Proposition 3.2. *In the capital-requirement game specified above, we get the following results:*

1. *At the second stage, the profit-maximizing bank realizes the project if and only if $p > p^B$ and one of the following conditions holds:*

   a) *The capital ratio is binding, $\hat{k} > \hat{k}^{bind}$, and allows positive profits, $\hat{k} < \min\left(\hat{k}_1, 1\right)$ with*

   $$\hat{k}_1 := \frac{p\,(d\,(R-1)+2)}{2\,(d\,(1-p)+p)} + \sqrt{dp\frac{p\left(R+\frac{1}{4}d\,(R-1)^2\right)-1}{(d\,(1-p)+p)^2}};$$

   in this case, the bank offers $r^B\left(\hat{k}\right) = \hat{r}$ to depositors; or

   b) *the capital ratio is not binding, $\hat{k} \leq \hat{k}^{bind}$; then the bank offers $r^B\left(\hat{k}\right) = r^B$ to depositors.*

   Inversely, at the second stage, the profit-maximizing bank cannot obtain positive profits and does not realize the project if $p \geq p^B$ or $\hat{k}_1 \leq \hat{k} \leq 1$ hold.

2. *At the first stage, we consider three cases:*

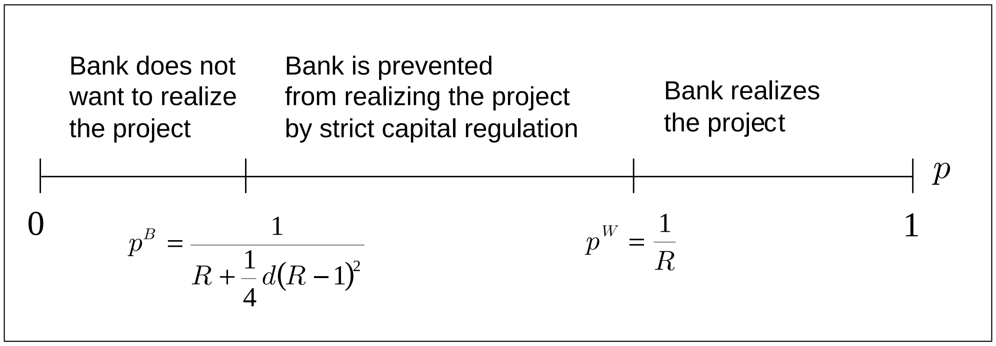

Figure 3.1: How equity regulation makes the bank choose good projects, only.

a) *If both the bank and the regulator learn a success probability p below their respective thresholds ($p \leq \min\left(p^B, p^W\right) = p^B$), every capital ratio is optimal because the bank refrains from the project even for $\hat{k} = 0$.*

b) *If both the bank and the regulator learn a success probability above their respective thresholds ($p \geq \max\left(p^B, p^W\right) = p^W$), the regulator should choose a non-binding the capital requirement.*

c) *If the bank likes to pursue the project ($p > p^B$) and the regulator likes to prevent the project ($p < p^W$), we have $\hat{k}_1 < 1$ and any capital requirement $\hat{k}_1 \leq \hat{k} \leq 1$ makes the bank refrain from the project as desired from a welfare point of view.*

The proof can be found in the appendix.

According to this proposition, the regulator possibly uses $\hat{k}$ to prevent the bank from carrying out the project but not to restrict the deposits in the case where the project should be carried out from the welfare point of view.

Figure 3.1 shows the regulator's and the bank's behavior depending on the project's success probability. Since the regulator's threshold probability p^W is more demanding than the bank's threshold probability p^B, the conflict of interest arises in the middle section, only. Here, the bank would like to pursue the project but is prevented from doing so by the regulator who chooses a prohibitive capital requirement.

According to the proposition, the regulator chooses the following capital requirements in the three sections shown in figure 3.1:

$$\hat{k}^* \begin{cases} \in [0,1], & p \leq p^B \\ \in \left[\hat{k}_1, 1\right], & p^B < p < p^W \\ = 0, & p \geq p^W \end{cases}$$

The regulator always obtains a non-negative payoff

$$W\left(\hat{k}^*\right) = \begin{cases} (Rp-1)\left(\frac{1}{2}d(R-1)+1\right), & p \geq p^W \\ 0, & p < p^W = \frac{1}{R}. \end{cases}$$

Note that there is no case in which the bank carries out the project under the capital restriction. It is for future reference, that we note welfare for the case where the project is carried out and the bank chooses the binding interest rate $\hat{r}$:

$$\begin{aligned} W(\hat{r}) &= (Rp-1)(d(\hat{r}-1)+1) \\ &= \frac{Rp-1}{\hat{k}}. \end{aligned} \tag{3.3}$$

For future reference, we note a lemma, the proof of which can be found in the appendix.

Lemma 3.3. *For $p > p^B$, we have $\frac{\partial \hat{k}_1}{\partial p} > 0$.*

3.3. Resolution

Instead of setting minimum capital requirements, the regulator may engage in bank resolution, i.e., he can stop any project the bank likes to go ahead with.

We suggest the following three stages. First, the bank learns p. The bank chooses to pursue the project or not. If the project is not pursued, the game is over. Otherwise, still within stage 1, the bank proposes the project to the regulating authority. Second, the regulator also learns p and then allows or prohibits the project (if any project has been submitted). Third, if the bank's project is accepted, the bank chooses r and employs equity E and deposits $D(r)$ for the project. Payoff functions are obvious.

Proposition 3.4. *In the resolution game with symmetric information, we get the following results:*

1. *If both the bank and the regulator learn a success probability p below their respective thresholds ($p \leq \min\left(p^B, p^W\right) = p^B$), it is irrelevant whether or not the bank proposes the project to the regulating authority which will block the project if submitted.*

2. *If both the bank and the regulator learn a success probability above their respective thresholds ($p \geq \max\left(p^B, p^W\right) = p^W$), the bank proposes the project which gets accepted by the regulating authority. The bank chooses r^B at the third stage.*

3. *If the bank likes to pursue the project ($p > p^B$) and the regulator likes to prevent the project ($p < p^W$), the regulator needs to disapprove any submission. Foreseeing this, the bank may decide not to submit the project but there is certainly no harm in trying.*

3.4. Comparison between capital requirement and bank resolution

Comparing the second part of proposition 3.2 and proposition 3.4, we see that, under perfect information, capital regulation and resolution lead to the same projects and payoffs. It is also clear that combining the two instruments does not increase welfare. Thus, from an ex-ante point of view, minimum capital requirements are sufficient for preventing excessive risk taking by banks.

4. Asymmetric information without signals

We now introduce asymmetric information and assume that p takes on two values, $p \in \{p_l, p_h\}$, with $0 < p_l < p_h \leq 1$. These probabilities are true with probability $\frac{1}{2}$ which we note by $prob\,(l) = prob\,(h) = \frac{1}{2}$. The true probability is known to the bank, but the regulator does not know whether p_l or p_h (or, simply l or h) will materialize. In this section, we derive the optimal capital-requirements policy, the optimal bank-resolution policy and compare the two optima. We do not consider a model where both instruments are in use. In fact, as we will see in section 5, the two instruments are substitutes in the sense that one of them is always sufficient.

4.1. Capital requirements

We start with the case where the public regulator pursues capital regulation, only. Our model has two stages. First, the regulator learns that l or h will come about with probability $\frac{1}{2}$, each, and then determines the capital ratio $\hat{k}$. Second, the bank learns l or h so that the probabilities p_l or p_h, respectively, will apply. The bank chooses to pursue the project or not. If the project is not pursued, the game is over. Otherwise, still within the second stage, the bank chooses $1 \leq r \leq \hat{r}$ and employs equity $E = 1$ and deposits $D(r) = d(r-1), d > 0$ for the project.

Since the only change with respect to the previous model concerns the reduced regulator's knowledge, the bank's, the depositors', and the deposit insurance's payoff functions are the same as in the symmetric-information case. However, the regulator's payoff function is

$$W(r) = \begin{cases} \frac{1}{2}W(p_l, r) + \frac{1}{2}W(p_h, r), & \text{project is realized at both } l \text{ and } h \\ \frac{1}{2}W(p_l, r) + \frac{1}{2} \cdot 0, & \text{project is realized at } l\text{, but not at } h \\ \frac{1}{2} \cdot 0 + \frac{1}{2}W(p_h, r), & \text{project is not realized at } l\text{, but at } h \\ 0, & \text{project is not realized in any case} \end{cases}$$

In proposition 3.2, we already specified the bank's behavior for given capital requirements. Optimal capital ratio depend on the relative magnitudes of p^B, p^W, p_l and p_h.

