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Regulation, Supervision, and Bank Risk-Taking

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Abstract

This paper presents a model of the interaction between a bank and a supervisor. The bank privately chooses the risk of its investment portfolio and the supervisor collects nonverifiable information on the future solvency of the bank and, based on of this information, may decide on its early liquidation. The paper characterizes the liquidation decision of the supervisor and the risk-taking decision of the bank. In line with recent empirical literature, the paper shows that supervision is effective in ameliorating the bank's risk-shifting incentives, and that a tougher supervisor leads to lower risk-taking. It also shows that higher noise in the supervisory information may be conducive to lower risk-taking, but that it always reduces welfare.

JEL Codes: G21, G28, D02.

Keywords: Bank risk-taking, bank supervision, bank regulation, capital requirements, deposit insurance, bank resolution, bank liquidation.

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1 Introduction

Bank supervision, unlike bank regulation, has not been until recently the subject of much academic interest. As stated by Eisenbach et al. (2016), regulation involves the establishment of rules under which banks operate, while supervision involves the assessment of safety and soundness of banks through monitoring, and the use of this information to request corrective actions. In contrast to regulation, that is based on verifiable information, supervisory actions are (partly) based on nonverifiable information.

In recent years a number of empirical papers on bank supervision (summarized in the literature review below) have been published, showing that supervision has a disciplining effect on bank risk-taking. The purpose of this paper is to construct a theoretical model of the interaction between a bank and a supervisor that can account for these empirical results. The model features a bank that privately chooses the risk of its investment portfolio and a supervisor that collects nonverifiable information on the future solvency of the bank and, based on this information, may decide on its early liquidation. The paper characterizes the liquidation decision of the supervisor and the risk-taking decision of the bank. The main result is that, compared to a laissez-faire situation, and for any quality of the supervisory information, supervision reduces the bank's risk-taking.

The model has three dates. At $t = 0$ the bank raises a unit amount of insured deposits and invests them in a risky asset that yields a *liquidation return* L at $t = 1$, and a *final return* R at $t = 2$, if not liquidated by the supervisor at $t = 1$. Both L and R are random variables with a variance that depends on the bank's choice of risk σ at $t = 0$. The supervisor observes at $t = 1$ a *noisy signal* s of the final return R of the bank's investment. To make the model tractable, I assume that the probability distribution of asset returns and supervisory signals is normal. And to guarantee an interior choice of risk, I assume that deviating from a reference value of risk $\overline{\sigma} > 0$ entails an increasing and convex cost for the bank. The interpretation is that $\overline{\sigma}$ characterizes the business model of the bank, which is risky, and that deviating from it is costly.

I first show that in the absence of regulation or supervision, the bank chooses a level of risk above the reference value $\overline{\sigma}$, and that introducing a capital requirement, so the bank has to fund at least a fraction $\overline{k}$ of its investment with equity capital, ameliorates the bank's risk-shifting incentives.

I then introduce a bank supervisor that observes at $t = 1$ a signal $s = R + \varepsilon$ of the final return R of the bank's investment. The variance of the noise term ε is proportional to a parameter τ, whose inverse measures the quality of the supervisory information. Thus, when $\tau = 0$ the supervisor observes at $t = 1$ the final return R that will obtain at $t = 2$, while when $\tau \to \infty$ the signal is completely uninformative.

I consider two possible types of supervisors, depending on the rule that maps the signal s into a liquidation decision. A first type (called an F supervisor) uses a *failing or likely to fail rule* whereby the bank is liquidated at $t = 1$ when the conditional expected final return $E(R \mid s)$ is smaller than the unit face value of the deposits. The condition $E(R \mid s) < 1$ yields a threshold $\widehat{s}$ such that the bank is liquidated when $s < \widehat{s}$. A second type (called an E supervisor) uses an *efficient liquidation rule* whereby the bank is liquidated at $t = 1$ when the conditional expected final return $E(R \mid s)$ is smaller than the conditional expected liquidation return $E(L \mid s)$. The condition $E(R \mid s) < E(L \mid s)$ yields a threshold s^* such that the bank is liquidated when $s < s^*$. I show that under a reasonable assumption $\widehat{s} > s^*$, so the F supervisor is tougher than the E supervisor, liquidating the bank for a larger set of signals (for which liquidation would be inefficient).

To analyze the bank's choice of risk under either type of supervisor, note that the bank will get a positive payoff when (i) the final return R is greater than the unit face value of deposits, and (ii) the signal s observed by the supervisor is greater than or equal to the threshold $\widehat{s}$ or s^*. Using the properties of truncated bivariate normal distributions (summarized in the Appendix), one can show that there is an analytical expression for the bank's expected payoff function, which can be used to derive the bank's choice of risk. I show that for any quality of the supervisory information, parameterized by $1/\tau$, an F supervisor leads to a lower choice of risk compared to an E supervisor, which in turn leads to a lower choice of risk than in the absence of supervision. The conclusion is that *supervision is effective in ameliorating the bank's risk-shifting incentives* and that *a tougher supervisor leads to lower risk-taking.*

A result that follows from this analysis is that, for the relevant range of values of τ, a lower quality of the supervisory information (a higher value of the variance of the noise) leads to lower risk-taking. This appears to be puzzling: why higher noise would improve incentives? To explain the result note that an increase in the variance of the supervisory noise has two effects. First, the supervisor reacts to the lower quality of its information by reducing the liquidation threshold, which implies that the size of the region where a bank that would have been solvent at $t = 2$ is liquidated at $t = 1$, because of a large negative realization of ε, is reduced. Second, a higher variance of the supervisory noise makes it more likely that large negative values of the noise ε in the supervisory signal s are realized. The first effect tends to increase the risk σ chosen by the bank, while the second effect goes in the opposite direction. One can show that the second effect dominates when τ is small. Arguably, when the supervisor has access to confidential bank information, it is reasonable to assume that the value of τ should be relatively small. Hence, the conclusion is that *a larger variance of the noise in the supervisory signal is conducive to lower risk-taking.*

Interestingly, Agarwal et al. (2024) find evidence in line with this prediction of the model. Using data on the supervisory ratings of US banks, they show that bank supervisors exercise significant personal discretion, which introduces noise into their ratings. This leads to "a large and persistent causal impact on future bank capitalization and supply of credit, leading to volatility and uncertainty in bank outcomes, and a *conservative anticipatory response by banks*" (my italics). In particular, "banks located in states where examiners exercise a high degree of absolute discretion relative to the national average appear to take precautionary measures by maintaining more capital and lower loan growth than other banks with similar observable fundamentals."

The welfare analysis of bank supervision is conducted under the assumptions that bank failure does not entail any externalities, bank supervision is costless, and the deposit insurer can fund its payouts by lump sum taxation. I show that, for the relevant range of values of τ, a supervisor that uses the efficient liquidation threshold s^* yields higher welfare that a supervisor that uses the failing or likely to fail threshold $\widehat{s}$. In other words, *a tougher supervisor leads to lower risk-taking but also to lower welfare.* Moreover, a higher noise in the supervisory information (an increase in τ) decreases welfare for both types of supervisors. This is also in line with the results of Agarwal et al. (2024) who find that the noise associated with supervisory discretion is potentially costly.

Literature review The empirical research with US data on the effects of bank supervision includes Agarwal et al. (2014), Hirtle et al. (2020), Kandrac and Schlusche (2021), Costello et al. (2019), Eisenbach et al. (2022), Beyhaghi et al. (2024) as well as the already cited paper by Agarwal et al. (2024). Agarwal et al. (2014) study supervisory decisions exploiting a legally determined rotation policy that assigns federal and state supervisors to the same bank at exogenously set time intervals. They find that federal supervisors are systematically tougher than state regulators. Leniency of state regulators relative to their federal counterparts is then related to higher failure rates.

Hirtle et al. (2020) use data on Federal Reserve supervisors' time use to show that the top-ranked banks by size within a Federal Reserve district receive more attention from supervisors, even after controlling for size, complexity, risk, and other characteristics. Using a matched sample approach, they find that these top-ranked banks hold less risky loan portfolios and engage in more conservative reserving practices.

Kandrac and Schlusche (2021) exploit an exogenous reduction in bank supervision to demonstrate a causal effect of supervisory oversight on financial institutions' risk-taking. Moreover, the reduction in oversight capacity led to more costly failures because more bad assets were passed to the government insurance fund.

Costello et al. (2019) use a novel measure of strictness in the enforcement of capital regulation to show that strict supervisors are more likely to enforce restatements of banks' call reports. Moreover, this effect is strongest in periods leading up to economic downturns and for banks with riskier asset portfolios.

Eisenbach et al. (2022) present a structural model of bank supervision that is estimated with data on work hours spent by Federal Reserve staff supervising bank holding companies. In the model the probability that a bank becomes distressed depends on the exogenous riskiness of the bank and the endogenous intensity of the supervision. The supervisor observes the riskiness of the bank, reflected in a supervisory rating, as well as a signal informative about future distress, and allocates a given amount of resources (hours) to minimize a weighted sum of distress probabilities of the supervised banks. The theoretical results show that supervisory hours are increasing in both bank size and risk, which is consistent with the empirical results.

Similar to Agarwal et al. (2024), Beyhaghi et al. (2024) use data on supervisory ratings of US banks to analyze the impact of supervision on risk-taking and loan growth. They show that tougher-than-expected bank ratings lead to decreased risk-taking, reduced profitability, and reduced loan growth at examined banks in the year following an examination.

The empirical research with European data includes Passalacqua et al. (2019), Haselmann et al. (2022), Kok et al. (2023), Bonfim et al. (2023), Abbassi et al. (2023), and Altavilla et al. (2024). Passalacqua et al. (2019) use data on unexpected bank inspections in Italy to show that inspected banks are more likely to reclassify loans as non performing after an audit, and that this reclassification leads to a temporary contraction in lending.

