I Spy with my Little Eye... a Banking Crisis

Early Warnings and Compensation Systems in Banks*

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Abstract

There is a puzzle concerning the anticipation of the banking crisis. Despite warning signs, the financial system seems to have been unable to aggregate the existing information. It went into the crisis predominantly unprepared. We construct a theoretic model of a bank that is financed with debt and equity, and a bank manager monitoring the bank's loan portfolio. The manager must be incentivized to warn the owners before a crisis. However, we find that the owners may implement a contract with too low incentives to communicate a warning, as refinancing conditions deteriorate when lenders notice an upcoming crisis. We discuss policies to improve information efficiency.

Keywords: Banking crises, information propagation, information efficiency, incentives, compensation, regulation.

JEL-Codes: G01, G21, L22.

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"Powerful few saw crash coming: I think a lot of people actually saw this train barreling down the tracks, CEOs, people in government, and they weren't telling us."

Andrew Ross Sorkin, New York Times columnist, 2009

1 Introduction

The financial crisis hit many by surprise. This is startling, given that warnings had been uttered in a number of notes and articles (see, e. g., Shiller, 2005; Rajan, 2006).[1] The chief economist of the Northern Trust Corporation, Paul Kasriel, already warned in 2004 of increased risks in the housing markets and the enormous effect this could have on the banking system and the whole economy (Kasriel, 2004). On the organizational level, inside individual banks, many expected a credit crunch (see the above citation). However, the information often was only inside the institutions, but was not forwarded to outsiders. If the information was publicly available, it does not seem to have been noticed sufficiently. So how could it happen that the necessary information did not reach the relevant regulatory authorities, and that banks predominantly went into the crisis unprepared? How was it possible that a crisis of this magnitude had not been anticipated?

Responding to the recent financial crisis, the U. S. Congress passed the Dodd-Frank Act, establishing the Financial Stability Oversight Council (FSOC). Its task is to identify and monitor excessive risks to the financial system. This central institution, collecting all available information regarding financial stability and providing early warnings, is meant to help prevent future crises. However, the crucial question is how to make information available for the FSOC in the first place, and how to set incentives for insiders to communicate significant information.

We construct a theoretical model with endogenous communication of warning signals in the banking system. There are three agents: bank owners, a bank manager, and lenders. The bank is financed with short-term debt and equity. It invests in a project, e. g., in a loan portfolio. The project can be in one of three states (good, critical, and default). In the good state, it cannot fail immediately. It must first pass through the critical state before potentially defaulting. The manager is needed for monitoring the project. Monitoring is costly, but reduces the probability of default and informs about the state of the project. Thus, the manager knows the state of the project, and can decide to communicate the transition. The owners can then react to cut losses, in the model by downsizing the portfolio. Hence, the manager's report is needed as an early warning.

[1] For instance, Rajan (2006) pointed out: "The inter-bank market could freeze up, and one could well have a full blown financial crisis."

Endogenously, the report has negative consequences for the manager; hence she needs to be incentivized to warn the owners. But if the owners react by cutting losses, this action is observed by financial markets. The bank's refinancing conditions deteriorate. Because of this externality to financial markets (lenders), the owners themselves face a reduced incentive to set up a compensation package that entails information efficiency. We thus ask the question, under which conditions do we find contractual arrangements that facilitate the propagation of critical information? Or, in other words, which factors influence the financial market's information efficiency?

From our analysis, we obtain a number of positive and normative results. First, the functioning of the information channel depends on the bank's equity ratio. The higher its leverage, the more the bank is hit by a deterioration of its refinancing conditions and the less prone the board is to implement the efficient contract. Thus, if the debt level is high, the board fears the negative information to become public most, because soaring financing costs are more costly the higher the debt is. Second, it depends on the project's future returns. If the profitability of the project is low, it does not pay for the board to incentivize the manager to monitor. Additionally, it is also an effect of competition. Low returns are typically found in a banking sector with high competition which would lead to less information efficiency. The low returns also increase the moral hazard problem, such that not only communication is reduced but also monitoring of the project. Before and during a financial crisis, typically both effects arise; the leverage of banks is likely to increase, and the bank's asset value drops. These effects tend to choke the information channel. Hence the model explains the blocked information transmission both before and during a financial crisis.

Normatively, the model can be used to test what types of financial regulation prohibit the choking of the information channel. We obtain two interesting results regarding different policy implications. First, capital regulation has a positive effect on the information channel. The higher the capital restrictions are, the higher the probability for communication in the bank. On the other hand, capital restrictions limit the overall investment size. Both effects, in our setup, lead to the result that stricter capital standards may increase welfare under certain conditions, for example if profitability of the project or the probability of the negative signal is not too high. Second, we find that the information channel is kept clear if contingent convertible bonds rather than straight bonds are used for refinancing. These bonds are converted into shares after a drop in the bank's share price, hence after the negative information triggered by the manager. In our setting, the conversion must come at a loss for lenders. This loss is anticipated; hence interest rates before the conversion increases. But the information is then less negative for the bank, because after the conversion, it no longer needs to fear an increase in refinancing rates. Thus, the deterrence from implementing an informative contract is reduced.