Proposition 4.1. *In the capital-requirement game under asymmetric information, we get the following results:*

1. *If $p^B < p^W \leq p_l < p_h$, the bank would like to go ahead with the project for both states of the world and the regulator agrees. Therefore, the optimal capital ratio is 0 or any other ratio below the binding one.*
2. *If $p_l < p_h \leq p^B < p^W$, both the regulator and the bank are against the project and any capital ratio will do.*
3. *If $p^B < p_l < p_h < p^W$, the bank likes to pursue the project, but the regulator likes to prevent the project and can do so by choosing any capital ratio in the interval $\left[\hat{k}_1(p_h), 1\right]$ (see 2.c in proposition 3.2).*
4. *If $p_l \leq p^B < p^W \leq p_h$, both the bank and the regulator want to pursue the project only in case of h but not in case of l. As in the first item above, all capital ratios from the interval $\left[0, \hat{k}^{bind}\right)$ are optimal.*
5. *If $p_l \leq p^B < p_h < p^W$, the bank wants to start the project in case of h but the regulator wants to prevent it in both states of the world. He can*

prevent the project by choosing a sufficiently large capital requirement from the interval $\left[\hat{k}_1(p_h), 1\right]$ *(see 2.c in proposition 3.2).*

6. *If* $p^B < p_l < p^W \leq p_h$*, the regulator has to choose between two different actions:*

   a) *Either the regulator sets the equity constaint at* $\hat{k}_1(p_l)$ *so that the bank pursues the project in case of* h*, only, and sets the rate of interest*

   $$\hat{r}\left(\hat{k}_1(p_l)\right) = 1 + \frac{1}{d}\frac{1-\hat{k}_1(p_l)}{\hat{k}}$$

   (see equation 3.2). In that case, welfare is given by (see equation 3.3):

   $$\frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l)} + \frac{1}{2}\cdot 0$$

   b) *Or the regulator chooses any equity ratio from the interval* $\left[0, \hat{k}^{bind}\right)$ *so that the bank pursues the project in both states of the world and employs the rate of interest* r^B*. Welfare is given by (see equation 3.1):*

   $$\begin{aligned} & W\left(r^B\right) = \frac{1}{2}W\left(p_l, r^B\right) + \frac{1}{2}W\left(p_h, r^B\right) \\ = & \frac{1}{2}(Rp_l-1)\left(\frac{1}{2}d(R-1)+1\right) + \frac{1}{2}(Rp_h-1)\left(\frac{1}{2}d(R-1)+1\right) \\ = & \left(\frac{1}{2}d(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right). \end{aligned}$$

   Discrimination by way of $\hat{k}_1(p_l)$ *(see 6.a) is optimal for sufficiently low* p_l *while a non-binding capital ratio (see 6.b) is best for a sufficiently high* p_l *(to be understood within the interval* $\left(p^B, p^W\right)$ *under consideration). There exists a* p_l^{MC} *(where* MC *stands for minimum capital requirements) such that discrimination is best for all* $p_l < p_l^{MC}$ *while a non-binding capital ratio is best for all* $p_l \geq p_l^{MC}$*.*

It is not difficult to show the first five items. For a proof of the sixth item, consult the appendix.

The intuition behind item 6 is as follows. According to 6.a, the regulator makes the bank choose the project in case of state of the world h, only, by setting the capital ratio $\hat{k}_1(p_l) < \hat{k}_1(p_h)$. This discrimination allows for an optimal project choice, but the interest rate $\hat{r}\left(\hat{k}_1(p_l)\right)$ is lower than r^B implying a welfare loss by diminished bank size. According to 6.b, the regulator allows the project in both states of the world. This has the disadvantage of the bank pursuing the project in state of the world l, which is especially serious if p_l is "far away" from p^W. However, the regulator enjoys the relatively high r^B in case of h and hence a large size of the bank.

4.2. Resolution

With resolution instead of capital regulation we have a three-stage model. First, the bank learns l or h. The bank chooses to pursue the project or not. If the project is not pursued, the game is over. Otherwise, still within stage 1, the bank proposes the project to the regulating authority. Second, the regulator learns the probabilities $\frac{1}{2}$ for the two probabilities and then allows or prohibits the project (if any project has been submitted). Third, if the bank's project is accepted, the bank chooses r and employs equity E and deposits $D(r)$ for the project.

Proposition 4.2. *In the resolution game under asymmetric information, we get the following results:*

1. *If $p^B < p^W \leq p_l < p_h$, the bank would like to go ahead with the project for both states of the world and the regulator agrees. Therefore, the bank submits the project (stage 1), the regulating authority allows it (stage 2), and the bank chooses r^B (stage 3).*

2. *If $p_l < p_h \leq p^B < p^W$, both the regulator and the bank are against the project. If the bank should submit the project (although it has no incentive to do so), the regulator forbids it.*

3. *If $p^B < p_l < p_h < p^W$, the bank likes to pursue the project, but the regulator likes to prevent the project and can do so by forbidding it. Foreseeing the regulator's decision, the bank need not bother to submit the project.*

4. *If $p_l \leq p^B < p^W \leq p_h$, both the bank and the regulator want to pursue the project only in case of h but not in case of l. Learning l, the bank will not*

submit the project, while h leads to the same backward-induction result as in the first item above.

5. *If $p_l \leq p^B < p_h < p^W$, the bank wants to start the project in case of h but the regulator wants to prevent it in both states of the world. The regulator will just say no to any project so that the bank's submission decision has no effect on final outcomes.*

6. *If $p^B < p_l < p^W \leq p_h$, the bank proposes the project in both cases. The regulator cannot differentiate between l and h and will allow in both cases or disallow in both cases. It is best to allow the project iff*

$$p^W \leq \frac{p_l + p_h}{2} \text{ or } p_l \geq 2p^W - p_h =: p_l^{BR}$$

holds where BR is reminiscent of bank resolution. Thus, welfare is given by

$$W = \begin{cases} 0, & (6a) \quad p^W > \frac{p_l+p_h}{2} \\ \left(\frac{1}{2}d\left(R-1\right)+1\right)\left(R\frac{p_l+p_h}{2}-1\right), & (6b) \quad p^W \leq \frac{p_l+p_h}{2} \end{cases}$$

We comment on the sixth item, only. The inequality $\frac{p_l+p_h}{2} \geq p^W$ in this item is justified by the equivalent inequality

$$\frac{1}{2}W\left(r^B, p_l\right) + \frac{1}{2}W\left(r^B, p_h\right) = \left(\frac{1}{2}d\left(R-1\right)+1\right)\left(R\frac{p_l+p_h}{2}-1\right) \geq 0.$$

In view of $p_l < \frac{p_l+p_h}{2} < p_h$, we have two interesting subcases of item 6:

(a) If $p_l < \frac{p_l+p_h}{2} < p^W \leq p_h$ (and in particular $p_l < p_l^{BR}$) hold, the project is forbidden although it should be allowed in state of the world h; the bank is closed when it should be left open ('type II' mistake or 'excessive intervention').

(b) If $p_l < p^W \leq \frac{p_l+p_h}{2} < p_h$ (and in particular $p_l \geq p_l^{BR}$) hold, the regulator allows the project although it should be disallowed in state of the world l from a first-best point of view; in this case the bank is left open when it should be closed ('type I' mistake or 'excessive forbearance').

4.3. Comparison between capital requirement and bank resolution

We are now able to compare minimum capital requirements and bank resolution from the view of social welfare. From propositions 4.1 and 4.2, we know that cases 1 through 5 in both propositions lead to the same final results while the case of the sixth item, $p^B < p_l < p^W \leq p_h$, prompts an interesting comparison.

Proposition 4.3. *Consider $p^B < p_l < p^W \leq p_h$. Within this case, $p_l^{MC} \leq p_l < p_l^{BR}$ cannot occur so that we distinguish three remaining subcases:*

(a) *If p_l is close to p^B ($p_l < \min\left(p_l^{MC}, p_l^{BR}\right)$), capital requirements (discrimination) are better than resolution (forbidding).*

(b) *If p_l is close to p^W ($p_l \geq \max\left(p_l^{MC}, p_l^{BR}\right)$), (non-binding!) capital requirements yield the same welfare*

$$\left(\frac{1}{2}d\,(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right)$$

as resolution (allowing).

(c) *If $p_l^{BR} \leq p_l < p_l^{MC}$, the capital requirement $\hat{k}_1(p_l)$ is better than resolution (allowing).*

The proof is as follows. To begin with, let us assume $p_l^{MC} \leq p_l < p_l^{BR}$. Then, according to proposition 4.1, a non-binding capital requirement should be employed, and, according to proposition 4.2, the project should be disallowed. However, the cases 6 (b) lead to the same payoff $\left(\frac{1}{2}d\,(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right)$ which has to be larger than $\frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l)} \geq 0$ by $p_l^{MC} \leq p_l$ and, at the same time, negative by $p_l < p_l^{BR}$. This is the desired contradiction.

Since (b) does not need any further explanations, we now turn to the proof of (a) and (c):

- Subcase (a) in the present proposition corresponds to (a) in the sixth items of propositions 4.1 and 4.2, respectively, and follows from the inequality $\frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l)} \geq 0$.