Haselmann et al. (2022) and Altavilla et al. (2024) analyze the effects of (tougher) supranational versus (softer) national banking supervision following the allocation in 2014 of supervisory responsibilities to the European Central Bank. The first paper uses data from the German credit register to show that (larger) banks under supranational supervision are required to increase regulatory capital for exposures to the same firm compared to (smaller) banks under a local supervisor. The second paper uses data of 15 European credit registers to show that the institutional change leading to the centralization of banking supervision reduced credit supply to firms with very high ex-ante and ex-post credit risk.

Kok et al. (2023) use confidential supervisory data on the 2016 European Union stress test to show that supervisory scrutiny associated to stress testing has a disciplining effect on bank risk-taking. In particular, they find that banks that participated in the stress test subsequently reduced their credit risk relative to banks that were not part of this exercise.

Bonfim et al. (2023) exploit a series of large-scale on-site inspections made on the credit portfolios of several Portuguese banks to investigate how these inspections affect banks' future lending decisions. They find that inspected banks become less likely to refinance zombie firms, immediately spurring their default.

Abbassi et al. (2024) exploit the European Central Bank's announcement of the 2013 asset quality review to show that reviewed German banks downsized their balance sheets by reducing their supply of credit and securities holdings. Moreover, this reduction was especially significant for riskier firms.

Another relevant empirical paper on the disciplining effects of bank supervision is Degryse et al. (2024). They show that the automatic alerts generated by the SupTech application used by the Central Bank of Brazil lead to increased provisions for risky loans and a reduction in lending to riskier borrowers.

All in all, *these empirical results provide strong evidence that increased bank supervision leads to a significant reduction in bank risk-taking*. The question that they beg is what is the mechanism whereby supervision has this effect on risk-taking. This is where the main contribution of this paper lies.

In contrast with the huge theoretical literature on bank regulation,[1] the literature on bank supervision is pretty thin. An early contribution is Mailath and Mester (1994). They consider a supervisor's incentives to close a bank, recognizing the opportunity cost of forgone intermediation if the bank is closed as well as the effect the supervisor's closure policy on the bank's risk-taking. They consider two objective functions for the supervisor, maximizing social welfare or minimizing closure costs, showing that even in the first case the lack of commitment power on the part of the supervisor leads to second-best outcomes.

Eisenbach et al. (2016) present a complex framework for the analysis of the interaction between a bank and a supervisor. In this framework, the bank first chooses a risk-taking action, the supervisor observes a signal about the bank's action and then chooses a corrective action. The final asset return, which determines whether the bank is solvent or fails, depends on both the bank's and the supervisor's actions. It is assumed that the bank's action is costly, and that the supervisor's monitoring and intervention are also costly. The supervisor also cares about possible negative spillovers from a bank failure. To simplify the model, they

[1] See, for example, Dewatripont and Tirole (1994), Bhattacharya (1998), Hellmann et al. (2000), and Repullo (2004), and Vives (2016).

assume that the bank's possible actions as well as the signals possible realizations are binary. Among many other results, they show that riskier banks receive more supervisory attention and feature a higher level of intervention than safer banks.[2]

Repullo (2018) presents a model in which a central and a local supervisor contribute their efforts to obtain information on the future solvency of a local bank, which is then used by the central supervisor to decide on its early liquidation. This hierarchical model is contrasted with the alternatives of decentralized and centralized supervision, where only the local or the central supervisor collects information and decides on liquidation. The local supervisor has a higher bias against liquidation and a lower cost of getting local information. The paper characterizes the conditions under which hierarchical supervision is the optimal institutional design. In contrast with the current paper, in my earlier paper the institutional structure of supervision does not affect bank risk-taking, which is taken to be exogenous. But as in my earlier paper, here I assume that the joint probability distribution of the liquidation return, the final return, and the supervisory signal is normal, taking advantage of the nice properties of normally distributed random variables.

Other theoretical papers that have analyzed the institutional structure of bank supervision are Colliard (2016), Calzolari et al. (2019), and Carletti et al. (2020). This last paper is especially interesting because it considers effect of the institutional structure of supervision on bank risk-taking.

Structure of the paper Section 2 presents the model setup. Section 3 characterizes the bank's choice of risk in the absence of regulation or supervision. Section 4 analyzes the effect of bank capital regulation on risk-taking. Section 5 analyzes the effect of bank supervision on risk-taking and welfare. Section 6 analyzes the effect of supervision when the bank is subject to a minimum capital requirement. Section 7 presents some concluding remarks. The Appendix summarizes some useful properties of the bivariate normal distribution.

[2] Eisenbach et al. (2016) is the working paper version of Eisenbach et al. (2022). One interesting difference between the two papers is that in the working paper the signal of the supervisor is about the bank's initial action, while in the published paper the signal is about future distress.

2 Model setup

Consider an economy with three dates ($t = 0, 1, 2$) and two risk-neutral agents: a bank and a bank supervisor. The bank raises a unit amount of deposits at $t = 0$, and invests them in an asset that has a random *final return* R at $t = 2$. The asset can be liquidated at $t = 1$, in which case it yields a random *liquidation return* L. Deposits are insured by a deposit insurer that charges a flat premium normalized to zero. The deposit rate is also normalized to zero.

Asset returns are normally distributed with

$$\begin{bmatrix} L \\ R \end{bmatrix} \sim N\left(\overline{R}\begin{bmatrix} a \\ 1 \end{bmatrix}, \sigma^2 \begin{bmatrix} b & c \\ c & 1 \end{bmatrix}\right), \tag{1}$$

where $\overline{R} > 1$, $0 < a < 1$, $b < 1$, and $c > 0$.

Thus, the expected final return $E(R) = \overline{R}$ is greater than the unit face value of the deposits, and it is also greater than the expected liquidation return $E(L) = a\overline{R}$. This means that, in the absence of information at $t = 1$, liquidation would be inefficient.

Moreover, the final return R has a higher variance than the liquidation return L, and both returns are positively correlated. These assumptions are very reasonable: uncertainty tends to increase with the passage of time, and the liquidation value of a financial asset (say a loan portfolio) tends to move in line with the final value of the asset.[3] Note that to ensure that the covariance matrix is positive-definite b must be greater than c^2, so $b < 1$ implies $c < 1$.

The liquidation return L is only relevant for the model with a bank supervisor, which on the basis of supervisory information on the final return of the bank's asset may decide to liquidate it at $t = 1$. In this case, it is assumed that the supervisor uses the liquidation proceeds to cover deposit insurance payouts, so that the bank gets a zero payoff upon liquidation.

The bank chooses at $t = 0$ the risk σ its portfolio. It is assumed that deviating from a reference value $\overline{\sigma} > 0$ entails a nonpecuniary cost for the bank given by

$$c(\sigma) = \frac{\gamma}{2}(\sigma - \overline{\sigma})^2, \tag{2}$$

[3] This is in contrast with many papers in the literature where the liquidation value is assumed to be a constant, which could be interpreted as the value of redeploying a real asset to other sectors of the economy.

where $\gamma > 0$. The interpretation is that $\overline{\sigma}$ characterizes the business model of the bank, and that deviating from it (in either direction) is costly.

3 Laissez-faire

This section characterizes the behavior of the bank in the absence of regulation or supervision. In this case, the objective function of the bank, denoted $v(\sigma)$, is to maximize its expected payoff at $t = 2$ net of the cost of risk-taking, which gives

$$v(\sigma) = \pi(\sigma) - c(\sigma),$$

where

$$\pi(\sigma) = E[\max\{R - 1, 0\}]$$

is the bank's expected payoff. Note that the cost of risk-taken $c(\sigma)$ is borne by the bank regardless of the final return R.

By assumption (1) we have $R \sim N(\overline{R}, \sigma^2)$, so by the properties of truncated normal distributions (see (19) in the Appendix) we get

$$\pi(\sigma) = E[R - 1 \mid R \geq 1] \Pr(R \geq 1) = (\overline{R} - 1)\Phi\left(\frac{\overline{R} - 1}{\sigma}\right) + \sigma\phi\left(\frac{\overline{R} - 1}{\sigma}\right),$$

where $\phi(x)$ and $\Phi(x)$ are, respectively, the density function and the cumulative distribution function of a standard normal random variable x. Hence, using (2) we have

$$v(\sigma) = (\overline{R} - 1)\Phi\left(\frac{\overline{R} - 1}{\sigma}\right) + \sigma\phi\left(\frac{\overline{R} - 1}{\sigma}\right) - \frac{\gamma}{2}(\sigma - \overline{\sigma})^2. \tag{3}$$

The function $\max\{R - 1, 0\}$ is convex, so by second-order stochastic dominance it follows that $\pi(\sigma)$ is increasing in σ. In particular, using the fact that $\phi'(x) = -x\phi(x)$ one can show that

$$\pi'(\sigma) = \phi\left(\frac{\overline{R} - 1}{\sigma}\right) > 0.$$

Subtracting from the expected payoff $\pi(\sigma)$ the convex cost of risk-taking $c(\sigma)$ allows us to find an interior solution to the maximization of the bank's objective function (3). To prove this, note that

$$\Phi\left(\frac{\overline{R} - 1}{\sigma}\right) < 1 \text{ and } \phi\left(\frac{\overline{R} - 1}{\sigma}\right) < \phi(0)$$

imply

$$v(\sigma) < \overline{R} - 1 + \sigma\phi(0) - \frac{\gamma}{2}(\sigma - \overline{\sigma})^2,$$

so we conclude

$$\lim_{\sigma\to\infty} v(\sigma) < \lim_{\sigma\to\infty}\left[\overline{R} - 1 + \sigma\phi(0) - \frac{\gamma}{2}(\sigma - \overline{\sigma})^2\right] = -\infty.$$

Moreover, since

$$v'(0) = \pi'(0) + \gamma\overline{\sigma} = \gamma\overline{\sigma} > 0,$$

it follows that the solution σ^* will be characterized by the first-order condition

$$\phi\left(\frac{\overline{R}-1}{\sigma}\right) - \gamma(\sigma - \overline{\sigma}) = 0, \tag{4}$$

which implies $\sigma^* > \overline{\sigma}$. Hence, under laissez-faire the bank will have an incentive to increase the risk of its investment above the reference value $\overline{\sigma}$.