The remainder of the paper is organized as follows. After a discussion of the related literature, Section 2 introduces our theoretical model. Section 3 discusses equilibria, starting with the communication equilibrium (in 3.1), then the no-communication equilibrium with monitoring (in 3.2), a mixed-strategy equilibrium (in 3.3) and finally the no-monitoring equilibrium (in 3.4). Section 3.5 analyzes conditions for the different equilibria. Section 4 shows the optimality of the communication equilibrium. Section 5 discusses several policy implications, as mentioned above. Section 6 concludes. Proofs are in the appendix.

Literature. Our paper connects to different strands of the economic literature. First, there are a number of related articles in the field of banking and compensation systems in banking. Fahlenbrach and Stulz (2011), for example, investigate the bank performance and CEO compensation during the financial crisis. Barro and Barro (1990) and John, Mehran, and Qian (2010) also analyze factors influencing CEO compensation in banks. In our model, the choice of compensation contracts has an effect on the information channel before and during a financial crisis. In equilibrium, wage payments are chosen to set incentives for information.

Second, the paper is related to agency theory within corporate finance. Aghion and Tirole (1997) argue that less communication and transfer of information from agent to principal may take place if the principal has formal authority as the agent is afraid of an abuse of the authority by a well informed principal. The paper of Aghion and Tirole deliberates the benefits of delegating formal authority versus the costs of losing it. In our setting, the lack of information stems from the bank's fear of higher (that is adjusted) risk compensation if the lenders are well informed. Benmelech, Kandel, and Veronesi (2010) find that stock-based compensation not only induces managers to exert costly effort but also to hide bad news about future growth options. This may also result in sub-optimal investment. Another paper that discusses lack of information in a principal agent setting is by Kanodia, Bushman, and Dickhaut (1989). In their model, agents do not change decisions once they are made because of a fear of revealing negative information about their human capital by admitting that another strategy might be better than the first chosen.

The literature on financial reporting is vast (see Verrecchia, 2001, for a survey). Here, financial reporting is a tool to mitigate and resolve agency problems. An example of this huge literature is the article of Lóránth and Morrison (2009) which is closely related to our model as the authors analyze the interdependency between internal information transmission and loan officer compensation in banks. Our model, however, differs from the above mentioned articles in several aspects. We analyze more than one agency problem: asymmetric information exists not only between the manager and the board of a bank but also between the bank and the financial markets lending money to the bank. However, we do not distinguish between different kinds of information (for example soft and hard information as in, e. g., Lóránth and

Morrison, 2009). We show that reporting or communication may always increase welfare, if the loan portfolio of the bank is monitored.

Third, there is a literature on dynamic contracting under asymmetric information. For example, Quadrini (2004) and DeMarzo and Fishman (2007) try to find and analyze contracts that reveal full information. Our result verifies that transfer of information is welfare optimal if effort costs are not too high. We also discuss policy implications to reach the equilibrium of communication and full information. However, the full revelation principle does not apply in our setting because of our structure of only short-term contracts.

We have a continuous-time moral hazard model at the heart of the paper. The lively continuous-time moral hazard literature is pushed forward mainly by two groups, Biais, Mariotti, Plantin, and Rochet (2007); Biais, Mariotti, Rochet, and Villeneuve (2010); Pagès (2009) as well as DeMarzo and Sannikov (2006); Sannikov (2007, 2008). However, we keep the model as simple as possible, basing it on a three-state Markov process.

The communication of bad news is somewhat similar to the communication of fraud. This is the subject of the literature on whistleblowing. Dyck, Morse, and Zingales (2010) analyze data about corporate frauds that took place in the U. S. and the actors that detect the fraud. They find that employees seem to lose outright from whistleblowing. This result underlines the need for better incentivizing for communication. In a dynamic setting, Povel, Singh, and Winton (2007) examine the incentives of not only bank managers but managers of any industry to commit fraud when firms seek funding from investors and investors can monitor firms at a cost to get a better signal about the true perspectives of the firm. In contrast to our model, fraud is not modeled to lead to a crisis or recession but the incentives for fraud change over the business cycle.

There are a number of articles with models in which not to collect information may have a positive effect for an agent under certain conditions (Carrillo and Mariotti, 2000; Kessler, 1998). This is called strategic ignorance. In our setup, we show that, without regulation, the board of the bank may also implement a contract that does not lead to a communication of information. We also define the conditions under which this equilibrium arises.

2 The Model

Consider a continuous time economy with three types of agents: a bank's board of directors (short: board), a bank manager (short: manager) and lenders. The structure of the model is given in Figure 1.

The **board** takes decisions on behalf of the owners (equity investors), who provide an endowment of E. The board (and equity investors) is risk-neutral and does not discount.

The bank can invest into a **project** (a loan portfolio) of size $I > E$ that pays a continuous return of R per unit of investment each period until it defaults. In our model, projects can be in three different states: class A, class B, and default. Class B projects can default at any time, the default intensity is $\beta > R$. Class A projects cannot default right away, they first deteriorate to class B projects, emitting a negative signal to the manager. The instantaneous probability of such a downgrading is $\alpha < \beta$ if the project is monitored, and $\alpha + \gamma$ if not monitored. The transition between classes A and B is observed only by the manager. Formally, we have a Markov chain with three states: A, B, and the default state. Transition goes only in one direction, from A to B to default, which is an absorbing state. The transition probability from A to B can be controlled by the manager. Initially, the project can be in state A (with probability $(\beta - \alpha)/\beta$) or B (with probability α/β).[2]

After investment, a fraction λ of the project can be liquidated at no cost, the rest $(1 - \lambda)$ cannot be liquidated at all. Hence, λ measures the liquidity of the project. Because $\beta > R$, the board wants to liquidate as much as possible of a project in class B. Hence, the information about a class transition is valuable, and the more valuable the higher the liquidity of the project. In the case of a loan portfolio, λ would be determined by the duration of contracts, and potentially by covenants in the contract. This λ is important for our model, as it measures the value of getting prepared in the eve of a crisis.