- In (c), the constellation $p_l^{BR} \leq p_l < p_l^{MC}$ implies that the project is allowed under resolution but that mimum capital requirements are used in order to discriminate. By $p_l < p_l^{MC}$, capital requirement $\hat{k}_1(p_l)$ is better than a non-binding capital requirement. Since a non-binding capital requirement leads to the same outcome as allowing under resolution, the claim (c) follows.

To understand the intuition behind this proposition, assume that the regulator has no additional information about the probabilities p_l and p_h. Then capital regulation is superior to bank resolution from a welfare point of view, because it makes the best use of the information available to the bank. If the regulator sets minimum capital requirements, the bank decides whether or not to continue with the project and will do so only if it should from a welfare point of view because the bank knows the state of the world l or h. With resolution, the regulator only knows the average probability $\frac{p_l+p_h}{2}$ but not the true probability and will make a mistake of either type I or type II which reduces social welfare.

5. Asymmetric information with imperfect signals

5.1. Signal quality

We now enrich the asymmetric-information model by letting the regulator receive an imperfect signal s_l or s_h about the probabilities p_l and p_h, respectively. The signal is symmetric and reveals the true state of the world with commonly known probability q :

$$prob\left(s_l | \, l \right) = prob\left(s_h | \, h \right) =: q.$$

We assume that both signals have the same probability as the corresponding states of the world, $prob\left(s_l\right) = prob\left(l\right) = \frac{1}{2}$ and $prob\left(s_h\right) = prob\left(h\right) = \frac{1}{2}$. By $prob\left(s_l | \, l \right) = \frac{prob(s_l \wedge l)}{prob(l)}$, we find $prob\left(s_l \wedge l\right) = \frac{1}{2}q$ and hence

$$prob\left(l | \, s_l \right) = \frac{prob\left(s_l \wedge l\right)}{prob\left(s_l\right)} = \frac{\frac{1}{2}q}{\frac{1}{2}} = q.$$

Thus, if the signal received by the regulator is s_l, the regulator's probability for l is q and the probability for h is $1-q$. We assume $q \geq \frac{1}{2}$ so that q can be interpreted as the signal's quality. In the extreme case of $q=1$, the regulator is as well informed as the bank (see section 3). The case of $q=\frac{1}{2}$ implies the model of section 4.

5.2. Model structure and supervision

We analyze both instruments in combination and consider the following four-stage model: First, the regulator learns that l or h will come about with probability $\frac{1}{2}$, each, and then determines the capital ratio $\hat{k}$. Second, the bank learns l or h so that the probabilities p_l or p_h, respectively, will apply. The bank chooses to pursue the project or not. If the project is not pursued, the game is over. Otherwise, still within the second stage, the bank proposes the project to the regulating authority. Third, if the regulating authority obtains the project submission, it gets a signal s_l or s_h about the states l or h, respectively. The regulating authority decides whether or not to allow the project to go ahead. Fourth, if the bank's project proposal is approved, the bank chooses $1 \leq r \leq \hat{r}$ and employs equity $E = 1$ and deposits $D(r) = d(r-1), d > 0$ for the project.

As in the asymmetric-information models without signals, case $p^B < p_l < p^W \leq p_h$ is the only interesting one. In all the other cases, capital regulation or resolution are equally good to ensure the regulator's preferences with respect to the chosen project (but not, as before, with respect to the rate of interest r). We also know that it is sufficient to restrict attention to the equity levels 0 and $\hat{k}_1(p_l)$. After all, non-binding equity levels above 0 have the same effect as 0, while unnecessarily harsh equity requirements above $\hat{k}_1(p_l)$ discriminate between projects l and h as well as capital requirement $\hat{k}_1(p_l)$, but reduce welfare in the good state. Hence, we have to distinguish between the following two subcases:

- In case of capital requirement $\hat{k}_1(p_l)$, the bank will submit project h only and the regulator has no reason to forbid it. At this stage (signals have not been received at stage 2), probabilities are $\frac{1}{2}$ for each case and welfare is given by
$$W = \frac{1}{2} \cdot \frac{Rp_h - 1}{\hat{k}_1(p_l)} + \frac{1}{2} \cdot 0$$
which is non-negative by $p^W \leq p_h$.

- In case of a non-binding capital requirement, the bank submits both projects. From the point of view of the regulator who has obtained a signal, welfare is given by
$$W = \begin{cases} \left(\frac{1}{2}d(R-1)+1\right)(R(qp_l + (1-q)p_h) - 1), & \text{signal } s_l \\ \left(\frac{1}{2}d(R-1)+1\right)(R(qp_h + (1-q)p_l) - 1), & \text{signal } s_h \end{cases}$$
which is greater than zero for
$$p^W \leq \begin{cases} qp_l + (1-q)p_h, & \text{signal } s_l \\ qp_h + (1-q)p_l, & \text{signal } s_h \end{cases}$$
Thus, the regulator chooses

$$\begin{cases} \text{allow}, & p^W \le qp_l + (1-q)\, p_h \text{ and signal } s_l \\ \text{allow}, & p^W \le qp_h + (1-q)\, p_l \text{ and signal } s_h \\ \text{forbid}, & \text{otherwise} \end{cases}$$

By $q \ge \frac{1}{2}$ and hence $qp_l + (1-q)\, p_h \le qp_h + (1-q)\, p_l$, the regulator is more willing to permit the project under signal s_h than under signal s_l. Note that the sixth item of proposition 4.2 is a special case of these results (just let $q = \frac{1}{2}$).

5.3. Optimal capital requirements in the presence of resolution

In order to find out whether capital ratio $\hat{k}_1(p_l)$ or 0 is best (stage 1), we consider three subcases of case $p^B < p_l < p^W \le p_h$.

- $p^B < p_l \le qp_l + (1-q)\, p_h \le qp_h + (1-q)\, p_l < p^W \le p_h$: If the regulator chooses capital requirement 0, his payoff is 0 because he will later forbid the project for both signals. Therefore, the regulator chooses $\hat{k}_1(p_l)$.

- $p^B < p_l \le qp_l + (1-q)\, p_h < p^W \le qp_h + (1-q)\, p_l \le p_h$: Equity requirement 0 has the regulator allow the project if he receives signal s_h, only. Then, expected welfare from the point of view of stage 1 is given by

$$W = \frac{1}{2} \cdot 0 + \frac{1}{2} \left(\left(\frac{1}{2} d\,(R-1) + 1 \right) (R\,(qp_h + (1-q)\, p_l) - 1) \right)$$

Equity regulation $\hat{k}_1(p_l)$ implies stage-1 welfare

$$\begin{aligned} W &= \frac{1}{2} \left(q \cdot 0 + (1-q) \frac{Rp_h - 1}{\hat{k}_1(p_l)} \right) + \frac{1}{2} \left(q \frac{Rp_h - 1}{\hat{k}_1(p_l)} + (1-q) \cdot 0 \right) \\ &= \frac{1}{2} \frac{Rp_h - 1}{\hat{k}_1(p_l)}, \end{aligned}$$

where $\frac{1}{2}$ refers to the probabilities for l or h, respectively. Note that we have to base the capital-requirement decision on a different inequality than in the asymmetric case without signals and with capital requirements, only (section 4.1). The difference is this: In that case, the bank pursues both projects. In the present case, the bank has to submit the project which is allowed in case of signal s_h, only. The choice of capital requirements in this case proves complicated.

- $p^B < p_l < p^W \leq qp_l + (1-q)\, p_h < qp_h + (1-q)\, p_l \leq p_h$: Under capital requirement 0, the regulator allows both projects and obtains the payoff

$$\left(\frac{1}{2}d\,(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right)$$

while capital requirement $\hat{k}_1\,(p_l)$ leads to expected welfare $q\frac{Rp_h-1}{\hat{k}_1(p_l)}$. The choice of capital requirements follows the sixth item in proposition 4.1.

To summarize our results, we further differentiate between $p^W < \frac{p_h+p_l}{2}$ and $p^W > \frac{p_h+p_l}{2}$.