Figure 1 plots the bank's expected payoff $\pi(\sigma)$ and objective function $v(\sigma)$, showing the bank's choice of risk σ^* in the absence of regulation or supervision.[4]

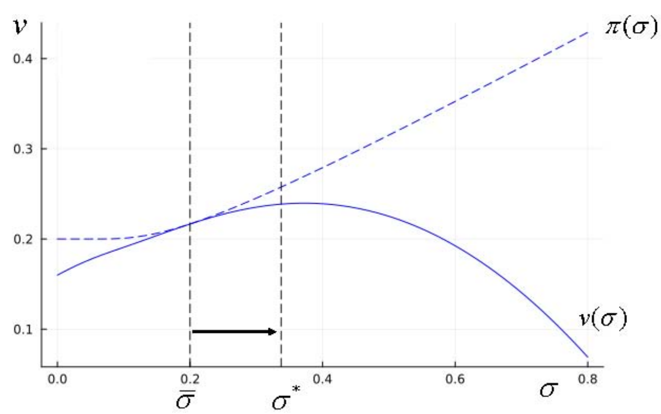

Figure 1. Risk-taking in laissez-faire

This figure plots the bank's expected payoff and objective function, showing the bank's excess risk-taking in the absence of regulation or supervision.

[4] The following parameter values are used in all the figures: $\overline{R} = 1.2$, $a = 0.8$, $b = 0.6$, $c = 0.2$, $\overline{\sigma} = 0.2$, and $\gamma = 2$. These values are not intended to provide a calibration of the model, since they are chosen to facilitate the graphical representation of the qualitative results of the paper.

Differentiating the first-order condition (4) yields the following comparative statics results

$$\frac{d\sigma^*}{d\gamma} = \frac{\sigma^* - \overline{\sigma}}{\frac{\partial}{\partial\sigma}\left[\phi\left(\frac{\overline{R}-1}{\sigma}\right) - \gamma(\sigma - \overline{\sigma})\right]} < 0,$$

$$\frac{d\sigma^*}{d\overline{R}} = -\frac{\frac{1}{\sigma}\phi'\left(\frac{\overline{R}-1}{\sigma}\right)}{\frac{\partial}{\partial\sigma}\left[\phi\left(\frac{\overline{R}-1}{\sigma}\right) - \gamma(\sigma - \overline{\sigma})\right]} < 0,$$

where we have used that $\sigma^* - \overline{\sigma} > 0$, $\overline{R} - 1 > 0$, and the fact that the denominator of these expressions is negative by the second-order condition that characterizes the solution σ^*.

Thus, increases in the cost of deviating from the reference value $\overline{\sigma}$ and increases in the expected return of the asset reduce the bank's choice of risk. To the extent that the expected return $\overline{R}$ can be taken as a proxy for the bank's market power, this second result is consistent with the classical "charter value view" on the determinants of banks' risk-taking.

4 Bank capital regulation

This section analyzes the bank's choice of risk when it is subject to a regulation that requires to fund at least a fraction $\overline{k} \in (0, 1)$ of its investment with equity capital. As it is standard in the literature, I assume that capital is more costly than deposits, and denote by $\delta > 0$ the excess cost of bank capital.[5]

The bank's objective function now becomes

$$v(\sigma; k) = \pi(\sigma; k) - c(\sigma),$$

where

$$\pi(\sigma; k) = E[\max\{R - (1 - k), 0\}] - (1 + \delta)k,$$

$k \geq \overline{k}$ is the bank's capital and $1 - k$ its deposit liabilities. Note that regardless of whether the final return R is greater or smaller than $1 - k$, the bank shareholders incur the cost $(1 + \delta)k$.

[5] It should be noted that with insured deposits this assumption would not be strictly needed, so we could assume $\delta = 0$. In Figure 2 below $\delta = 0.1$.

Differentiating $\pi(\sigma; k)$ with respect to k gives

$$\frac{\partial \pi(\sigma; k)}{\partial k} = \frac{\partial}{\partial k} \int_{1-k}^{\infty} [R - (1-k)] \phi \left(\frac{R - \overline{R}}{\sigma} \right) dR - (1+\delta) = \Phi \left(\frac{\overline{R} - (1-k)}{\sigma} \right) - (1+\delta) < 0.$$

Thus, the capital requirement will always be binding.

Following the same steps as in the laissez-faire case, the bank's objective function may be written as

$$v(\sigma; \overline{k}) = [\overline{R} - (1-\overline{k})])\Phi \left(\frac{\overline{R} - (1-\overline{k})}{\sigma} \right) + \sigma \phi \left(\frac{\overline{R} - (1-\overline{k})}{\sigma} \right) - (1+\delta)\overline{k} - \frac{\gamma}{2}(\sigma - \overline{\sigma})^2. \quad (5)$$

The first-order condition that characterizes the bank's choice of risk is now

$$\phi \left(\frac{\overline{R} - (1-\overline{k})}{\sigma} \right) - \gamma(\sigma - \overline{\sigma}) = 0. \quad (6)$$

Let $\sigma^*(k)$ denote the solution to this equation. As in the laissez-faire case we have $\sigma^*(\overline{k}) > \overline{\sigma}$, so the bank will have an incentive to increase the risk of its investment above the reference value $\overline{\sigma}$.

Differentiating the first-order condition (6) gives

$$\frac{d\sigma^*(\overline{k})}{d\overline{k}} = -\frac{\frac{1}{\sigma}\phi' \left(\frac{\overline{R}-(1-\overline{k})}{\sigma} \right)}{\frac{\partial}{\partial \sigma} \left[\phi \left(\frac{\overline{R}-(1-\overline{k})}{\sigma} \right) - \gamma(\sigma - \overline{\sigma}) \right]} < 0,$$

where we have used that $\overline{R} - (1-\overline{k}) > \overline{R} - 1 > 0$, and the fact that the denominator of this expression is negative by the second-order condition that characterizes the solution $\sigma^*(k)$. Thus, an increase in the capital requirement $\overline{k}$ reduces the bank's risk-taking.

Figure 2 shows the bank's expected payoff and objective function without (in blue) and with (in green) a capital requirement $\overline{k} = 0.1$. The introduction of a capital requirement shifts down both functions, reflecting the increase in the cost of funding and the reduction in the deposit insurance subsidy. However, due to a "skin in the game" effect, the bank chooses a lower level of risk compared to the laissez-faire case.

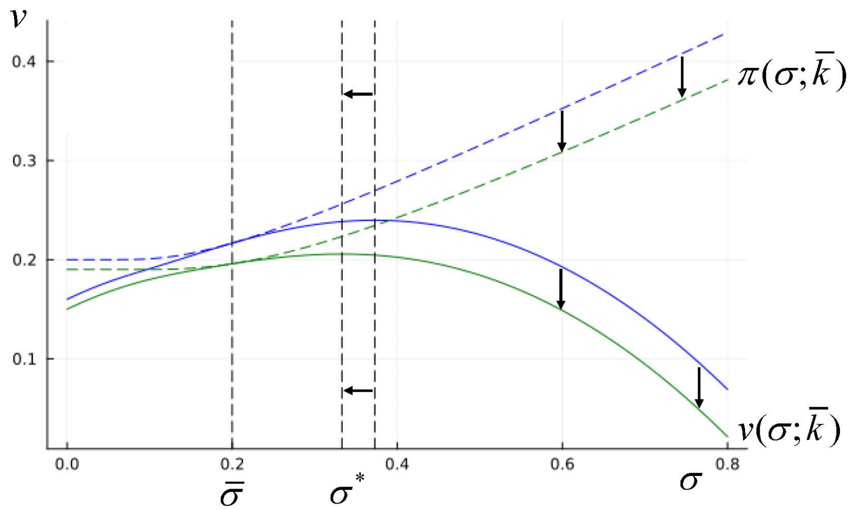

Figure 2. Risk-taking with a capital requirement

This figure plots the bank's expected payoff and objective function without (blue lines) and with (green lines) a capital requirement, showing its effect in reducing the bank's excess risk-taking.

Panel A of Figure 3 plots the function $\sigma^*(\overline{k})$, showing the effect of the capital requirement $\overline{k}$ (in the horizontal axis) on the bank's choice of risk σ^* (in the vertical axis). The function $\sigma^*(\overline{k})$ is decreasing with $\sigma^*(0)$ corresponding to the choice of risk in laissez-faire.

Panel B of Figure 3 shows the effect of the capital requirement $\overline{k}$ (in the horizontal axis) on the bank's probability of failure (in the vertical axis) given by

$$\Pr(R < 1 - \overline{k}) = \Phi\left(\frac{(1-\overline{k}) - \overline{R}}{\sigma^*(\overline{k})}\right).$$

Note that higher capital requirements decrease the numerator $(1-\overline{k}) - \overline{R}$ (which is negative) and decrease the denominator $\sigma^*(\overline{k})$. Both effects reduce the value of the ratio (making it more negative), which implies a lower probability of failure.

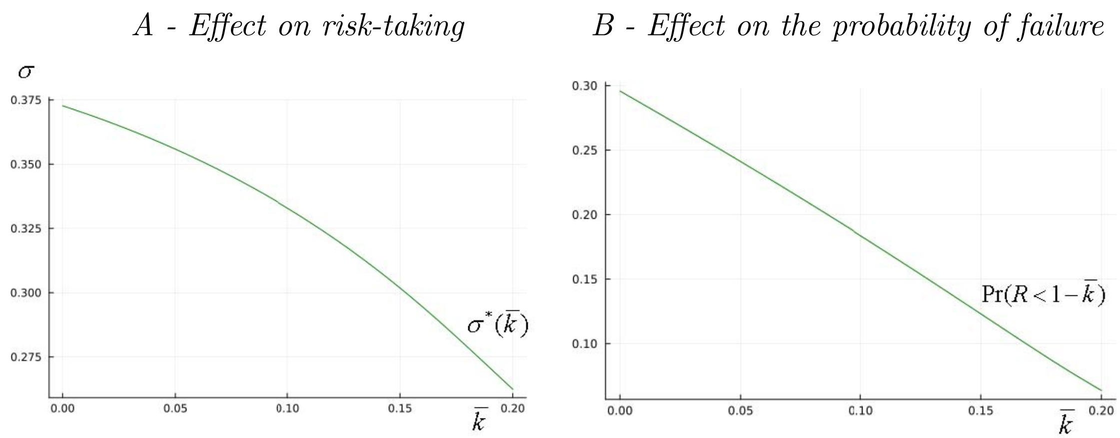

Figure 3. Effect of capital requirements on risk-taking and the probability of failure

This figure shows the relationship between the capital requirement (in the horizontal axis) and the bank's choice of risk (Panel A) and probability of failure (Panel B).