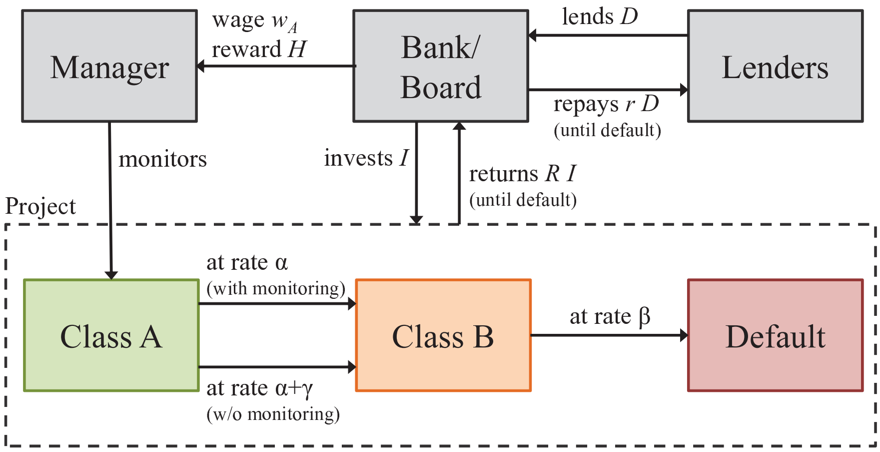
Monitoring is carried out by the **manager**; it costs an instantaneous c per unit of investment. The monitoring choice is not observable. The manager is risk-neutral and has a discount rate of ρ.[3] Discounting implies that the manager prefers her salary to be paid out early. Deferring payments comes at a cost. The manager's opportunity wage is w_0. Without loss of generality, we normalize $w_0 = 0$.

Lenders are risk-neutral and do not discount. They have an endowment of more than $I - E$, thus they can provide finance for the project. There is debt-finance, where $D = I - E$ is the amount of debt. The lenders lend at a competitive rate, hence the risk-free rate is zero. For the actual interest rate r that the bank must pay, its current default risk is taken into account. The lenders observe when the project is downsized and when the manager is assigned new tasks. They do not observe the

[2]With this initial setting, the expected project quality is unchanged as long as the manager monitors. The project has an initial expected quality as if it had already been monitored before. Mathematically, we start on an eigenvalue of the dynamic system.

[3]The assumption that managers discount more heavily is standard in the corporate finance literature, see for example Tirole (2006), based on Aghion, Bolton, and Tirole (2004). It is used to endogenize short-term compensation.

Figure 1: Structure of the Model



actual wage contract for the manager. All contracts (debt and labor contracts) are short-term; there is no long-term commitment. Consequently, the contracting space is incomplete. The short-term contracting is in line with maturity transformation that banks carry out given the project is long term.

One can interpret this model as follows. The manager is a bank employee who is incentivized to monitor a loan portfolio. She can observe the quality of the loan (A or B). Loans in class B can default at any time, so the manager can exert effort for monitoring in order to reach the lower transition rate α instead of $\alpha + \gamma$ and to keep the loans in class A as long as possible. But because the effort choice is not observable, the manager collects an additional rent as incentive, which she does not want to lose. The board would like to know the class of the loans. It wants to react upon that information, for example by restructuring a loan that deteriorates, or by increasing reserves. In our model, we have two advantages of early information. First and foremost, the board may liquidate a fraction λ of the project. This way, it can cut losses. The second reason is endogenous: The manager discounts at a higher rate, so she wants her salary as early as possible. As long as the manager needs to be incentivized, wages must be paid continuously such that monitoring does not break down. But when the project is in class B, the manager's effort is no longer needed. The board benefits from paying only the opportunity costs of the manager w_0 after the transition date. There is no need to promise future incentive wages. In other words, a compensation package is put up to incentivize the manager. However, when negative information arrives, this package is changed, to the detriment of the manager. Therefore, the manager reports the deterioration only reluctantly. She needs to be compensated, for example with a one-off reward.

The model thus contains the following features. An insider in a leveraged bank has preferential access to information about the bank's assets. She needs to be incentivized to communicate this information. She may see the crisis coming, but not let others know. Giving her the right incentives is costly. The costs are born entirely by the bank, but the bank's lenders also benefit because they can raise interest rates. As a consequence, the board has insufficient incentives to implement a contract that informs markets. Using this model, we can analyze what factors drive the information propagation. Possibly, the manager foresees an upcoming crisis, but decision makers and markets are left ignorant.