Proposition 5.1. *If the regulator receives a perfect signal about the true probability of success, capital requirements are not necessary and resolution allows to make the bank pursue the project iff it is welfare maximizing. Assume $p^B < p_l < p^W \leq p_h$. In case of an informative but imperfect signal ($\frac{1}{2} \leq q < 1$), the welfare-maximizing capital requirements are given by*

$$\hat{k}^* \begin{cases} = \hat{k}_1\,(p_l)\,, & \text{(i)} \quad p^W > \frac{p_h+p_l}{2} \wedge \frac{1}{2} \leq q < \frac{p^W-p_l}{p_h-p_l} \\ = \hat{k}_1\,(p_l)\,, & \text{(ii)} \quad p^W > \frac{p_h+p_l}{2} \wedge q \geq \frac{p^W-p_l}{p_h-p_l} \wedge p_l \text{ close to } p^B \\ = \hat{k}_1\,(p_l)\,, & \text{(iii)} \quad p^W > \frac{p_h+p_l}{2} \wedge q \geq \frac{p^W-p_l}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge q < \frac{2}{d(R-1)+2} \\ \in \left[0, \hat{k}^{bind}\right], & \text{(iv)} \quad p^W > \frac{p_h+p_l}{2} \wedge q \geq \frac{p^W-p_l}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge \frac{2}{d(R-1)+2} \leq q \leq 1 \\ = \hat{k}_1\,(p_l)\,, & \text{(v)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge p_l \text{ close to } p^B \\ = \hat{k}_1\,(p_l)\,, & \text{(vi)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge q > \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge q < \frac{2}{d(R-1)+2} \\ \in \left[0, \hat{k}^{bind}\right], & \text{(vii)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge q > \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge \frac{2}{d(R-1)+2} \leq q \leq 1 \\ \in \left[0, \hat{k}^{bind}\right], & \text{(viii)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge \frac{1}{2} \leq q \leq \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^W \end{cases}$$

As always, consult the appendix for a proof.

The conditions are not very clear-cut. However, $\hat{k}_1\,(p_l)$ tends to be better than any non-binding capital requirement from $\left[0, \hat{k}^{\text{bind}}\right]$ if

- q is small relative to $\frac{p^W-p_l}{p_h-p_l}$ ((i) versus (iv)),
- q is small relative to $\frac{2}{d(R-1)+2}$ ((iii) and (vi) versus (iv) and (vii)),
- p_l close to p^B ((ii) and (v) versus (iv), (vii), and (viii))

The proposition yields two insights. First of all, the capital requirements do not unambiguously depend on whether or not the average success probability $\frac{p_h+p_l}{2}$ is above or below the threshold p^W critical for the regulator. Second, the regulator may waive the setting of minimum capital requirements and use the bank resolution scheme if the quality of the signal is sufficiently high. In particular, if signal quality is above $\frac{2}{d(R-1)+2}$, capital requirement $\hat{k}_1(p_l)$ tends to be worse than a non-binding capital requirement. The intuitive reason is this: $q < \frac{2}{d(R-1)+2}$ tends to be fulfilled for small d and small R, i.e., if it is difficult for the bank to attract deposits and if the project is not very profitable and welfare-enhancing. In that case, lowering the amount of deposits (a consequence of equity constraint $\hat{k}_1(p_l)$) does not pose major welfare problems. In contrast, if the quality of the signal is relatively low, the capital requirement $\hat{k}_1(p_l)$ is sufficient to let the bank realize the project in case of state of the world h, only, and bank resolution is not needed.

6. Introducing systemic banks

6.1. Basic model with a systemic bank

We return to the basic model, but assume that bank failures cause systemic costs. Systemic costs may result from contagion effects or from herd behavior. They may also arise if bank failure materially disrupts the payments system or the functioning of financial markets. We take these costs not as given but assume that they increase in the size of the bank's balance sheet $(D+E)$,

$$C = (1-p)c(D(r)+E),$$

with $c > 0$. Therefore, welfare is given by

$$\begin{aligned} W(p,r) &= (Rp-1)E + p(R-r)D - (1-p)c(D(r)+E) \\ &\quad + (r-1)D(r) - (1-p)rD(r) \\ &= (Rp-1)(D(r)+E) - (1-p)c(D(r)+E) \\ &= (Rp - [1+(1-p)c])(D(r)+E) \end{aligned}$$

if the project is pursued with rate of interest r, and 0, otherwise.

Proposition 6.1. *After taking systemic costs into account, the bank's optimal behavior is equal to the one specified in proposition 3.1. The regulator's payoff is*

$$W\left(r^B\right) = \left(Rp - [1 + (1-p)\,c]\right)\left(\frac{1}{2}d\,(R-1) + 1\right)$$

From the point of view of welfare maximization, the project should be executed in case of

$$p \geq \frac{1+c}{R+c} =: p^W(c) \;\; \text{or } c \leq \frac{Rp-1}{1-p}$$

Now, there are two negative externalities in the bank's decision. First of all, the bank externalizes part of the risk by letting the deposit insurance pay in case of project failure. For this reason, p^B is smaller than $\frac{1}{R}$ (which is the regulator's threshold without system costs). Second, the bank does not care about the systemic cost. By $\frac{\partial \frac{1+c}{R+c}}{\partial c} > 0$, we find

$$p^B < \frac{1}{R} < \frac{1+c}{R+c}$$

The proof is found in the appendix.

6.2. Capital requirements

Turning to capital requirements, results are the same as for the non-systemic case where the newly defined $p^W(c)$ replaces p^W. However, part 2.c of proposition 3.2 differs:

Proposition 6.2. *In the capital-requirement game with systemic costs, items 1.a through 2.b of proposition 3.2 apply. For parameter constellation $p^B < p < p^W(c)$, any capital requirement $\hat{k}_1 \leq \hat{k} < 1$ (if there is any) makes the bank refrain from the project. We need to distinguish two subcases:*

1. *If $p^B < \frac{1}{R} \leq p < p^W(c)$, we have $\hat{k}_1 \geq 1$ so that even a capital requirement of 1 is not sufficient to thwart the bank's project plan. The optimal capital requirement is 1.*

2. *If $p^B < p < \frac{1}{R} \leq p^W(c)$, we have $\hat{k}_1 < 1$ and the project can be prevented. The optimal capital requirement is $\hat{k}_1$ (or higher).*

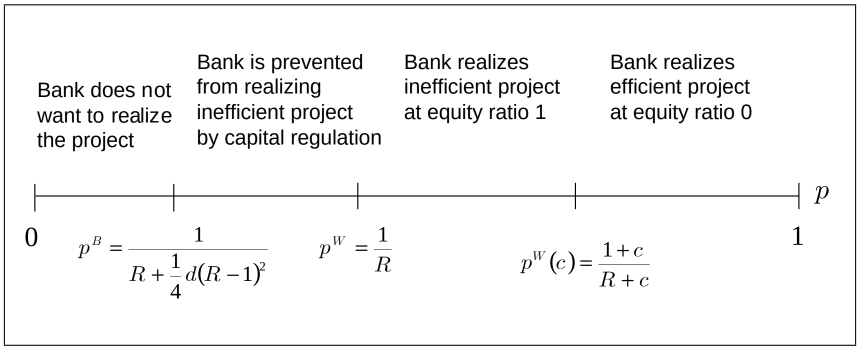

Figure 6.1: Equity regulation may sometimes not be sufficient to prevent an inefficient project.

The proof can be found in the appendix.

The main results of the above proposition are summarized in figure 6.1. According to the proposition, the regulator chooses

$$\hat{k}^* \begin{cases} \in [0,1], & \text{(a)} \quad p \leq p^B \\ = 0, & \text{(b)} \quad p \geq p^W(c) > p^B \\ = 1, & \text{(c)} \quad p^B < \frac{1}{R} \leq p < p^W(c) \\ \in \left[\hat{k}_1, 1\right], & \text{(d)} \quad p^B < p < \frac{1}{R} \leq p^W(c) \end{cases}$$

and cannot always prevent a negative payoff:

$$W\left(\hat{k}^*\right) = \begin{cases} 0, & \text{(a)} \quad p \leq p^B \\ (Rp - [1 + (1-p)c])\left(\frac{1}{2}d(R-1)+1\right) \geq 0, & \text{(b)} \quad p \geq p^W(c) > p^B \\ (Rp - [1 + (1-p)c]) \cdot 1 < 0, & \text{(c)} \quad p^B < \frac{1}{R} \leq p < p^W(c) \\ 0 & \text{(d)} \quad p^B < p < \frac{1}{R} \leq p^W(c) \end{cases}$$

In case of (c), which corresponds to the first sub-case of the above proposition, welfare is negative, but the capital ratio of 1 disallows any deposits to be used in the project.

6.3. Resolution

Proposition 3.4 applies with the systemic model, also. In contrast to the model without systemic costs, capital regulation and resolution do not, in general, lead to the same projects and payoffs. Using (a) through (d) from the previous subsection (see $\hat{k}^*$ and $W\left(\hat{k}^*\right)$, respectively), capital regulation and resolution yield the same results under (a), (b), and (d). However, under (c), supervision is better because the project can be disallowed preventing a negative payoff.

7. Conclusions

In this paper we have analyzed the incentive effects of minimum capital requirements and special bank resolution schemes that allow authorities to take control over a bank at an early stage of its financial difficulties without prior agreement of shareholders. We asked how special resolution schemes influence banks' risk taking incentives and whether regulators should substitute bank-closure policies by minimum capital requirements.

We argue, firstly, that minimum capital requirements and bank closure policies influence banks' risk-taking behavior through different channels: When setting minimum capital requirements, regulators use the bank's information about the project and, at the same time, deleverage the bank's project. Bank-closure policies neither use the bank's information nor influence the size of the bank if allowed open.