The results obtained so far on the bank's incentives for excess risk-taking and the effect of capital requirements in ameliorating them are fairly standard, except for the specific model setup. The novel contribution of this paper is to show how this setup can be used to analyze the effect of bank supervision on risk-taking, which is done in the next section.

5 Bank supervision

I now introduce a bank supervisor that observes at $t = 1$ a *nonverifiable signal*

$$s = R + \varepsilon \tag{7}$$

of the final return R of the bank's investment. The noise term ε is assumed to be independent of the liquidation return L and the final return R, and has a distribution $N(0, \tau\sigma^2)$. The lower the value of τ the higher the quality (technically the precision) of the supervisory information. When $\tau = 0$ the supervisor observes at $t = 1$ the final return R that will obtain at $t = 2$, while when $\tau \to \infty$ the signal is completely uninformative.[6]

[6] Note that despite the fact that for $\tau = 0$ the signal s reveals the final return R, the liquidation return L will still be uncertain, with $L \mid R \sim N(a\overline{R} + c(R - \overline{R}), (b - c^2)\sigma^2)$.

It should be noted that the signal s is not about the choice of σ by the bank at $t = 0$, but about the consequences of this choice in terms of a particular value of the final return R at $t = 2$. Arguably, this provides a better approximation to the actual behavior of bank supervisors who care about risk-taking only to the extent that it may lead to low return realizations.

By assumptions (1) and (7) we have $s \sim N(\overline{R}, (1+\tau)\sigma^2)$, $\text{Cov}(R, s) = \text{Var}(R) = \sigma^2$, and $\text{Cov}(L, s) = \text{Cov}(L, R) = c\sigma^2$. Hence, the joint probability distribution of the liquidation return L, the final return R, and the supervisory signal s is

$$\begin{bmatrix} L \\ R \\ s \end{bmatrix} \sim N\left(\overline{R} \begin{bmatrix} a \\ 1 \\ 1 \end{bmatrix}, \sigma^2 \begin{bmatrix} b & c & c \\ c & 1 & 1 \\ c & 1 & 1+\tau \end{bmatrix} \right). \tag{8}$$

By the properties of normal distributions (see (18) in the Appendix) we have

$$E(L \mid s) = a\overline{R} + \frac{c(s - \overline{R})}{1+\tau}, \tag{9}$$

$$E(R \mid s) = \overline{R} + \frac{s - \overline{R}}{1+\tau}. \tag{10}$$

Since $c < 1$ the slope of $E(L \mid s)$ is smaller than the slope of $E(R \mid s)$, which implies

$$E(L \mid s) > E(R \mid s) \quad \text{if and only if} \quad s < s^*,$$

where

$$s^* = \overline{R} - \frac{(1+\tau)(1-a)}{1-c}\overline{R} \tag{11}$$

is the *efficient liquidation threshold*.

Substituting s^* from (11) into (9) and (10) gives

$$E(L \mid s^*) = E(R \mid s^*) = \frac{a-c}{1-c}\overline{R}.$$

I assume that parameter values satisfy

$$\frac{a-c}{1-c}\overline{R} < 1. \tag{12}$$

This means that the efficient liquidation threshold s^* is such that the corresponding conditional expected final return $E(R \mid s^*)$ is less than the unit face value of the deposits, so efficient liquidation occurs only if the bank is effectively bankrupt.[7]

Figure 4 shows the determination of the efficient liquidation threshold by the intersection of the lines $E(L \mid s)$ and $E(R \mid s)$. For signals to the left of s^* liquidation at $t = 1$ would be efficient, while for signals to the right of s^* continuation until $t = 2$ would be efficient.

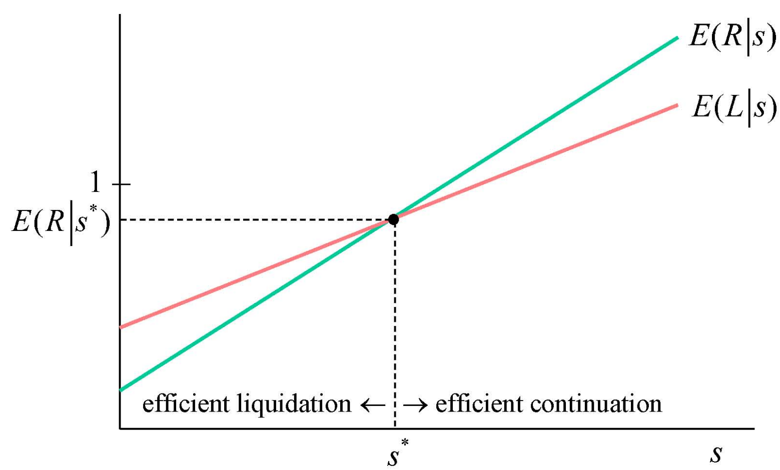

Figure 4. Efficient liquidation threshold

This figure shows the determination of the efficient liquidation threshold which characterizes the set of signals for which liquidation (to the left) or continuation (to the right) is efficient.

In what follows I first analyze the bank's choice of risk when the supervisor closes the bank at $t = 1$ when it is *failing or likely to fail*, that is when she observes a signal s such that the conditional expected final return $E(R \mid s)$ is smaller than the unit face value of the deposits.[8] The case where the supervisor uses the efficient liquidation threshold s^* instead

[7]Interestingly, $E(L \mid s^*) = E(R \mid s^*)$ does not depend on the bank's choice of risk σ nor on the parameter τ that characterizes the variance of the noise of the supervisory information.

[8]According to the Banking Supervision guidelines of the European Central Bank, "there are four reasons why a bank can be declared failing or likely to fail: (i) it no longer fulfils the requirements for authorization by the supervisor, (ii) it has more liabilities than assets, (iii) it is unable to pay its debts as they fall due, and (iv) it requires extraordinary financial public support. At the time of declaring a bank as failing or likely to fail, one of the above conditions must be met or be likely to be met." In our setup, the supervisor assesses that the bank has "more liabilities than assets" whenever $E(R \mid s) < 1$.

of the failing or likely to fail threshold $\widehat{s}$, and the comparison between the two thresholds, will be discussed below.

Using (10) we have

$$E(R \mid s) = \overline{R} + \frac{s - \overline{R}}{1+\tau} < 1 \quad \text{if and only if} \quad s < \widehat{s} = 1 - \tau(\overline{R} - 1). \tag{13}$$

Note that the higher the parameter τ that characterizes the variance of the noise of the supervisory information, the lower the liquidation threshold $\widehat{s}$ and hence the softer the supervisor.[9]

As noted in Section 2, I assume that if the bank is declared failing or likely to fail, the supervisor uses the liquidation proceeds to cover deposit insurance payouts, so that the bank gets a zero payoff upon liquidation. Under this assumption, the bank's objective function becomes

$$v(\sigma; \widehat{s}) = \pi(\sigma; \widehat{s}) - c(\sigma),$$

where

$$\pi(\sigma; \widehat{s}) = E[R - 1 \mid R \geq 1 \text{ and } s \geq \widehat{s}] \Pr(R \geq 1 \text{ and } s \geq \widehat{s})$$

is the bank's expected payoff when the supervisor uses the failing or likely to fail threshold, that is when it liquidates the bank upon observing a signal $s < \widehat{s}$.

Using the properties of truncated bivariate normal distributions (see (20) in the Appendix) we have

$$\begin{aligned} \pi(\sigma; \widehat{s}) \;&=\; (\overline{R} - 1)\Phi\left(\frac{\overline{R}-1}{\sigma}, \frac{\overline{R}-\widehat{s}}{\sigma\sqrt{1+\tau}}; \frac{1}{\sqrt{1+\tau}}\right) + \sigma\phi\left(\frac{\overline{R}-1}{\sigma}\right)\Phi\left(\frac{1-\widehat{s}}{\sigma\sqrt{\tau}}\right) \\ &\quad + \frac{\sigma}{\sqrt{1+\tau}}\phi\left(\frac{\overline{R}-\widehat{s}}{\sigma\sqrt{1+\tau}}\right)\Phi\left(\frac{\widehat{s}-1+\tau(\overline{R}-1)}{\sigma\sqrt{\tau(1+\tau)}}\right), \end{aligned}$$

where $\Phi(\cdot, \cdot; \rho)$ is the cumulative distribution function of a standard bivariate normal distribution with correlation coefficient ρ.[10] Substituting $\widehat{s} = 1 - \tau(\overline{R} - 1)$ from (13) into this

[9] Interestingly, neither the threshold s^* nor the threshold $\widehat{s}$ depend on the bank's choice of risk σ. This might not hold for alternative specifications of the probability distribution of signals and returns.

[10] The correspondence between the variables in the expression in the Appendix and the variables in the model is as follows: $x_1 = R - 1$, $x_2 = s$, $\mu_1 = \overline{R} - 1, \mu_2 = \overline{R}$, $\sigma_1 = \sigma$, $\sigma_2 = \sigma\sqrt{1+\tau}$, $\rho = 1/\sqrt{1+\tau}$, $\overline{x}_1 = 0$, and $\overline{x}_2 = \widehat{s}$.

expression then gives

$$\pi(\sigma;\tau) = (\overline{R}-1)\Phi\left(\frac{\overline{R}-1}{\sigma}, \frac{\sqrt{1+\tau}(\overline{R}-1)}{\sigma}; \frac{1}{\sqrt{1+\tau}}\right) + \sigma\phi\left(\frac{\overline{R}-1}{\sigma}\right)\Phi\left(\frac{\sqrt{\tau}(\overline{R}-1)}{\sigma}\right) + \frac{\sigma}{2\sqrt{1+\tau}}\phi\left(\frac{\sqrt{1+\tau}(\overline{R}-1)}{\sigma}\right).$$

Figure 5 shows the bank's expected payoff and objective function without (in blue) and with (in red) a supervisor that uses the failing or likely to fail threshold for $\tau = 1$. The effect of bank supervision is similar to that of bank capital regulation analyzed in Section 4: both functions are shifted down, in this case because of the negative effect of the possible early liquidation on the bank's expected payoff, and as a result the bank chooses a lower level of risk compared to the laissez-faire case.