3 Equilibrium

There are three potential types of equilibrium, with different wage contracts. In all cases, the manager receives at least her opportunity costs w_0 as fixed salary. *First*, the board can pay the manager zero incentive wages in addition to w_0. As a consequence, the manager does not monitor the project, the decay rate of class A projects is $\alpha + \gamma$ rather than just α. This equilibrium is indexed with a '0' (for no monitoring and no communication). *Second*, the board can pay the manager w_0 plus an incentive wage until the project defaults. In this case, the manager has no incentive to inform the board about the true class of the project, because as soon as the board would get to know that the project is in class B, it would stop paying incentive wages. Therefore, the wage cannot depend on the class of the project. In this equilibrium, the wage is just high enough to induce the manager to exert effort (efficiency wage). This equilibrium is indexed with 'NC' (for no communication). *Third*, the board can promise the manager a one-off reward H for admitting when the project moves to class B. The board then reacts by liquidating part of the project, and by cutting back the competence and wage of the manager. In this equilibrium, information flows to the board and, as a consequence, to the capital market. Lenders take the downsizing as negative information and increase interest rates. The benefit of the reward H is to get the negative information as soon as possible, and to react. Otherwise, the incentive payments to the manager would only add to the wage bill. This equilibrium is indexed with a 'C' (for communication). We show that besides one further equilibrium (indexed with 'Mix') that mixes between 'C' and 'NC', there are no other types of equilibria. We start with discussing the most interesting equilibrium C.

3.1 The Communication Equilibrium (C)

In this equilibrium, the board pays w_0 and a positive efficiency wage w_A^* to the manager until the date when the manager admits that the project class has deteriorated.

At that date (t_A), the manager is promised a one-off reward H^* as a compensation. We now calculate the equilibrium values for w_A^* and H^*, and expected profits in equilibrium.

The Lenders. Within this equilibrium, the lenders are always informed about the project class. As long as there are no news about the project, it is in class A. But when the manager receives the reward and the project is downsized, the only reason can be that the class has switched to B. Interest rates r_A and r_B are set accordingly.

As long as the project is in class A, the lenders know that the instantaneous default rate is zero. Opportunity costs of lending are zero, thus they demand no interest rates, $r_A = 0$. After a negative signal, the instantaneous probability of default is β, so the lenders must be compensated by an interest rate of $r_B > 0$. The repayment after $\mathrm{d}t$ periods is then $e^{r_B \,\mathrm{d}t} D$, leading to an expected repayment of $e^{r_B \,\mathrm{d}t} e^{-\beta \,\mathrm{d}t} D = e^{r_B - \beta \,\mathrm{d}t} D$. The participation constraint is binding for lenders. The interest rate r_B is only just sufficient to compensate the lenders for the opportunity cost of 0. Hence, $r_B = \beta$.

The Manager. In the communication equilibrium C, the manager works on the project until she receives and transmits information about a deterioration. She then receives a reward H, but the future wage is reduced. Wage w_A and reward H have to be chosen such that the manager behaves as required. Assume for a moment that the manager is at date t_A, hence the transition from class A to B has just occurred. The manager now decides whether to communicate the bad news. If she does, she gets a one-off reward H. If she does not, she gets the incentive wage w_A until the project defaults. Her expected utility additional to her utility from the reservation wage w_0 is then

$$\begin{aligned} U_B &= \int_0^{\infty} \Big(\int_0^{t_B} w_A \, e^{-\rho t} \mathrm{d}t \Big) \beta \, e^{-\beta t_B} \, dt_B \\ &= \frac{w_A}{\beta + \rho}. \end{aligned} \tag{1}$$

This term consists of several parts. The project is already in class B, hence the date t_B at which the loan finally defaults is distributed with density $f(t_B) = \beta \, e^{-\beta t_B}$. Until this date, the manager collects her wage w_A, discounted with the factor $e^{-\rho t}$. The reward H must be at least as large as this term. In equilibrium, the inequality is binding, $H = w_A/(\beta + \rho)$. Note that the optimal reward H is proportional to the wage w_A. The reward compensates the manager for forgone wages. Hence, the higher the wages, the higher H must be.

The wage w_A must be high enough to motivate the manager to monitor the project. If she does monitor a loan in class A, the manager's expected utility is

$$\begin{aligned} U_A &= \int_0^\infty \left[e^{-\rho\, t_A}\, H + \int_0^{t_A} (w_A - c\, I)\, e^{-\rho\, t}\, \mathrm{d}t \right] \alpha\, e^{-\alpha\, t_A}\, \mathrm{d}t_A \\ &= \frac{\alpha\, H + w_A - c\, I}{\alpha + \rho}. \end{aligned} \tag{2}$$

Again, there are several parts. If the project is monitored, the stochastic time of transition to class B is distributed with density $f(t_A) = \alpha\, e^{-\alpha\, t_A}$. At date t_A, the manager collects the reward H, discounted with the factor $e^{-\rho\, t_A}$. Until that date, from now to t_A, she gets the wage w_A but exerts the effort at cost $c\, I$, both also discounted with the factor $e^{-\rho\, t}$.

Now assume the manager decides whether to monitor in the next period of duration $\mathrm{d}t$. If she does monitor, her expected utility is

$$\alpha\, \mathrm{d}t\, H\, e^{-\rho\, \mathrm{d}t} + (1 - \alpha\, \mathrm{d}t)\, U_A\, e^{-\rho\, \mathrm{d}t} + (w_A\, e^{-\rho\, \mathrm{d}t} - c\, I)\, \mathrm{d}t. \tag{3}$$

With probability $\alpha\, \mathrm{d}t$, the class switches from A to B, and the manager collects her reward H, to be discounted with $e^{-\rho\, \mathrm{d}t}$. With converse probability $(1 - \alpha\, \mathrm{d}t)$, the project remains in A, and the aggregate future utility is given by U_A as in (2). Over the period $\mathrm{d}t$, the wage w_A is collected and effort costs $c\, I$ are paid. However, if the manager chooses not to monitor, her expected utility becomes

$$(\alpha + \gamma)\, \mathrm{d}t\, H\, e^{-\rho\, \mathrm{d}t} + (1 - (\alpha + \gamma)\, \mathrm{d}t)\, U_A\, e^{-\rho\, \mathrm{d}t} + w_A\, \mathrm{d}t, \tag{4}$$

with U_A defined in (2). The transition probability increases from $\alpha\, \mathrm{d}t$ to $(\alpha + \gamma)\, \mathrm{d}t$, but the manager forgoes the cost $c\, I$. In equilibrium, the board sets the wage w_A just high enough to induce effort, (3) = (4). Solving for w_A^* and H^* and taking the limit $\mathrm{d}t \to 0$, we get the following lemma.