Secondly, we find that capital requirements are better from a welfare point of view if the quality of the information gathered by the regulator is relatively bad, if the bank has difficulties to attract deposits and / or if the bank project's rate of return is low.

Binding capital requirements always limit deposits and hence the risk taken by a bank. However, in the presence of systemic costs, we finally find that even a 100 per cent capital requirement may not be sufficient to abolish excessive bank risk-taking behavior. Then, the regulator should also have the right to close-down a bank if, through supervision, he receives a signal that the bank's project is too risky.

Our results build upon a number of assumptions, and it may be worthwhile to check how critical they are. Firstly, we have assumed that neither bank supervision nor bank resolution is costly for the regulator. Introducing such costs would tilt the balance against special resolution schemes. Secondly, we presumed that the bank never violates the minimum capital requirement set by the regulator; the role of supervision is limited to find out the bank's probability of success, but not controlling the bank's adhering to capital requirements. This assumption seems to be justified by the fact that, at least in the European Union, most banks hold a regulatory capital buffer, i.e., capital in excess of regulatory requirements. Thirdly, bank resolution in our model means liquidating the bank under consideration and not maintaining the entity as a going concern. We have further assumed that authorities resolve a troubled bank before the project is realized and that the bank's liquidation value does not differ from the bank's equity capital. Therefore, the bank can effectively be liquidated without any losses falling on shareholder, and neither tax payers nor the deposit insurance bear any costs of bank bailout. Dropping this assumption would shift the balance against bank resolution schemes. Finally, we assumed that a single regulator is responsible for both setting minimum capital requirements and for supervising and eventually liquidating a troubled bank. We thus neglected possible conflicts of interest, which could arise if several authorities with diverging mandates decide independently about bank regulation tools.

Our model allows for a number of policy conclusions. Firstly, with respect to non-systemic banks, bank resolution schemes and minimum capital requirements are substitutes. If one takes the quality of the regulator's signal as an indicator for the quality of supervision, countries where bank supervision is sufficiently good could try doing without minimum capital requirements. Note, however, that our model uses a representative bank. Yet, heterogeneity of banks together with uniform minimum capital requirements may well provide arguments for also using both instruments. Secondly, capital requirements might not be sufficient to prevent systemic banks from pursuing projects which are too risky from a social point of view; in this case, capital requirements should be supplemented with bank resolution schemes. Note that our model and our arguments are agnostic with respect to the very important questions of (i) whether banks should be declared systemic or not and (ii) which criteria should be used to decide which banks are to be considered as systemic.

As already mentioned in the introduction, we did not discuss potential merits of an international harmonization of special resolution schemes across banks. Such a harmonization may be in order if banks are internationally active and supply banking services globally. In that case, a SIFI's incentive to invest into a risky project might be underestimated by a regulator who only cares about national welfare and ignores social welfare in other countries where the bank does business as well.

8. References

Acharya, V.V. (2003), Is the International Convergence of Capital Adequacy Regulation Desirable?, Journal of Finance, Vol. 58(6), 2745-2781.

Aggarwal, R., Jacques, K.T. (2001), The Impact of FDICIA and Prompt Corrective Action on Bank Capital and Risk: Estimates Using a Simultaneous, *Journal of Banking & Finance*, Vol. 25, Issue 6, 1139-1160.

Aghion, P., Bolton, P. (1992), An Imcomplete Contract Approach to Financial Contracting, *Review of Economic Studies*, Vol. 59, 473-494.

Basel Committee on Banking Supervision (2010), *Report and Recommendations of the Cross-border Bank Resolution Group*, March, http://www.bis.org/publ/bcbs169.pdf.

Čihak, M., Nier, E. (2010), The Need for Special Resolution Regimes for Financial Institutions - The Case of the European Union, *IMF Working Paper*, WP /09/200, Washington.

Davies, S. M., McManus, D. A. (1991), The Effects of Closure Policies on Bank Risk-taking, *Journal of Banking & Finance*, Vol. 15, 917-938.

Dell'Ariccia, G., Marquez, R. (2006), Competition among Regulators and Credit Market Integration, *Journal of Financial Economics*, Vol. 79, 401-430.

Deutsche Bundesbank (2011), Fundamental Features of the German Bank Restructuring Act, *Monthly Bulletin*, Vol 63(6), 59-75.

Dewatripont, M. Tirole, J. (1993), Efficient Government Structure: Implication for Banking Regulation, in: Mayer, C.; Vives, X., eds., *Capital Markets and Financial Intermediation*, Cambridge: Cambridge University Press.

Dewatripont, M. Tirole, J. (1994), *The Prudential Regulation of Banks*, Cambridge, London.

Dewatripont, M., Rochet, J.-C., Tirole, J. (2010), *Balancing the Banks. Global Lessons from the Financial Crisis*, Princeton, Oxford: Princeton University Press.

European Commission (2010), *DG Internal Market and Services Working Document, Technical Details of a possible EU Framework for Bank Recovery and Resolution*, http://ec.europa.eu/internal_market/consultations/docs/2011/crisis_ management/consultation_paper_en.pdf.

Financial Stability Board (2010), *Reducing the Moral Hazard Posed by Systemically Important Financial Institutions – FSB Recommendations and Time Lines*, October, http://www.financialstabilityboard.org/publications/r_101111a.pdf.

Freixas, X., Parigi, B. (2007), Bank Regulation and Prompt Corrective Action, *CESifo* WP 2136, Munich.

Freixas, X., Gabillon, E. (1999), Optimal Regulation of a Fully Insured Deposit Banking System, *Journal of Regulatory Economics*, Vol. 16(2), 111-134.

Freixas, J.-C., Rochet, J.-C (2008), *Microeconomics of Banking*, 2. ed., Cambridge, London.

Furlong, F. T., Keeley, M. C. (1989), Capital Regulation and Bank Risk-taking: A Note, *Journal of Banking and Finance*, Vol. 13 (6), 883–891.

Gennotte, G., Pyle, D. (1991), Capital Controls and Bank Risk, *Journal of Banking & Finance*, Vol. 15, 805-824.

Giammarino, R. M., Lewis, T.R., Sappington, D. (1993), An Incentive Approach to Banking Regulation, *Journal of Finance*, Vol. 48, 1523-1542.

Hart, O. D., Jaffee, D. M. (1974), On the Application of Portfolio Theory on Depository Financial Institutions, *Review of Economic Studies*, 41, 129-147.

Holthausen, C., Ronde, T. (2004), Cooperation in International Banking Supervision, European Central Bank, Working Paper Series, No. 316, Frankfurt.

Jacques, K.T., Aggarwal, R. (1998), Assessing the Impact of Prompt Corrective Action on Bank Capital and Risk, Federal Reserve Bank of New York, *Economic Policy Review*, Vol. 4.3, 23-32.

Kahane, Y. (1977), Capital Adequacy and the Regulation of Financial Intermediaries, *Journal of Banking and Finance*, Vol 1(2), 207–218.

Kahn, C. M., Santos, J. A. C. (2005), Allocating Bank Regulatory Powers: Lender of Last Resort, Deposit Insurance and Supervision, *European Economic Review*, Vol. 49, 2107-2136.

Kahn, C. M., Santos, J. A. C. (2006), Who Should Act as Lender of Last Resort? An Incomplete Contracts Model: A Comment, *Journal of Money, Credit, & Banking*, Vol. 38, 1111-1118.

Keeley, M. C., Furlong, F. T. (1990), A Reexamination of the Mean-Variance Analysis of Bank Capital Regulation, *Journal of Banking and Finance*, Vol. 14, 69-84.

Kim, D., Santomero, A. M. (1988), Risk in Banking and Capital Regulation, *Journal of Finance*, Vol. 43(5), 1219–1233.

Kocherlakota, N.R., Shim, I, (2005), Forbearance and Prompt Corrective Action, *Journal of Money, Credit, & Banking*, Vol. 39(5), 1107-1129.

Koehn, M., Santomero, A.M. (1980), Regulation of Bank Capital and Portfolio Risk, *Journal of Finance,* Vol. 35 (5), 1235–1244.

Nakaso, H. (2001), The Financial Crisis in Japan During the 1990s: How the Bank of Japan Responded and the Lessons Learnt. BIS Papers No. 6, Basel, October.

Nier, E., Baumann, U. (2006), Market Discipline, Disclosure and Moral Hazard in Banking, *Journal of Financial Intermediation*, Vol. 15, 333-362.

Repullo, R. (2000), Who Should Act as a Lender of Last Resort? An Incomplete Contracts Model, *Journal of Money, Credit, and Banking,* Vol. 32, 580-605.

Rochet, J.-Ch. (1992), Capital Requirements and the Behavior of Commercial Banks, *European Economic Review*, Vol. 36, 1137-1170.

Shim, I. (2006), Dynamic Prudential Regulation: Is Prompt Corrective Action Optimal?, Bank for International Settlements, *Working Paper* No 206, Basel May 2006.