Let us now define $\sigma^*(\tau) = \arg\max_\sigma v(\sigma;\tau)$, that is the bank's choice of risk when the variance of the noise in the supervisor's signal is $\tau\sigma^2$. To analyze the effect of supervisory noise on bank risk-taking, it is useful to start with the limit cases $\tau = 0$ and $\tau \to \infty$.

When $\tau = 0$ the supervisor observes at $t = 1$ the value of the final return R that will obtain at $t = 2$. Moreover, the liquidation threshold defined in (13) becomes $\widehat{s} = 1$, which coincides with the value of the bank's liabilities. This means that the bank would be liquidated by the supervisor at $t = 1$ if and only if the bank would fail at $t = 2$. Supervision would not have any effect on the bank's choice of risk, which would be identical to the one in laissez-faire.

When $\tau \to \infty$ the liquidation threshold defined in (13) satisfies $\widehat{s} \to -\infty$, which means that the supervisor would never liquidate the bank at $t = 1$. Once again, supervision would not have any effect on the bank's choice of risk, which would be identical to the one in laissez-faire.

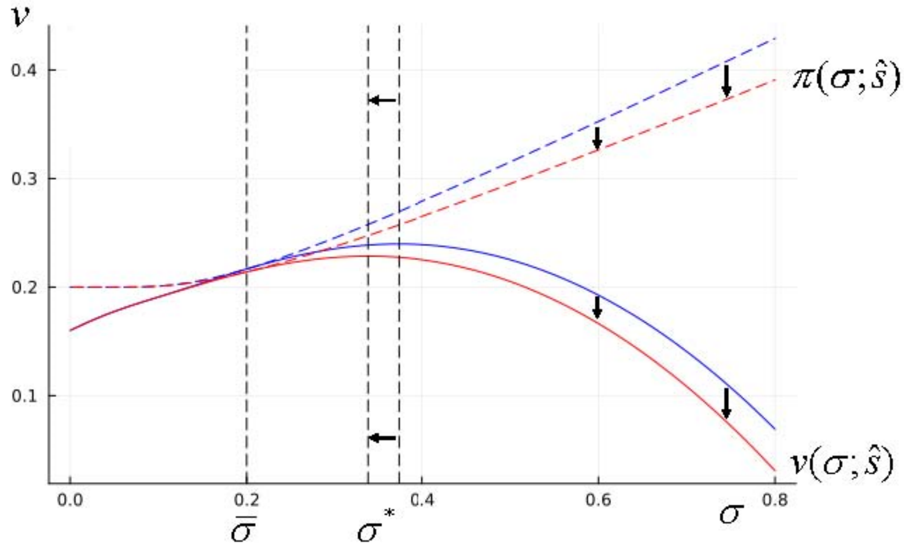

Figure 5. Risk-taking with bank supervision

This figure plots bank's expected payoff and objective function without (blue lines) and with (red lines) a supervisor that uses the failing or likely to fail threshold, showing its effect in reducing the bank's excess risk-taking.

Thus, in the two limit cases of perfectly informative ($\tau = 0$) and perfectly uninformative ($\tau \to \infty$) supervisory information the bank's choice of risk is the same as in laissez-faire. At the same time, Figure 5 shows that for $0 < \tau < \infty$ the bank chooses a lower level of risk compared to the laissez-faire case, so $\sigma^*(\tau)$ cannot be monotonic.

Figure 6 plots the function $\sigma^*(\tau)$, showing that the effect of parameter τ (in the horizontal axis) on the bank's choice of risk σ^* (in the vertical axis) is U-shaped, first decreasing and then increasing, with $\sigma^*(0)$ and $\lim_{\tau\to\infty}\sigma^*(\tau)$ equal to the choice of risk in laissez-faire. But since the supervisory signal is $s = R + \varepsilon$, with $R \sim N(\overline{R}, \sigma^2)$ and $\varepsilon \sim N(0, \tau\sigma^2)$, it is reasonable to assume that the relevant range of values of τ is close to the origin. In this range, the higher τ the lower the bank's choice of risk $\sigma^*(\tau)$.

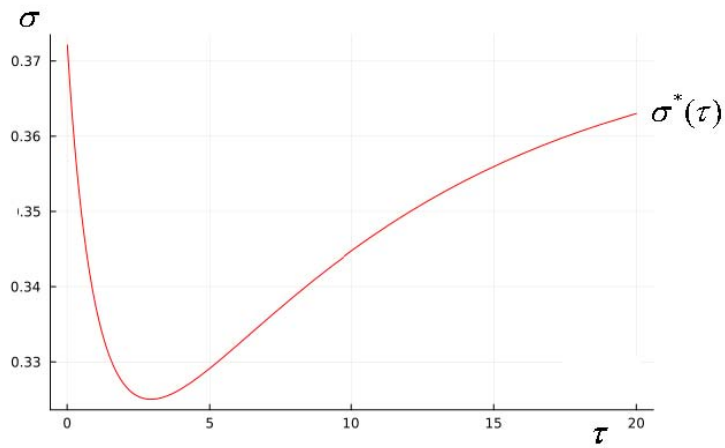

Figure 6. Effect of variance of noise on risk-taking

This figure shows the relationship between the variance of noise parameter in the supervisor's signal (in the horizontal axis) and the bank's choice of risk (in the vertical axis).

To explain why the disciplining effects of bank supervision come from the fact that supervisory information is noisy, consider Figure 7. The four panels plot regions with the final return R in the horizontal axis and the noise in the supervisory signal ε in the vertical axis. Panel A shows the region with $R < 1$ where the bank would fail at $t = 2$, and Panel B the region with $s = R + \varepsilon < \widehat{s}$ where the bank would be liquidated by the supervisor at $t = 1$. The key intersection region in Panel C shows the combinations of R and ε for which the bank is liquidated at $t = 1$ but it would have been solvent at $t = 2$. In this region, the supervisor makes a type I (or false positive) error, liquidating the bank when it should have been allowed to continue. This error is due to a large negative realization of the noise term ε, which worsens the signal s observed by the supervisor. Finally, Panel D shows the effect of an increase in the variance of the noise parameter τ, which according to (13) reduces the liquidation threshold $\widehat{s}$.

An increase in τ has two effects. First, it reduces the size of the key region in Figure 7, where the bank is erroneously liquidated at $t = 1$. Second, it makes it more likely that large negative values of the noise ε in the supervisory signal s are realized. The first effect tends to increase the risk σ chosen by the bank, while the second effect goes in the opposite direction. Our results in Figure 6 show that the first (second) effect dominates when τ is large (small). As argued above, when the supervisor has access to confidential bank information, it is reasonable to assume that the value of τ should be small, in particular smaller than the critical value in Figure 6 where the relationship between τ and $\sigma^*(\tau)$ becomes increasing. Hence, the conclusion is that for reasonable parameter values *higher noise in the supervisory information is conducive to lower risk-taking.*

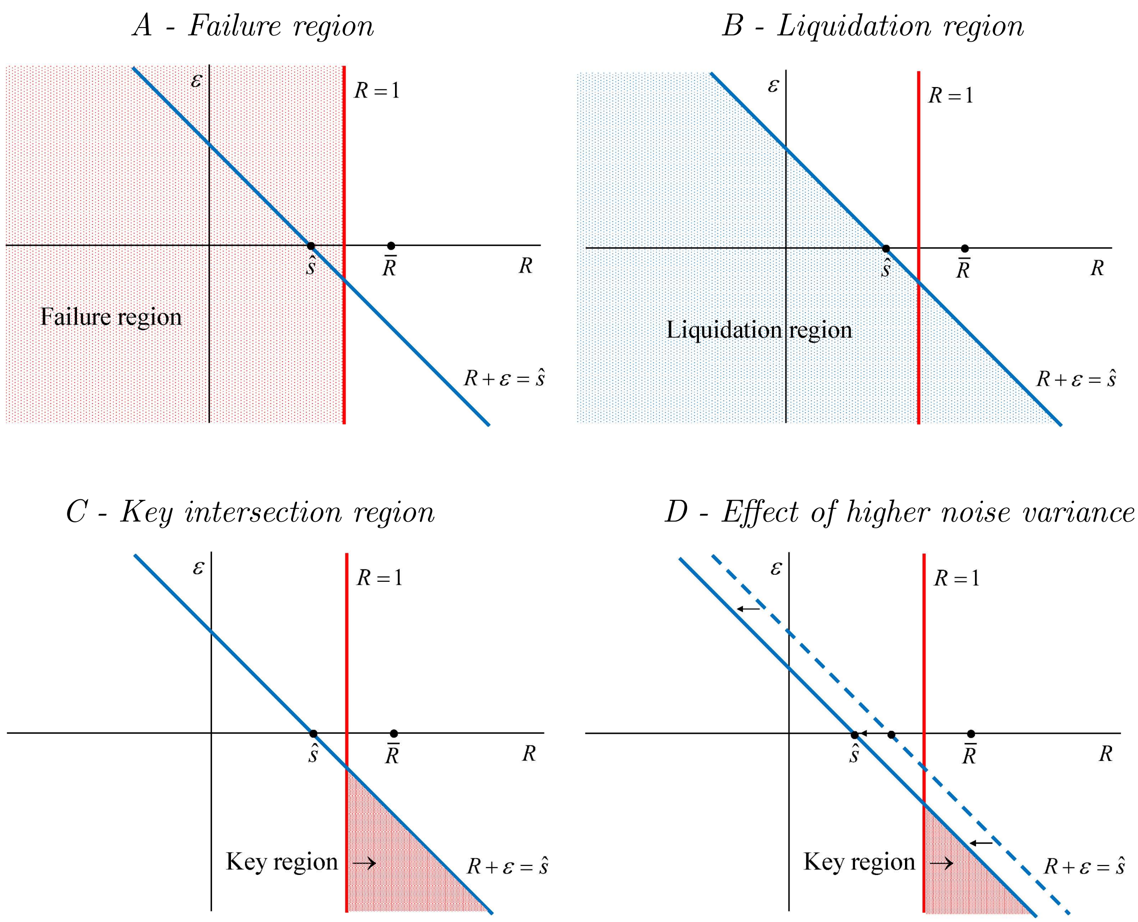

Figure 7. Failure and liquidation regions

This figure plots regions in a space with the final bank return in the horizontal axis and the noise in the supervisory signal in the vertical axis. Panel A shows the region where the bank would fail at $t = 2$. Panel B shows the region where the bank would be liquidated by the supervisor at $t = 1$. Panel C shows the intersection of these two regions where a solvent bank at $t = 2$ would be liquidated at $t = 1$. Panel D shows the effect on the intersection region in Panel C of an increase in the variance of the noise parameter.