Lemma 1 *Optimal wage and reward in the communication equilibrium are*

$$w_A^* = \frac{(\beta + \rho)\, (\alpha + \gamma + \rho)}{\gamma\, \beta}\, c\, I \quad \textit{and} \tag{5}$$

$$H^* = \frac{\alpha + \gamma + \rho}{\gamma\, \beta}\, c\, I. \tag{6}$$

The Board. We can finally calculate the bank's expected profit in this equilibrium. The board implements a contract that pays a wage $w_0 + w_A^*$ to the manager, and a reward H^* when a downgrade in the project class is reported. But even after that, the project continues to pay off. The default rate is β, and as long as the project does not default, it pays a continuous $R\,I\,(1-\lambda)$ as a fraction λ of the investment is recalled after the downgrade and used for a reduction of the debt. The expected aggregate payoff to the bank, net of interest payments, is

$$\begin{aligned}
\Pi_{\mathrm{C}} = \frac{\beta-\alpha}{\beta} \int_0^\infty \Big[\int_0^{t_A} (R\,I - r_A\,D - w_A)\,\mathrm{d}t - H \\
+ \int_{t_A}^\infty \Big\{ \int_{t_A}^{t_B} (R\,I\,(1-\lambda) - r_B\,(D - \lambda\,I))\,\mathrm{d}t \Big\}\,\beta\,e^{-\beta\,(t_B - t_A)} dt_B \Big]\,\alpha\,e^{-\alpha\,t_A}\,\mathrm{d}t_A \\
+ \frac{\alpha}{\beta} \Big[-H + \int_0^\infty \Big\{ \int_0^{t_B} (R\,I\,(1-\lambda) - r_B\,(D - \lambda\,I))\,\mathrm{d}t \Big\}\,\beta\,e^{-\beta\,t_B}\,dt_B \Big] \\
= \frac{R\,I}{\alpha} - \frac{(R - r_B)\,\lambda\,I}{\beta} - H^* - \frac{\alpha\,r_B\,D + (\beta-\alpha)\,(w_A^* + r_A\,D)}{\alpha\,\beta} \\
= \frac{R\,I}{\alpha} + \Big(1 - \frac{R}{\beta}\Big)\,\lambda\,I - D - \frac{(\alpha+\gamma+\rho)\,(\beta^2 + \rho\,(\beta-\alpha))}{\gamma\,\alpha\,\beta^2}\,c\,I. \qquad (7)
\end{aligned}$$

There are several parts. The board does not know whether the project is in class A or B at the start. With probability $(\beta-\alpha)/\beta$, it starts in class A. The date t_A of transition to class B is stochastic, with density $f(t_A) = \alpha\,e^{-\alpha\,t_A}$. Until this date t_A, the bank receives $R\,I$ from the project, but pays $r_A\,D$ to lenders and the wage w_A to the manager. At date t_A, the manager reports the transition, hence the board pays the reward H. The information becomes public, raising the refinancing rate from $r_A = 0$ to $r_B = \beta$. The size of the project is now $I\,(1-\lambda)$, the outstanding debt is $D - \lambda\,I$, both smaller than before. The project may now default at any time, and the default date t_B is distributed with density $f(t_B) = \beta\,e^{-\beta\,(t_B - t_A)}$, starting at date t_A. With probability α/β, the project starts in class B right away. The board immediately pays the reward, recalls part of the loan, and collects $R\,I\,(1-\lambda)$ and pays $r_B\,(D - \lambda\,I)$ for refinancing until the project defaults. Inserting w_A^*, H^*, $r_A = 0$ and $r_B = \beta$, we get equation (7).

However, for the board, it may not be optimal to implement a contract that induces the manager to monitor and communicate information. Out of equilibrium, the board may profit from low refinancing conditions, but save the reward H of even the efficiency wage w_A. Lenders anticipate this behavior, and equilibrium C breaks down. For example, if the monitoring cost c is high in comparison to γ, then it may be optimal to pay the manager lower incentive wages w_A (in fact, zero wages). The optimal reward H would then also be zero. If the difference between R and the default intensity in class B β is very small, there is not much incentive to reduce the outstanding debt. Also, the board might want to induce the manager to monitor, but not to communicate the deterioration of project quality. Looking at the board's incentives out of equilibrium, we derive the following conditions (with proof in the appendix). The parameter range is plotted in Figure 2 below on page 17.