Tirole, J. (1994), On Banking and Intermediation, *European Economic Review*, Vol. 38 (3-4), 469-487.

Weinstock, P. (2009), Prompt Corrective Action, *The Banking Law Review*, 317-324.

9. Appendix

A. Proof of proposition 3.1

Forming the first and second derivatives of the bank's profit function with respect to r, we find

$$\begin{aligned}\frac{\partial \Pi}{\partial r} &= dp\,(R+1-2r)\\ \frac{\partial^2 \Pi}{(\partial r)^2} &= -2dp < 0,\end{aligned}$$

so that the profit function is strictly concave. If (!) the bank pursues the project, the optimal interest rate is $r^B = \frac{1}{2}(R+1)$ where $r^B > 1$ is true by $R > 1$. The bank will pursue the project iff

$$\Pi\left(r^B\right) = \frac{1}{4}\left(4Rp + dp + R^2dp - 2Rdp - 4\right) > 0$$

or

$$p > \frac{1}{R + \frac{1}{4}d\,(R-1)^2} =: p^B$$

holds.

B. Proof of proposition 3.2

Part 2.a of the proposition is obvious. Part 2.b holds because the regulator with welfare function $W(p,r) = (Rp-1)(d(r-1)+1)$ benefits from as high an interest rate as possible in case of $p \geq p^W$.

Turning to 1.a and 1.b, we assume $p > p^B$ and want to show that $\hat{k} < \min\left(\hat{k}_1, 1\right)$ leads to a positive profit if the project is to be pursued. Also, it is assumed, that the capital ratio is binding and, therefore, the associated rate of return $\hat{r}$ has to be bindung, $\hat{r} < r^B$. By the concavity of the profit function, the bank's profit unter the restriction of $\hat{k}$ is maximized at $\hat{r}$.

Thus, we need to find the condition for $\Pi(\hat{r}) > 0$. By equation 3.2, this inequality is equivalent to

$$-p + 2p\hat{k} - d\hat{k}^2 - p\hat{k}^2 - dp\hat{k} + dp\hat{k}^2 + Rdp\hat{k} > 0$$

or

$$\hat{k}^2 - \frac{p(-d + Rd + 2)}{d(1-p)+p}\hat{k} + \frac{p}{d(1-p)+p} < 0. \tag{B.1}$$

Solving the corresponding equality yields

$$\hat{k}_{1,2} = \frac{p(d(R-1)+2)}{2(d(1-p)+p)} \pm \sqrt{dp\frac{p\left(R + \frac{1}{4}d(R-1)^2\right) - 1}{(d(1-p)+p)^2}}.$$

The expression below the root is positive by $p > p^B$ so that we have $\hat{k}_{1,2} \in \mathbb{R}$. $p > p^B$ also implies

$$0 \underset{(i)}{<} \hat{k}_2 \underset{(ii)}{<} \hat{k}^{\text{bind}} \underset{(iii)}{<} \hat{k}_1$$

the proofs of which are postponed for a while.

These inequalities imply that $\hat{k}_2$ is irrelevant because it is not binding. The proof of 1.a and 1.b now simply rests on the fact that the parabola specified by B.1 opens upward. 2.c is also obvious together with the observation

$$\hat{k}_1 \underset{(iv)}{<} 1$$

in case of $p^B < p < p^W$.

We now turn to the proofs of the four inequalities. We proceed by contradiction.

(i) Assume $\hat{k}_2 \leq 0$. We then have

$$\frac{p\left(-d+Rd+2\right)}{2\left(d\left(1-p\right)+p\right)} \leq \sqrt{dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2}}.$$

Since both sides are positive, we can square both expressions and find the inequality

$$\begin{aligned} 0 &\geq \left(\frac{p\left(-d+Rd+2\right)}{2\left(d\left(1-p\right)+p\right)}\right)^2 - dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2} \\ &= \frac{p}{d\left(1-p\right)+p} \end{aligned}$$

which is false by $d > 0$ and $p > 0$.

(ii) We assume $\frac{2}{d(R-1)+2} = \hat{k}^{\text{bind}} \leq \hat{k}_2$ which can be rewritten as

$$\begin{aligned} & -2d\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)\left(d\left(R-1\right)+2\right)} \\ = & \frac{2}{d\left(R-1\right)+2} - \frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)} \leq -\sqrt{\frac{1}{4}dp\frac{p\left(4R+d\left(R-1\right)^2\right)-4}{\left(d\left(1-p\right)+p\right)^2}} \end{aligned}$$

The left-hand side is negative by $p > p^B$. Multiplying with -1, squaring and simplifying yields

$$\begin{aligned} 0 &\leq \left(-\frac{2}{d\left(R-1\right)+2} + \frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)}\right)^2 - \frac{1}{4}dp\frac{p\left(4R+d\left(R-1\right)^2\right)-4}{\left(d\left(1-p\right)+p\right)^2} \\ &= -\frac{4d}{\left(p+d\left(1-p\right)\right)\left(d\left(R-1\right)+2\right)^2}\left(p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1\right) \end{aligned}$$

which is false, again by $p > p^B$.

(iii) The inequality $\frac{2}{d(R-1)+2} = \hat{k}^{\text{bind}} \geq \hat{k}_1$ amounts to the contradiction

$$\begin{aligned} 0 &\geq -2d\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(R-1\right)+2\right)\left(d\left(1-p\right)+p\right)} \\ &= \frac{2}{d\left(R-1\right)+2} - \frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)} \geq \sqrt{\frac{1}{4}dp\frac{p\left(4R+d\left(R-1\right)^2\right)-4}{\left(d\left(1-p\right)+p\right)^2}}, \end{aligned}$$

once again by $p > p^B$.

(iv) Finally, let us assume $\hat{k}_1 \geq 1$. We then have

$$\begin{aligned}
\sqrt{dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2}} &\geq 1-\frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)} \\
&= \frac{1}{2}d\frac{p+Rp-2}{-d-p+dp}.
\end{aligned}$$

If the right-hand side is positive, we get

$$dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2} \geq \left(\frac{1}{2}d\frac{p+Rp-2}{-d-p+dp}\right)^2$$

and hence $d\frac{Rp-1}{d(1-p)+p} \geq 0$ which is equivalent to $p \geq \frac{1}{R}$ contradicting the assumption $p^B < p < p^W$.

If the right-hand side is negative, we obtain $p > \frac{2}{R+1}$. By $\frac{2}{R+1} > \frac{1}{R}$, we again get the desired contradiction.

C. Proof of lemma 3.3

Differentiating the first summand of $\hat{k}_1$ with respect to p yields

$$\frac{\partial\left(\frac{p(d(R-1)+2)}{2(d(1-p)+p)}\right)}{\partial p} = \frac{1}{2}d\frac{\left(d\left(R-1\right)+2\right)}{\left(d\left(1-p\right)+p\right)^2} > 0.$$

For the second summand (without the root), we find

$$\frac{\partial\left(dp\frac{p\left(R+\frac{1}{4}d(R-1)^2\right)-1}{(d(1-p)+p)^2}\right)}{\partial p} = \frac{1}{2}d\frac{p\left(d\left[4R-2+d\left(R-1\right)^2\right]+2\right)-2d}{\left(d\left(1-p\right)+p\right)^3}$$

which is also positive by

$$\begin{aligned}
& p\left(d\left[4R-2+d\left(R-1\right)^2\right]+2\right)-2d \\
> \;& p^B\left(d\left[4R-2+d\left(R-1\right)^2\right]+2\right)-2d \\
= \;& 2\frac{\left(d\left(R-1\right)+2\right)^2}{4R+d\left(R-1\right)^2} \\
> \;& 0.
\end{aligned}$$

D. Proof of proposition 4.1

From the main text, it is clear that discriminating is best for

$$\frac{1}{2} \cdot \frac{Rp_h - 1}{\hat{k}_1(p_l)} > \left(\frac{1}{2} d(R-1) + 1\right)\left(R\frac{p_l + p_h}{2} - 1\right)$$

which can be rewritten as

$$\begin{aligned} & \frac{p_l(d(R-1)+2)}{2(d(1-p_l)+p_l)} + \sqrt{dp_l \frac{p_l\left(R + \frac{1}{4}d(R-1)^2\right) - 1}{(d(1-p_l)+p_l)^2}} \\ = \quad & \hat{k}_1(p_l) \begin{cases} < \frac{Rp_h - 1}{(d(R-1)+2)\left(R\frac{p_l+p_h}{2} - 1\right)} & \text{and } R\frac{p_l+p_h}{2} - 1 > 0 \text{ or} \\ > \frac{Rp_h - 1}{(d(R-1)+2)\left(R\frac{p_l+p_h}{2} - 1\right)} & \text{and } R\frac{p_l+p_h}{2} - 1 < 0 \end{cases} \end{aligned}$$