5.1 F and E supervisors

I next analyze the effect on risk-taking of a supervisor that uses the efficient liquidation threshold s^* instead of the failing or likely to fail threshold $\widehat{s}$. To facilitate the presentation, a supervisor that uses the s^* threshold will be called an E *supervisor*, while a supervisor that uses the $\widehat{s}$ threshold will be called an F *supervisor*.

First, note that assumption (12) together with the definitions of (11) and (13) of s^* and $\widehat{s}$ imply

$$\widehat{s} - s^* = (1+\tau)\left(1 - \frac{a-c}{1-c}\overline{R}\right) > 0. \tag{14}$$

Thus, for the same value of τ, the failing or likely to fail threshold $\widehat{s}$ is higher than the efficient liquidation threshold s^*, which means that *the* F *supervisor is tougher than the* E *supervisor*. This implies that there is a range of signals for which the liquidation policy of the F supervisor is inefficient, that is $E(L \mid s) < E(R \mid s)$ for $s \in (s^*, \widehat{s})$.

The fact that the threshold s^* of the E supervisor is smaller than the threshold $\widehat{s}$ of the F supervisor implies that the key intersection region where the bank is erroneously liquidated at $t = 1$ becomes smaller with an E supervisor; see Panel A of Figure 8. This implies that, for the same variance of the supervisory noise ε, it is less likely that the bank fall into this region, so the bank will choose an higher value of σ with an E supervisor.

Panel B of Figure 8 shows the effect of parameter τ (in the horizontal axis) on the bank's choice of risk (in the vertical axis) under an E supervisor and an F supervisor, denoted $\sigma_E^*(\tau)$ and $\sigma_F^*(\tau)$, respectively.[11] Thus, we have $\sigma_E^*(\tau) > \sigma_F^*(\tau)$ for $\tau > 0$, so the softer E supervisor leads to higher risk-taking. Moreover, as argued above, for either $\tau = 0$ or $\tau \to \infty$ the bank's choice of risk under either type of supervisor equals or tends to its choice of risk in laissez-faire.

[11] The function $\sigma_F^*(\tau)$ in Panel B of Figure 8 is the same as the function $\sigma^*(\tau)$ in Figure 6.

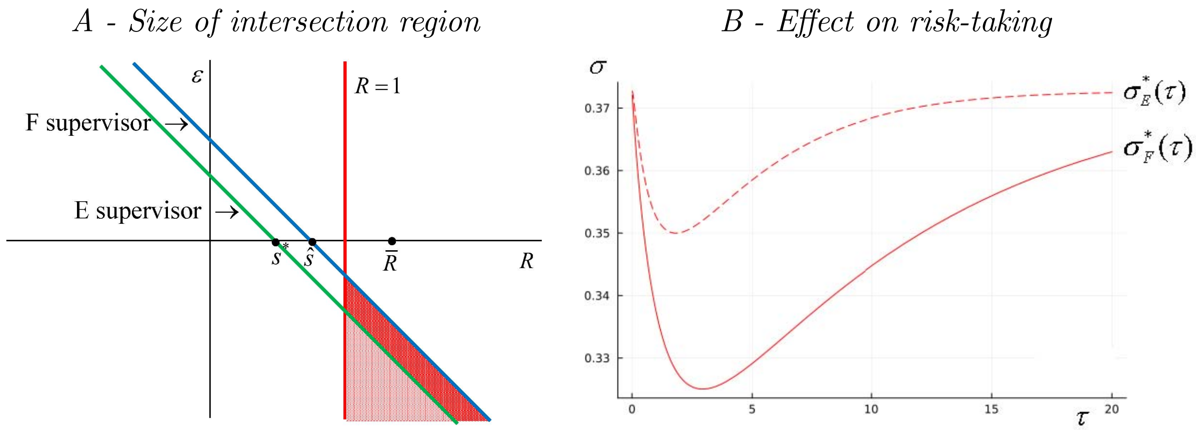

Figure 8. F and E supervisors

Panel A of this figure plots the regions in a space with the final bank return in the horizontal axis and the noise in the supervisory signal in the vertical axis where a solvent bank at $t = 2$ would be liquidated at $t = 1$ by an F and an E supervisor. Panel B shows the relationship between the varaince of noise paramter in the supervisor's signal (in the horizontal axis) and the bank's choice of risk (in the vertical axis) with an F and an E supervisor.

Summing up, this section has analyzed the bank's choice of risk when there is a supervisor that observes a signal s on the final return R of the bank's investment, liquidating the bank when the signal is below a threshold. Two thresholds have been considered: the efficient liquidation threshold s^* and the failing or likely to fail threshold $\widehat{s}$. Both thresholds lead the bank to choose a lower level of risk, compared to laissez-faire. Thus, *supervision is effective in ameliorating the bank's risk-shifting incentives.* Moreover, since the efficient liquidation threshold s^* is below the failing or likely to fail threshold $\widehat{s}$, the bank chooses a higher level of risk with s^*. In other words, *a tougher supervisor leads to lower risk-taking.*

5.2 Welfare analysis

I next turn to the welfare analysis of bank supervision. I assume that (i) bank liquidation at $t = 1$ or failure at $t = 2$ does not entail any externalities, (ii) bank supervision is costless, and (iii) the deposit insurer can fund its payouts by lump sum taxation. Under these conditions, social welfare is simply the expected payoff of the investment, taking into account the liquidation threshold of the relevant supervisor, minus the bank's cost of risk-taking and the unit cost of the investment.

Then, the welfare associated with the liquidation threshold $\widehat{s}$ used by the F supervisor is given by

$$w_F(\tau) = E(R \mid s \geq \widehat{s}) \Pr(s \geq \widehat{s}) + E(L \mid s < \widehat{s}) \Pr(s < \widehat{s}) - c(\sigma) - 1, \tag{15}$$

where $\sigma = \sigma_F^*(\tau)$ is the bank's choice of risk under $\widehat{s}$. The welfare associated with the liquidation threshold s^* used by the E supervisor is given by

$$w_E(\tau) = E(R \mid s \geq s^*) \Pr(s \geq s^*) + E(L \mid s < s^*) \Pr(s < s^*) - c(\sigma) - 1, \tag{16}$$

where $\sigma = \sigma_E^*(\tau)$ is the bank's choice of risk under s^*.

By the properties of truncated bivariate normal distributions (see (21) and (22) in the Appendix) we have

$$E(R \mid s \geq \widehat{s}) \Pr(s \geq \widehat{s}) = \overline{R}\Phi\left(\frac{\overline{R} - \widehat{s}}{\sigma\sqrt{1+\tau}}\right) + \frac{\sigma}{\sqrt{1+\tau}}\phi\left(\frac{\overline{R} - \widehat{s}}{\sigma\sqrt{1+\tau}}\right),$$

and

$$E(L \mid s < \widehat{s}) \Pr(s < \widehat{s}) = a\overline{R}\Phi\left(\frac{\widehat{s} - \overline{R}}{\sigma\sqrt{1+\tau}}\right) - \frac{\sigma c}{\sqrt{b(1+\tau)}}\phi\left(\frac{\widehat{s} - \overline{R}}{\sigma\sqrt{1+\tau}}\right),$$

and similarly for $E(R \mid s \geq s^*) \Pr(s \geq s^*)$ and $E(L \mid s < s^*) \Pr(s < s^*)$, where we have used the fact that by (8) the correlation coefficient between R and s is $(1+\tau)^{-1/2}$ and the correlation coefficient between L and s is $c[b(1+\tau)]^{-1/2}$.

Substituting the threshold $\widehat{s}$ from (13) into these expressions, plugging them into (15) and rearranging gives the welfare corresponding to an F supervisor as a function of parameter τ, which is

$$\begin{aligned} w_F(\tau) \;&=\; a\overline{R} + (1-a)\overline{R}\Phi\left(\frac{\sqrt{1+\tau}(\overline{R}-1)}{\sigma}\right) \\ &\quad + \frac{\sigma}{\sqrt{1+\tau}}\left(1 - \frac{c}{\sqrt{b}}\right)\phi\left(\frac{\sqrt{1+\tau}(\overline{R}-1)}{\sigma}\right) - c(\sigma) - 1, \end{aligned}$$

where $\sigma = \sigma_F^*(\tau)$ is the bank's choice of risk under an F supervisor.

Similarly, substituting the threshold s^* from (11) into the expressions corresponding to the E supervisor, plugging them into (16) and rearranging gives the welfare corresponding to an E supervisor as a function of parameter τ, which is

$$\begin{aligned} w_E(\tau) &= a\overline{R} + (1-a)\overline{R}\Phi\left(\frac{\sqrt{1+\tau}(1-a)\overline{R}}{\sigma(1-c)}\right) \\ &\quad + \frac{\sigma}{\sqrt{1+\tau}}\left(1-\frac{c}{\sqrt{b}}\right)\phi\left(\frac{\sqrt{1+\tau}(1-a)\overline{R}}{\sigma(1-c)}\right) - c(\sigma) - 1, \end{aligned}$$

where $\sigma = \sigma_E^*(\tau)$ is the bank's choice of risk under an E supervisor.