Proposition 1 *The equilibrium 'C' with efficiency wage and reward as in Lemma 1 exists if and only if*

$$D \leq \left(1 - \frac{R}{\beta}\right) \lambda I + \frac{\rho(\alpha + \gamma + \rho)}{\gamma \beta^2} c I, \tag{8}$$

otherwise the board deviates and leaves the reward out of the contract,

$$D \leq \frac{\gamma(\beta - \alpha)}{\alpha(\alpha + \gamma)\beta} R I + \left(1 - \frac{R}{\beta}\right) \lambda I - \frac{(\alpha + \gamma + \rho)\left(\beta^2 + \rho(\beta - \alpha)\right)}{\gamma \alpha \beta^2} c I, \tag{9}$$

otherwise the board deviates and drops the efficiency wage.

3.2 The No-Communication Equilibrium (NC)

We now discuss equilibrium NC, in which the board induces the manager to monitor the loan, but does not pay a reward when informed about a rating transition. Without the reward, the manager is not incentivized to communicate. We follow the same structure as above.

The Lenders. The lenders anticipate not to get any information about the project's current class. They must therefore set interest rates according to their beliefs. Initially, the project is in class A with probability $(\beta - \alpha)/\beta$, and in class B with probability α/β. In the first period of duration $\mathrm{d}t$, the expected return is thus

$$D(1 + r\,\mathrm{d}t)\, e^{-(\frac{\beta-\alpha}{\beta}\cdot 0 + \frac{\alpha}{\beta}\cdot\beta)\,\mathrm{d}t} = D(1 + r\,\mathrm{d}t)(1 - \alpha\,\mathrm{d}t) = D + D(r - \alpha)\,\mathrm{d}t. \tag{10}$$

The participation constraint is binding if initially $r = \alpha < \beta$. As time elapses, the beliefs about the class of the project might change. We argue that it is constant in our setting. Let us call $p_A(t)$ the probability that the project is in class A at date t, and $p_B(t)$ the probability that it is in class B, and $p_D(t)$ the probability that it has already defaulted. Then if the loan is monitored, the following differential equations describe the evolution of probabilities.

$$\dot{p}_A(t) = -\alpha\, p_A(t), \quad \dot{p}_B(t) = \alpha\, p_A(t) - \beta\, p_B(t), \tag{11}$$

with $p_D(t) = 1 - p_A(t) - p_B(t)$, and $p_A(0) = (\beta - \alpha)/\beta$, $p_B(0) = \alpha/\beta$, $p_D(0) = 0$. This linear ordinary differential equation can be solved,

$$p_A(t) = \frac{\beta - \alpha}{\beta} e^{-\alpha t}, \quad \text{and} \quad p_B(t) = \frac{\alpha}{\beta} e^{-\alpha t}. \tag{12}$$

Both probabilities decrease at the same rate α. The probability of a class A project decreases at rate α anyway, and class B projects diminish at rate β, but new class

B projects arrive from class A all the time, so the aggregate growth rate is also $-\alpha$. The reason is that we have chosen the initial condition, $p_A(0) = (\beta - \alpha)/\beta$ and $p_B(0) = \alpha/\beta$, as an eigenvector of the dynamic system. This makes the evolution of probabilities especially simple. The probability of being in class A, conditional on not being in default, is constant at $(\beta - \alpha)/\alpha$.

The Manager. If the board does not want to induce the manager to communicate, it sets $H = 0$. Consequently, we need to calculate the manager's behavior depending on the wage w_A only. Assume that the project is currently in class A. The manager's discounted expected utility is then

$$\begin{aligned} U_A &= \int_0^\infty \Big[\int_{t_A}^\infty \Big\{ \int_0^{t_A} (w_A - c\,I)\, e^{-\rho t}\, \mathrm{d}t + \int_{t_A}^{t_B} w_A\, e^{-\rho t}\, \mathrm{d}t \Big\} \beta\, e^{-\beta\,(t_B - t_A)}\, dt_B \Big] \alpha\, e^{-\alpha\, t_A}\, dt_A \\ &= \frac{\alpha + \beta + \rho}{(\alpha + \rho)\,(\beta + \rho)}\, w_A - \frac{c\,I}{\beta + \rho}. \end{aligned} \tag{13}$$

Let us give some intuition. The date t_A of transition from A to B is distributed with density $f(t_A) = \alpha\, e^{-\alpha\, t_A}$. For a given t_A, the final default date t_B is distributed with density $\beta\, e^{-\beta\,(t_B - t_A)}$. Between date 0 and t_A, the managers receives the wage w_A net of $c\,I$, discounted by $e^{-\rho t}$. Between t_A and t_B, she gets the wage but no longer exerts effort. From a project in class B, the expected utility would only be

$$\begin{aligned} U_B &= \int_0^\infty \Big\{ \int_0^{t_B} w_A\, e^{-\rho t}\, \mathrm{d}t \Big\}\, \beta\, e^{-\beta\, t_B}\, dt_B \\ &= \frac{w_A}{\beta + \rho}. \end{aligned} \tag{14}$$

Now assume the manager considers to deviate from the equilibrium behavior and not monitor for a short period $\mathrm{d}t$. If she behaves, the expected utility is

$$\alpha\, \mathrm{d}t\, U_B\, e^{-\rho\, \mathrm{d}t} + (1 - \alpha\, \mathrm{d}t)\, U_A\, e^{-\rho\, \mathrm{d}t} + (w_A\, e^{-\rho\, \mathrm{d}t} - c\,I)\, \mathrm{d}t. \tag{15}$$

If she shirks, the expected utility becomes

$$(\alpha + \gamma)\, \mathrm{d}t\, U_B\, e^{-\rho\, \mathrm{d}t} + (1 - (\alpha + \gamma)\, \mathrm{d}t)\, U_A\, e^{-\rho\, \mathrm{d}t} + w_A\, e^{-\rho\, \mathrm{d}t}\, \mathrm{d}t. \tag{16}$$

In equilibrium, the incentive condition is binding. Setting (15) = (16), taking the limit $\mathrm{d}t \to 0$ and solving for w_A yields

$$w_A^* = \frac{(\alpha + \gamma + \rho)\,(\beta + \rho)}{\gamma\, \beta}\, c\,I. \tag{17}$$

The wage is exactly as in the former equilibrium. This is not surprising, given that the manager was just indifferent between taking the reward or not..