For $p_l := p^B$, this inequalities amount to

$$\hat{k}_1\left(p^B\right) = \frac{2}{d(R-1)+2} \begin{cases} < \frac{Rp_h - 1}{(d(R-1)+2)\left(R\frac{p^B+p_h}{2} - 1\right)} & \text{and } R\frac{p^B+p_h}{2} - 1 > 0 \text{ or} \\ > \frac{Rp_h - 1}{(d(R-1)+2)\left(R\frac{p^B+p_h}{2} - 1\right)} & \text{and } R\frac{p^B+p_h}{2} - 1 < 0 \end{cases} \tag{D.1}$$

or

$$\begin{aligned} & \frac{2}{d(R-1)+2} - \frac{Rp_h - 1}{(d(R-1)+2)\left(R\frac{p^B+p_h}{2} - 1\right)} \\ = \quad & \frac{Rp^B - 1}{(d(R-1)+2)\left(R\frac{p^B+p_h}{2} - 1\right)} < 0 \text{ and } R\frac{p^B + p_h}{2} - 1 > 0 \text{ or} \\ & \frac{2}{d(R-1)+2} - \frac{Rp_h - 1}{(d(R-1)+2)\left(R\frac{p^B+p_h}{2} - 1\right)} \\ = \quad & \frac{Rp^B - 1}{(d(R-1)+2)\left(R\frac{p^B+p_h}{2} - 1\right)} > 0 \text{ and } R\frac{p^B + p_h}{2} - 1 < 0 \end{aligned}$$

or

$$\begin{aligned} R &< \frac{1}{p^B} \text{ and } R\frac{p^B + p_h}{2} - 1 > 0 \text{ or} \\ R &< \frac{1}{p^B} \text{ and } R\frac{p^B + p_h}{2} - 1 < 0 \end{aligned}$$

or

$$R<\frac{1}{p^B}$$

which is always fulfilled by $p^B<p^W$. From the continuity of the terms involved, we can conclude that the regulator chooses $\hat{k}_1(p_l)$ for sufficiently low p_l (close to p^B).

For $p_l:=p^W$, the inequalities in D.1 lead to

$$\hat{k}_1\left(p^W\right)=1\begin{cases}<\frac{Rp_h-1}{(d(R-1)+2)\left(R\frac{\frac{1}{R}+p_h}{2}-1\right)}=\frac{2}{d(R-1)+2} \text{ and } R>\frac{1}{p_h} \text{ or}\\ >\frac{2}{d(R-1)+2} \text{ and } R<\frac{1}{p_h}\end{cases}$$

where, by $\frac{1}{R}=p^W\leq p_h$, the second case is excluded and, turning to the first case, the contradiction $1<\frac{2}{d(R-1)+2}<1$ follows from $d(R-1)>0$. Thus, for $p_l=p^W$, discriminating is not best and hence any non-binding capital ratio is optimal "near" p^W.

We now show the existence of a p_l^{MC} that separates the p^B and the p^W regions. We employ a proof by contradiction. Assume $p^B<p_l<p_l+\varepsilon<p^W\leq p_h$ such that capital requirement $\hat{k}_1(p_l)$ is best for $p_l+\varepsilon$ while 0 is best for p_l. Then, we find

$$\begin{aligned}\frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l+\varepsilon)} &> \left(\frac{1}{2}d(R-1)+1\right)\left(R\frac{p_l+\varepsilon+p_h}{2}-1\right) \text{ and}\\ \frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l)} &\leq \left(\frac{1}{2}d(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right)\end{aligned}$$

and hence

$$\begin{aligned}\frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l+\varepsilon)} &> \left(\frac{1}{2}d(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right)+\left(\frac{1}{2}d(R-1)+1\right)R\frac{\varepsilon}{2}\\ &> \left(\frac{1}{2}d(R-1)+1\right)\left(R\frac{p_l+p_h}{2}-1\right)\\ &\geq \frac{1}{2}\cdot\frac{Rp_h-1}{\hat{k}_1(p_l)}\end{aligned}$$

and

$$p^W<p_h \text{ and } \hat{k}_1(p_l+\varepsilon)<\hat{k}_1(p_l)$$

However, $\hat{k}_1(p_l+\varepsilon)<\hat{k}_1(p_l)$ is the desired contradiction to lemma B.1.

E. Proof of proposition 5.1

As in the main text, we consider three subcases of case $p^B < p_l < p^W \leq p_h$, but add some mathematical detail:

(A) $p^B < p_l \leq qp_l + (1-q)\,p_h \leq qp_h + (1-q)\,p_l < p^W \leq p_h$ (which holds for $\frac{1}{2} \leq q < \frac{p^W - p_l}{p_h - p_l}$; this q-interval is non-empty interval by $p^W > \frac{1}{2}(p_h + p_l)$): As argued in the main text, the regulator chooses $\hat{k}_1(p_l)$.

(B) $p^B < p_l \leq qp_l + (1-q)\,p_h < p^W \leq qp_h + (1-q)\,p_l \leq p_h$ (which holds for $q > \frac{p_h - p^W}{p_h - p_l}$ and $p^W \leq \frac{p_h + p_l}{2}$ (in which case $p_h - p^W \geq p^W - p_l$ and $\frac{1}{2} \leq \frac{p_h - p^W}{p_h - p_l}$) or $q \geq \frac{p^W - p_l}{p_h - p_l}$ and $p^W > \frac{p_h + p_l}{2}$ (in which case $p_h - p^W < p^W - p_l$ and $\frac{1}{2} < \frac{p^W - p_l}{p_h - p_l}$)): Using the welfare functions specified in the main text, it is clear that $\hat{k}_1(p_l)$ is best for

$$\frac{Rp_h - 1}{\hat{k}_1(p_l)} > \left(\frac{1}{2}d(R-1) + 1\right)(R(qp_h + (1-q)\,p_l) - 1)\,.$$

By $p^W \leq qp_h + (1-q)\,p_l$, this can be rewritten as

$$\begin{aligned} & \frac{p_l(d(R-1)+2)}{2(d(1-p_l)+p_l)} + \sqrt{dp_l \frac{p_l\left(R + \frac{1}{4}d(R-1)^2\right) - 1}{(d(1-p_l)+p_l)^2}} \\ = \quad & \hat{k}_1(p_l) < \frac{Rp_h - 1}{\left(\frac{1}{2}d(R-1)+1\right)(R(qp_h + (1-q)\,p_l) - 1)} \end{aligned}$$

For $p_l := p^B$, this inequality can be simplified. We find

$$\hat{k}_1\left(p^B\right) = \frac{1}{\frac{1}{2}d(R-1)+1} < \frac{Rp_h - 1}{\left(\frac{1}{2}d(R-1)+1\right)(R(qp_h + (1-q)\,p^B) - 1)}$$

or

$$\begin{aligned} & \frac{1}{\frac{1}{2}d(R-1)+1} - \frac{Rp_h - 1}{\left(\frac{1}{2}d(R-1)+1\right)(R(qp_h + (1-q)\,p^B) - 1)} \\ = \quad & \frac{1}{\frac{1}{2}d(R-1)+1}\left(1 - \frac{Rp_h - 1}{(R(qp_h + (1-q)\,p^B) - 1)}\right) < 0 \end{aligned}$$

or

$$Rp_h - 1 > R\left(qp_h + (1-q)\,p^B\right) - 1$$

or

$$R(1-q)\left(p_h - p^B\right) > 0$$

or

$$q < 1.$$

From the continuity of the terms involved, we can conclude that the regulator who observes an imperfect signal chooses $\hat{k}_1(p_l)$ for sufficiently low p_l (close to p^B).

For $p_l := p^W$, we obtain the inequality

$$\begin{aligned}
\hat{k}_1\left(p^W\right) &= 1 < \frac{Rp_h - 1}{\left(\frac{1}{2}d(R-1)+1\right)\left(R\left(qp_h + (1-q)\frac{1}{R}\right)-1\right)} \\
&= \frac{2}{q\left(d(R-1)+2\right)}
\end{aligned}$$

or

$$\begin{aligned}
q &< \frac{2}{d(R-1)+2} \\
\frac{2}{d(R-1)+2} &< \frac{1}{2} \Leftrightarrow \\
2 &< d(R-1)
\end{aligned}$$

Thus, $\hat{k}_1(p_l)$ is best for p_l "near" p^W if the signal quality is below the threshold $q < \frac{2}{d(R-1)+2}$. This threshold obeys $\frac{2}{d(R-1)+2} > \frac{1}{2}$ iff $2 < d(R-1)$ holds. Above this treshold, i.e., for $\frac{2}{d(R-1)+2} \leq q \leq 1$, capital requirement 0 is best for sufficiently high p_l.

The proof of the existence of a p_l^{MC} separating the p^B and the p^W regions follows the corresponding proof for proposition 4.1 quite closely.