Figure 9 plots the functions $w_F(\tau)$ and $w_E(\tau)$ showing the effect of the variance of the noise parameter τ (in the horizontal axis) on welfare (in the vertical axis) under an E supervisor and an F supervisor. It also plots the welfare in laissez-faire w_L, which is obviously independent of τ.

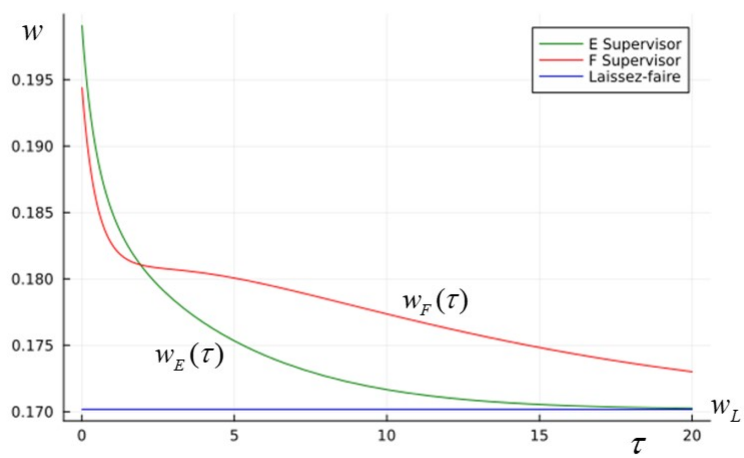

Figure 9. Welfare effects of bank supervision

This figure shows the relationship between the variance of noise parameter (in the horizontal axis) and the welfare (in the vertical axis) associated with an E supervisor (green line), an F supervisor (red line), and in laissez-faire (blue line).

The fact both types of supervisors improve upon the welfare in laissez-faire should not be surprising, since early liquidation is better than continuation for a large range of signals (namely $s < s^*$) and that we are abstracting from the costs of supervision. What might be surprising is that the two functions are decreasing, so a lower quality of the supervisory information reduces welfare, even in the range of (low) values of τ for which (as illustrated in Panel B of Figure 8) it also reduces risk-taking for both types of supervisors.

To explain the intuition for this result note that the function $w_E(\tau)$ in (16) may be written as

$$w_E(\tau) = E[\max\{E(R \mid s), E(L \mid s)\}] - c(\sigma) - 1.$$

Since the function $\max\{E(R \mid s), E(L \mid s)\}$ is convex in s (see Figure 4), by second-order stochastic dominance it follows that its expectation is increasing in $\text{Var}(s) = (1+\tau)\sigma^2$. One can show that an increase in τ in the relevant range reduces the bank's choice of risk $\sigma_E^*(\tau)$ so that $\text{Var}(s)$ goes down. This explains the reduction in the corresponding level of welfare $w_E(\tau)$. A similar, but slightly more complicated argument, explains why $w_F(\tau)$ is also initially decreasing in τ. The complication arises because there is a jump in the welfare function at $\widehat{s}$, where the bank is liquidated by the F supervisor and the expected liquidation value is smaller than the expected continuation value, which implies that the welfare function is neither concave nor convex in s. Beyond this initial range of values of τ, both $w_E(\tau)$ and $w_F(\tau)$ are still decreasing because a high value of τ makes it more likely that large negative values of the noise ε in the supervisory information are realized, in which case the bank would be erroneously liquidated at $t = 1$. Finally, for low values of τ, $w_E(\tau)$ is greater than $w_F(\tau)$, with the ranking reversing for higher values of τ. The reversal can be explained by the fact that, by (14), the gap between s^* and $\widehat{s}$ increases with τ, which concavifies the welfare function under an F supervisor.

Summing up, this section has analyzed the welfare effects of the two types of supervisors, showing that they dominate the welfare in laissez-faire and that, in the absence of supervision costs, an increase in the quality of supervisory information (a reduction of parameter τ in the variance of the noise) increases welfare for both types of supervisors.[12] Putting these results together with our previous results the conclusion is that, for the relevant range of the quality of supervisory information, *a better informed supervisor leads to both higher risk-taking and higher welfare.*

[12] Note that if we were to take into account the costs of supervision, which may be exploding when $\tau \to 0$, there could be an interior welfare maximizing solution $\tau^* > 0$.

6 Bank supervision with capital requirements

This section analyzes the effect of supervision when the bank is subject to a minimum capital requirement $\overline{k}$. I restrict attention to the case where the supervisor liquidates the bank at $t = 1$ when it is failing of likely to fail, that is when it observes a signal s such that the expected final return $E(R \mid s)$ is smaller than the face value of the deposits, which is now $1 - \overline{k}$. Thus, we have

$$E(R \mid s) = \overline{R} + \frac{s - \overline{R}}{1+\tau} < 1 - \overline{k} \quad \text{if and only if} \quad s < \widehat{s}(\overline{k}) = 1 - \overline{k} - \tau[\overline{R} - (1 - \overline{k})]. \qquad (17)$$

Since the threshold $\widehat{s}(\overline{k})$ is decreasing in $\overline{k}$, the range of signals for which the bank is assessed to be failing or likely to fail is smaller. In other words, the supervisor becomes softer when the bank has a capital buffer. As before, the higher the noise parameter τ in the supervisory information, the lower the liquidation threshold $\widehat{s}(\overline{k})$ and hence the softer the supervisor.

The bank's objective function now becomes

$$v(\sigma; \overline{k}, \widehat{s}) = \pi(\sigma; \overline{k}, \widehat{s}) - c(\sigma),$$

where

$$\pi(\sigma; \overline{k}, \widehat{s}) = E[R - (1 - \overline{k}) \mid R \geq 1 - \overline{k} \text{ and } s \geq \widehat{s}] \Pr(R \geq 1 - \overline{k} \text{ and } s \geq \widehat{s}) - (1+\delta)\overline{k}.$$

is the bank's expected payoff when it is subject to a capital requirement $\overline{k}$ and the supervisor uses the failing or likely to fail threshold $\widehat{s} = \widehat{s}(\overline{k})$.

Using the properties of truncated bivariate normal distributions (see (20) in the Appendix) we have

$$\begin{aligned} \pi(\sigma; \overline{k}, \widehat{s}) \quad = \quad & [\overline{R} - (1 - \overline{k})]\Phi\left(\frac{\overline{R} - (1 - \overline{k})}{\sigma}, \frac{\overline{R} - \widehat{s}}{\sigma\sqrt{1+\tau}}; \frac{1}{\sqrt{1+\tau}}\right) \\ & + \sigma\phi\left(\frac{\overline{R} - (1 - \overline{k})}{\sigma}\right)\Phi\left(\frac{1 - \overline{k} - \widehat{s}}{\sigma\sqrt{\tau}}\right) \\ & + \frac{\sigma}{\sqrt{1+\tau}}\phi\left(\frac{\overline{R} - \widehat{s}}{\sigma\sqrt{1+\tau}}\right)\Phi\left(\frac{\widehat{s} - (1 - \overline{k}) + \tau[\overline{R} - (1 - \overline{k})]}{\sigma\sqrt{\tau(1+\tau)}}\right) - (1+\delta)\overline{k}, \end{aligned}$$

where $\Phi(\cdot,\cdot;\rho)$ is the cumulative distribution function of a standard bivariate normal distribution with correlation coefficient ρ.[13] Substituting $\widehat{s}=\widehat{s}(\overline{k})=1-\overline{k}-\tau[\overline{R}-(1-\overline{k})]$ from (17) into this expression then gives

$$\begin{aligned}\pi(\sigma;\overline{k},\tau) &= [\overline{R}-(1-\overline{k})]\Phi\left(\frac{\overline{R}-(1-\overline{k})}{\sigma},\frac{\sqrt{1+\tau}[\overline{R}-(1-\overline{k})]}{\sigma};\frac{1}{\sqrt{1+\tau}}\right)\\ &\quad+\sigma\phi\left(\frac{\overline{R}-(1-\overline{k})}{\sigma}\right)\Phi\left(\frac{\sqrt{\tau}[\overline{R}-(1-\overline{k})]}{\sigma}\right)\\ &\quad+\frac{\sigma}{2\sqrt{1+\tau}}\phi\left(\frac{\sqrt{1+\tau}[\overline{R}-(1-\overline{k})]}{\sigma}\right)-(1+\delta)\overline{k}.\end{aligned}$$

Panel A of Figure 10 plots the function $\sigma^*(\overline{k};\tau)=\arg\max_\sigma v(\sigma;\overline{k},\tau)$, showing the effect of the capital requirement $\overline{k}$ (in the horizontal axis) on the bank's choice of risk for $\tau\to\infty$ (no supervision) and $\tau=1$ (supervision). Both functions are decreasing, so higher capital requirements reduce the bank's choice of risk. Moreover, bank supervision has an additional ameliorating effect on risk-taking.

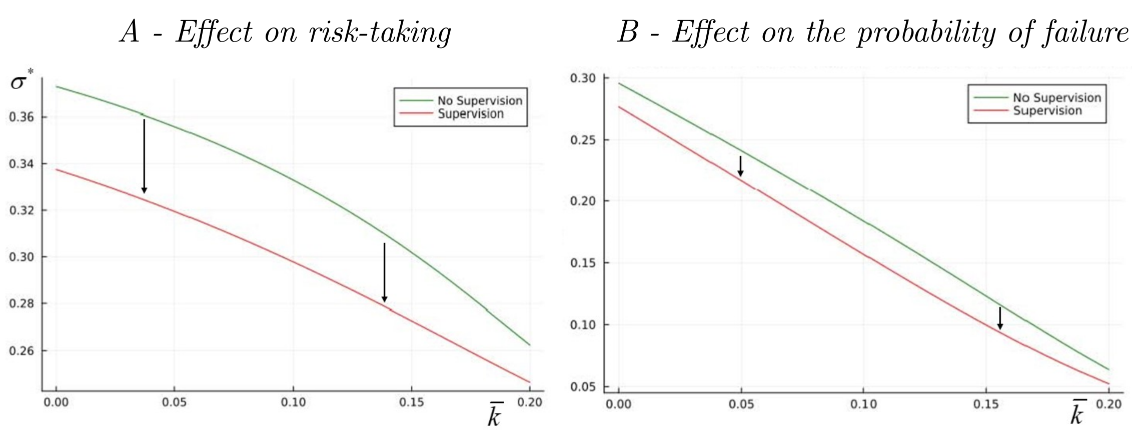

Figure 10. Effect of capital requirements and supervision on risk-taking and the probability of failure

This figure shows the relationship between the capital requirement (in the horizontal axis) and the bank's choice of risk (Panel A) and probability of failure (Panel B) with and without supervision.