The Board. In equilibrium, the bank's expected profit is

$$\begin{aligned}
\Pi_{\text{NC}} = \frac{\beta-\alpha}{\beta} \int_0^\infty \Big[& \int_0^{t_A} (R\,I - r\,D - w_A)\,\mathrm{d}t \\
& + \int_{t_A}^\infty \Big(\int_{t_A}^{t_B} (R\,I - r\,D - w_A)\,\mathrm{d}t \Big)\, \beta e^{-\beta\,(t_B - t_A)} dt_B \Big]\, \alpha e^{-\alpha\, t_A} dt_A \\
+ \frac{\alpha}{\beta} \int_0^\infty & \Big(\int_0^{t_B} (R\,I - r\,D - w_A)\,\mathrm{d}t \Big)\, \beta e^{-\beta\, t_B} dt_B \\
= \frac{R\,I - r\,D - w_A}{\alpha} & = \frac{R\,I}{\alpha} - D - \frac{(\gamma+\alpha+\rho)\,(\beta+\rho)}{\gamma\,\alpha\,\beta}\,c\,I,
\end{aligned} \tag{18}$$

consisting of different parts. While the earnings $R\,I$ and the payments $r\,D$ and w_A always remain the same as there is no new information during the process until default, the probabilities of default differ. With probability $(\beta-\alpha)/\beta$, the project initially is in class A, and with probability α/β it is in class B. At time t_A transition from class A to class B happens, with density $f(t_A) = \alpha\, e^{-\alpha\, t_A}$. At date t_B, the project may default with density $f(t_B) = \beta\, e^{-\beta\,(t_B - t_A)}$. Inserting w_A^* and $r = \alpha$ yields (18). The proof of the following proposition is in the appendix.

Proposition 2 *The equilibrium 'NC' with efficiency wage as in (17) but no reward exists if and only if*

$$D \leq \frac{R\,I}{\alpha} - \frac{(\alpha+\gamma)\,(\beta+\rho)\,(\gamma+\alpha+\rho)}{\gamma^2\,\alpha\,(\beta-\alpha)}\,c\,I, \tag{19}$$

otherwise the board deviates and drops the efficiency wage, and

$$D \geq \frac{\beta-R}{\beta-\alpha}\,\lambda\,I + \frac{\rho\,(\gamma+\alpha+\rho)}{\gamma\,\beta\,(\beta-\alpha)}\,c\,I, \tag{20}$$

otherwise the board prefers to have a reward for communication.

If the monitoring costs c are very high, it may be too expensive for the board to pay the incentive wage w_A. However, if the difference between refinancing costs β of class B and the returns of the project is high and there is not much difference between the two transition rates β and α, the board is more interested in receiving the information in order to be able to reduce the costly outstanding debt.

3.3 The Mixed-Strategy Equilibrium

So far, two equilibria are defined. However, there can be a mixture of these equilibria. As the boundaries of the two equilibria C and NC are not identical, the space between them is filled by an equilibrium in which both strategies are chosen with certain probabilities. The higher the debt level and the higher the increase of the refinancing costs after the warning, the more profitable it is for the board not to pay a reward. On the other hand, the increase of refinancing costs after the warning is reduced if the board does not pay the reward. Therefore, a mixed-strategy equilibrium, where the board randomizes between contracts with and without reward, exists. In the mixed-strategy equilibrium we assume the board to choose strategy C with probability p_{C} and strategy NC with probability $p_{\mathrm{NC}} = 1 - p_{\mathrm{C}}$. The lenders anticipate the mixed strategy and require the following interest rate r if they have no information about a transition of the project from class A to B,

$$\begin{aligned} r_{\mathrm{Mix}} &= \frac{0\, p_{\mathrm{C}}\, \frac{\beta-\alpha}{\beta} + 0\,(1-p_{\mathrm{C}})\, \frac{\beta-\alpha}{\beta} + \beta\,(1-p_{\mathrm{C}})\frac{\alpha}{\beta}}{p_{\mathrm{C}}\, \frac{\beta-\alpha}{\beta} + (1-p_{\mathrm{C}})\, \frac{\beta-\alpha}{\beta} + (1-p_{\mathrm{C}})\, \frac{\alpha}{\beta}} \\ &= \frac{(1-p_{\mathrm{C}})\,\alpha\,\beta}{\beta - \alpha p_{\mathrm{C}}}. \end{aligned} \tag{21}$$

The interest rate takes the expected probabilities of default into account. With probability $\frac{\beta-\alpha}{\beta}$, the project initially is in class A, and with probability $\frac{\alpha}{\beta}$ it is in class B. Only if strategy C (with probability p_{C}) is chosen and the project is in class B, the lenders and the board have exact knowledge about the probability of default, which in this case is β. The other three cases have to be summed up and weighted by the sum of their probabilities to calculate r. As the probabilities for being in class A or B both decay with the same rate α, proportions remain constant. Therefore, interest rate r remains constant during time as well.