(C) $p^B < p_l < p^W \leq qp_l + (1-q)p_h < qp_h + (1-q)p_l \leq p_h$ (which holds for $\frac{1}{2} \leq q \leq \frac{p_h - p^W}{p_h - p_l}$ which describes a non-empty interval by $p^W \leq \frac{1}{2}(p_h + p_l)$): Under capital requirement 0, the regulator allows both projects and obtains the payoff

$$\left(\frac{1}{2}d(R-1)+1\right)\left(R\left(qp_h + (1-q)p_l\right)-1\right).$$

which is smaller than $q\frac{Rp_h-1}{\hat{k}_1(p_l)}$ for sufficiently low p_l (close to p^B) and larger for sufficiently large p_l (close to p^W) as we now show: $\hat{k}_1(p_l)$ is better than 0 for

$$q\frac{Rp_h-1}{\hat{k}_1(p_l)} > \left(\frac{1}{2}d(R-1)+1\right)(R(qp_h+(1-q)p_l)-1).$$

By $p^W \leq qp_h+(1-q)p_l$, this can be rewritten as

$$\begin{aligned} & \frac{p_l(d(R-1)+2)}{2(d(1-p_l)+p_l)}+\sqrt{dp_l\frac{p_l\left(R+\frac{1}{4}d(R-1)^2\right)-1}{(d(1-p_l)+p_l)^2}} \\ = \quad & \hat{k}_1(p_l) < \frac{q(Rp_h-1)}{\left(\frac{1}{2}d(R-1)+1\right)(R(qp_h+(1-q)p_l)-1)} \end{aligned}$$

For $p_l := p^B$, this inequality can be simplified. We find

$$\hat{k}_1\left(p^B\right)=\frac{2}{d(R-1)+2} < \frac{q(Rp_h-1)}{\left(\frac{1}{2}d(R-1)+1\right)(R(qp_h+(1-q)p^B)-1)}$$

or

$$\begin{aligned} & \frac{2}{d(R-1)+2}-\frac{q(Rp_h-1)}{\left(\frac{1}{2}d(R-1)+1\right)(R(qp_h+(1-q)p^B)-1)} \\ = \quad & \frac{2}{d(R-1)+2}\left(1-\frac{q(Rp_h-1)}{(R(qp_h+(1-q)p^B)-1)}\right)<0 \end{aligned}$$

or

$$q(Rp_h-1) > R\left(qp_h+(1-q)p^B\right)-1$$

or

$$\left(Rp^B-1\right)(1-q)<0$$

or

$$q<1 \text{ and } p^B<p^W.$$

From the continuity of the terms involved, we can conclude that the regulator who observes an imperfect signal chooses $\hat{k}_1(p_l)$ for sufficiently low p_l (close to p^B).

For $p_l := p^W$, we obtain the contradiction

$$\begin{aligned}
\hat{k}_1\left(p^W\right) &= 1 < \frac{q\left(Rp_h - 1\right)}{\left(\frac{1}{2}d\left(R-1\right)+1\right)\left(R\left(qp_h + \left(1-q\right)\frac{1}{R}\right)-1\right)} \\
&= \frac{2}{d\left(R-1\right)+2} < 1.
\end{aligned}$$

Thus, for $p_l = p^W$, discriminating is not best and hence any non-binding capital ratio is optimal "near" p^W.

Again, following the proof of proposition 4.1, the two regions can be separated.

To summarize our results, we further differentiate between $p^W < \frac{p_h+p_l}{2}$ (which is equivalent to $\frac{p^W-p_l}{p_h-p_l} < \frac{p_h-p^W}{p_h-p_l}$ so that the first subcase is empty) and $p^W > \frac{p_h+p_l}{2}$ (which is equivalent to $\frac{p^W-p_l}{p_h-p_l} > \frac{p_h-p^W}{p_h-p_l}$ so that the third case is empty). We arrive at the following table where (A), (B) and (C) refer to the three cases above:

$$\hat{k}^* \begin{cases}
= \hat{k}_1\left(p_l\right), & \text{(i), (A)} \quad p^W > \frac{p_h+p_l}{2} \wedge \frac{1}{2} \leq q < \frac{p^W-p_l}{p_h-p_l} \\
= \hat{k}_1\left(p_l\right), & \text{(v'), (B)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge q > \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^B \\
= \hat{k}_1\left(p_l\right), & \text{(vi), (B)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge q > \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge q < \frac{2}{d(R-1)+2} \\
\in \left[0, \hat{k}^{\text{bind}}\right], & \text{(vii), (B)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge q > \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge \frac{2}{d(R-1)+2} \leq q \leq 1 \\
= \hat{k}_1\left(p_l\right), & \text{(ii), (B)} \quad p^W > \frac{p_h+p_l}{2} \wedge q \geq \frac{p^W-p_l}{p_h-p_l} \wedge p_l \text{ close to } p^B \\
= \hat{k}_1\left(p_l\right), & \text{(iii), (B)} \quad p^W > \frac{p_h+p_l}{2} \wedge q \geq \frac{p^W-p_l}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge q < \frac{2}{d(R-1)+2} \\
\in \left[0, \hat{k}^{\text{bind}}\right], & \text{(iv), (B)} \quad p^W > \frac{p_h+p_l}{2} \wedge q \geq \frac{p^W-p_l}{p_h-p_l} \wedge p_l \text{ close to } p^W \wedge \frac{2}{d(R-1)+2} \leq q \leq 1 \\
\in \left[0, \hat{k}^{\text{bind}}\right], & \text{(viii), (C)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge \frac{1}{2} \leq q \leq \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^W \\
= \hat{k}_1\left(p_l\right), & \text{(v"), (C)} \quad p^W \leq \frac{p_h+p_l}{2} \wedge \frac{1}{2} \leq q \leq \frac{p_h-p^W}{p_h-p_l} \wedge p_l \text{ close to } p^B
\end{cases}$$

where the conditions on p_l

- in subcase (v') versus subcases (vi) and (vii),
- in subcase (ii) versus subcases (iii) and (iv), and
- in subcase (viii) versus subcase (v")

allow separating p_l^{MC}s as in proposition 4.1. We can rearrange this table so that we obtain the one shown in the preposition.

F. Proof of proposition 6.2

In the proof of proposition 3.2, we have shown

$$0 \underset{(i)}{<} \hat{k}_2 \underset{(ii)}{<} \hat{k}^{\mathrm{bind}} \underset{(iii)}{<} \hat{k}_1$$

the proofs of which are postponed for a while. Assuming $p \geq p^B$, we now add $\hat{k}_1 \geq 1 \Leftrightarrow p \geq \frac{1}{R}$. Indeed, $\hat{k}_1 \geq 1$ is equlivalent to

$$\begin{aligned}
\sqrt{dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2}} &\geq 1-\frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)} \\
&= -\frac{1}{2}d\frac{p\left(R+1\right)-2}{d\left(1-p\right)+p}.
\end{aligned}$$

If the right-hand side is positive, squaring yields

$$dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2} \geq \left(\frac{1}{2}d\frac{p+Rp-2}{-d-p+dp}\right)^2$$

and hence $d\frac{Rp-1}{d(1-p)+p} \geq 0$ which is equivalent to $p \geq \frac{1}{R}$.

If the right-hand side is negative, we obtain $p > \frac{2}{R+1} > \frac{1}{R}$.

Inversely, $p \geq \frac{1}{R}$ implies $d\frac{Rp-1}{d(1-p)+p} > 0$ and hence

$$\begin{aligned}
dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2} &> \left(\frac{1}{2}d\frac{p+Rp-2}{-d-p+dp}\right)^2 \\
&= \left(1-\frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)}\right)^2
\end{aligned}$$

The term in brackets $1-\frac{p(d(R-1)+2)}{2(d(1-p)+p)}$ can be negative or positive. If $1-\frac{p(d(R-1)+2)}{2(d(1-p)+p)} \geq 0$ holds, we have

$$\sqrt{dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^2\right)-1}{\left(d\left(1-p\right)+p\right)^2}} > 1-\frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)},$$

i.e., $\hat{k}_1 > 1$. If it is strictly negative, we obtain

$$p > \frac{2}{R+1} > \frac{1}{R}.$$

In that case, we obtain

$$\begin{aligned}\sqrt{dp\frac{p\left(R+\frac{1}{4}d\left(R-1\right)^{2}\right)-1}{\left(d\left(1-p\right)+p\right)^{2}}} &> \frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)}-1\\ &> 1-\frac{p\left(d\left(R-1\right)+2\right)}{2\left(d\left(1-p\right)+p\right)}\end{aligned}$$

and hence, again, $\hat{k}_1 > 1$.

Now, note that $\hat{k}_1 > 1$ implies that $\hat{k} = 1$ fulfills B.1. Thus, in the first subcase, the bank will pursue the project for any capital ratio and, in the presence of $(Rp - [1 + (1-p)\,c]) < 0$, the optimal capital ratio is 1.