[13] The correspondence between the variables in the expression in the Appendix and the variables in the model is as follows: $x_1=R-(1-\overline{k})$, $x_2=s$, $\mu_1=\overline{R}-(1-\overline{k})$, $\mu_2=\overline{R}$, $\sigma_1=\sigma$, $\sigma_2=\sigma\sqrt{1+\tau}$, $\rho=1/\sqrt{1+\tau}$, $\overline{x}_1=0$, and $\overline{x}_2=\widehat{s}$.

The bank's probability of failure under regulation and supervision is given by

$$\begin{aligned}\Pr(R < 1-\overline{k} \text{ or } s < \widehat{s}) &= 1 - \Pr(R \geq 1-\overline{k} \text{ and } s \geq \widehat{s}) \\ &= 1 - \Phi\left(\frac{\overline{R}-(1-\overline{k})}{\sigma^*(\overline{k};\tau)}, \frac{\sqrt{1+\tau}[\overline{R}-(1-\overline{k})]}{\sigma^*(\overline{k};\tau)}; \frac{1}{\sqrt{1+\tau}}\right).\end{aligned}$$

Panel B of Figure 10 shows the effect of the capital requirement $\overline{k}$ (in the horizontal axis) on the bank's probability of failure (in the vertical axis) for $\tau \to \infty$ (no supervision) and $\tau = 1$ (supervision). The effect of regulation and supervision on the bank's probability of failure mirrors their effect on the bank's choice of risk shown in Panel A.

The conclusion that follows from this analysis is that the effects of supervision on risk-taking and the probability of failure do not vary much with the capital requirement. Thus, for any given quality of the supervisory information, one could target a desired level of safety and soundness by adjusting the capital requirement.

It is important to note that there is an additional role of supervision that it is not taken into account in these results, namely ensuring the compliance with the regulation. Our focus is on the assessment of solvency by gathering confidential supervisory information and the use of this information to take corrective actions (in our case liquidation). But the very significant effects of regulation on risk-shifting incentives require that it be properly enforced, which is a key role of bank supervision.

7 Concluding remarks

This paper presents a model of the interaction between a bank that chooses the risk of its investment portfolio and a supervisor that collects nonverifiable information on the future solvency of the bank and, based on of this information, may decide on its early liquidation. The paper characterizes the liquidation decision of the supervisor and the risk-taking decision of the bank. In line with recent empirical literature, the paper shows that supervision is effective in ameliorating the bank's risk-shifting incentives, and that a tougher supervisor leads to lower risk-taking. Somewhat surprisingly, it shows that higher noise in the supervisory information may be conducive to lower risk-taking, but that it always reduces welfare.

I would like to conclude with a few remarks. First, the beneficial effects of a tough supervisor are reminiscent of the old literature on the benefits of delegating monetary policy to a conservative central banker, that is a central banker with preferences biased towards price stability. Such central banker delivers better outcomes in terms of both employment and inflation. In our case, delegation of supervision to an agent with preferences biased towards liquidation delivers better outcomes in terms of risk-taking.

Second, it should be noted that the closure of a bank by a supervisor using the failing or likely to fail need not imply liquidation, since it could lead to the transfer of the bank to another authority (such as the Federal Deposit Insurance Corporation in the US or the Single Resolution Board in the European Union) that would decide between resolution and liquidation. In this case the bank would only be liquidated it is efficient to do so, that is when the conditional expected liquidation return is greater than the conditional expected final return. Either way, the bank shareholders would be wiped out (and the management fired), which is key for controlling risk-taking incentives.

Third, the model is static, but one could easily construct a dynamic version with endogenous charter values. As it is well known in the banking literature (see, for example, Repullo, 2004), charter values (the discounted value of future rents) provide incentives for prudent bank behavior, so one would expect that the effect of both regulation and supervision be more muted.

Appendix

Some useful properties of normal distributions

This Appendix summarizes four properties of the expectation of normal random variables used in the paper.[14] Consider a pair (x_1, x_2) of random variables with

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \sim N\left(\begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}, \begin{bmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix} \right),$$

where $-1 < \rho < 1$.

The first property is the expectation of x_1 conditional on x_2, which is

$$E(x_1 \mid x_2) = \mu_1 + \frac{\rho\sigma_1}{\sigma_2}(x_2 - \mu_2). \tag{18}$$

The second property is the expectation of x_1 conditional on $x_1 \geq \overline{x}_1$, which is

$$E(x_1 \mid x_1 \geq \overline{x}_1) = \mu_1 + \sigma_1 \frac{\phi\left(\frac{\mu_1 - \overline{x}_1}{\sigma_1}\right)}{\Phi\left(\frac{\mu_1 - \overline{x}_1}{\sigma_1}\right)}.$$

Since

$$\Pr(x_1 \geq \overline{x}_1) = \Phi\left(\frac{\mu_1 - \overline{x}_1}{\sigma_1}\right),$$

this implies

$$E(x_1 \mid x_1 \geq \overline{x}_1)\Pr(x_1 \geq \overline{x}_1) = \mu_1 \Phi\left(\frac{\mu_1 - \overline{x}_1}{\sigma_1}\right) + \sigma_1 \phi\left(\frac{\mu_1 - \overline{x}_1}{\sigma_1}\right). \tag{19}$$

The third property is the expectation of x_1 conditional on $x_1 \geq \overline{x}_1$ and $x_2 \geq \overline{x}_2$, which is

$$\begin{aligned} E(x_1 \mid x_1 \geq \overline{x}_1 \text{ and } x_2 \geq \overline{x}_2) \quad = \quad & \mu_1 + \frac{\sigma_1}{F(\overline{x}_1, \overline{x}_2)} \phi\left(\frac{\overline{x}_1 - \mu_1}{\sigma_1}\right) \Phi\left(\frac{\rho\frac{\overline{x}_1 - \mu_1}{\sigma_1} - \frac{\overline{x}_2 - \mu_2}{\sigma_2}}{\sqrt{1-\rho^2}}\right) \\ & + \frac{\rho\sigma_1}{F(\overline{x}_1, \overline{x}_2)} \phi\left(\frac{\overline{x}_2 - \mu_2}{\sigma_2}\right) \Phi\left(\frac{\rho\frac{\overline{x}_2 - \mu_2}{\sigma_2} - \frac{\overline{x}_1 - \mu_1}{\sigma_1}}{\sqrt{1-\rho^2}}\right) \end{aligned}$$

where

$$F(\overline{x}_1, \overline{x}_2) = \Pr(x_1 \geq \overline{x}_1 \text{ and } x_2 \geq \overline{x}_2) = \Phi\left(\frac{\mu_1 - \overline{x}_1}{\sigma_1}, \frac{\mu_2 - \overline{x}_2}{\sigma_2}; \rho\right)$$

[14] See the Appendix in Maddala (1983). He cites the work of Rosenbaum (1961) for the moments of the truncated bivariate normal distribution.

and $\Phi(\cdot,\cdot;\rho)$ is the cumulative distribution function of a standard bivariate normal distribution with correlation coefficient ρ. This implies

$$\begin{aligned}
&E(x_1 \mid x_1 \geq \overline{x}_1 \text{ and } x_2 \geq \overline{x}_2)\Pr(x_1 \geq \overline{x}_1 \text{ and } x_2 \geq \overline{x}_2) \\
&\quad = \mu_1\Phi\left(\frac{\mu_1-\overline{x}_1}{\sigma_1},\frac{\mu_2-\overline{x}_2}{\sigma_2};\rho\right) + \sigma_1\phi\left(\frac{\overline{x}_1-\mu_1}{\sigma_1}\right)\Phi\left(\frac{\rho\frac{\overline{x}_1-\mu_1}{\sigma_1}-\frac{\overline{x}_2-\mu_2}{\sigma_2}}{\sqrt{1-\rho^2}}\right) \\
&\qquad +\rho\sigma_1\phi\left(\frac{\overline{x}_2-\mu_2}{\sigma_2}\right)\Phi\left(\frac{\rho\frac{\overline{x}_2-\mu_2}{\sigma_2}-\frac{\overline{x}_1-\mu_1}{\sigma_1}}{\sqrt{1-\rho^2}}\right) \qquad (20)
\end{aligned}$$

The fourth property specializes the previous result for the case where $\overline{x}_1 = -\infty$, which gives

$$E(x_1 \mid x_2 \geq \overline{x}_2)\Pr(x_2 \geq \overline{x}_2) = \mu_1\Phi\left(\frac{\mu_2-\overline{x}_2}{\sigma_2}\right) + \rho\sigma_1\phi\left(\frac{\overline{x}_2-\mu_2}{\sigma_2}\right). \qquad (21)$$

From here it follows that

$$\begin{aligned}
E(x_1 \mid x_2 < \overline{x}_2)\Pr(x_2 < \overline{x}_2) &= E(x_1 \mid -x_2 > -\overline{x}_2)\Pr(-x_2 > -\overline{x}_2) \\
&= \mu_1\Phi\left(\frac{\overline{x}_2-\mu_2}{\sigma_2}\right) - \rho\sigma_1\phi\left(\frac{\mu_2-\overline{x}_2}{\sigma_2}\right). \qquad (22)
\end{aligned}$$

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