The mixed-strategy equilibrium exists, if the board is indifferent between playing strategy C and playing strategy NC. Therefore, we can calculate probability p_{C} by setting $\Pi_{\mathrm{NC}} = \Pi_{\mathrm{C}}$ and inserting w_A^*, H^*, $r = r_{\mathrm{Mix}}$ and $r_B = \beta$,

$$\begin{aligned} \frac{R\,I - r\,D - w_A}{\alpha} &= \frac{R\,I}{\alpha} - \frac{(R-r_B)}{\beta}\,\lambda\,I - H - \frac{\alpha\,r_B\,D + (\beta-\alpha)\,(w_A + r\,D)}{\alpha\,\beta}, \\ p_{\mathrm{C}} &= \frac{\beta}{\alpha}\left(1 - \frac{\beta-\alpha}{\rho\,\frac{\alpha+\gamma+\rho}{\gamma\,\beta}\,c + \lambda\,(\beta-R)}\,\frac{D}{I}\right). \end{aligned} \tag{22}$$

In this mixed-strategy equilibrium, the board plays strategy C with probability p_{C} and strategy NC with probability $(1-p_{\mathrm{C}})$. Inserting r and p_{C} as in (21) and in (22), the bank's expected return is

$$\begin{aligned} \Pi_{\mathrm{Mix}} &= p_{\mathrm{C}}\,\Pi_{\mathrm{C}} + (1-p_{\mathrm{C}})\Pi_{\mathrm{NC}} = \Pi_{\mathrm{C}} \\ &= \frac{1}{\alpha}\left(R\,I + (\beta-R)\,\lambda\,I - \beta\,D - \frac{\alpha+\gamma+\rho}{\gamma}\,c\,I\right). \end{aligned} \tag{23}$$

Proposition 3 *If neither equilibrium C nor equilibrium NC exists and if*

$$D \leq \frac{R\,I}{\beta} + \left(1 - \frac{R}{\beta}\right) \lambda\, I - \left(\alpha + \gamma + \frac{\alpha\,(\beta+\gamma)\,\rho}{\beta^2}\right) \frac{\alpha+\gamma+\rho}{(\beta-\alpha)\,\gamma^2}\, c\, I, \tag{24}$$

then there is a mixed-strategy equilibrium in which strategy C and NC are mixed. Strategy C is chosen with probability p_C as in (22) and strategy NC is played with probability $(1-p_C)$.

3.4 The No-Monitoring Equilibrium

In this equilibrium (indexed with '0'), the board offers low wages and no reward. Consequently, the manager shirks, the loan is not monitored, and neither board nor lenders know whether the project is in class A or B.

The Lenders. Consider now equilibrium 0, in which the board pays only w_0 but neither the reward nor an efficiency wage. Consequently, the manager does not monitor the project. Hence, starting from a project that is in class A with probability $(\beta-\alpha)/\beta$ and in B with probability α/β, the average quality deteriorates continuously over time. Given that the project is not monitored, the transition from class A to B happens relatively fast. This is anticipated by the lenders. Formally, the decay rate in class A increases to $\alpha+\gamma$. The probabilities $p_A(t)$ and $p_B(t)$ are no longer an eigenvector of the dynamic system, so the evolution is

$$\begin{aligned} p_A(t) &= \frac{\beta-\alpha}{\beta}\, e^{-(\alpha+\gamma)\,t}, \quad \text{and} \\ p_B(t) &= \frac{\beta-\alpha}{\beta}\, \frac{\alpha+\gamma}{\beta-\alpha-\gamma}\, e^{-(\alpha+\gamma)\,t} - \frac{\gamma}{\beta-\alpha-\gamma}\, e^{-\beta\,t}. \end{aligned} \tag{25}$$

The instantaneous probability of default is then

$$\frac{0\cdot p_A(t) + \beta \cdot p_B(t)}{p_A(t)+p_B(t)} = \frac{(\alpha+\gamma)\,(\beta-\alpha) - \beta\,\gamma\, e^{-(\beta-\alpha-\gamma)\,t}}{\beta-\alpha-\gamma\, e^{-(\beta-\alpha-\gamma)\,t}}. \tag{26}$$

In order to break even at each point in time, the interest rate $r(t)$ must be equal to this rate. There is one more consequence. The probability that the project has defaulted at date t_B is

$$F(t_B) = 1 - \big(p_A(t) + p_B(t)\big) = 1 - \frac{(\beta-\alpha)\, e^{-(\alpha+\gamma)\,t_B} - \gamma\, e^{-\beta\, t_B}}{\beta - (\alpha+\gamma)}. \tag{27}$$

This is the probability distribution function of the default date t_B. The density function of the default date t_B is thus

$$f(t_B) = \frac{(\gamma+\alpha)\,(\beta-\alpha)\, e^{-(\alpha+\gamma)\,t_B} - \gamma\,\beta\, e^{-\beta\, t_B}}{\beta-(\alpha+\gamma)}. \tag{28}$$

The Board. The bank's expected profit in equilibrium 0 is

$$\begin{aligned}\Pi_0 &= \int_0^\infty \int_0^{t_B} \big(R\, I - r(t)\, D\big) \mathrm{d}t\, f(t_B)\, dt_B \\ &= \int_0^\infty \int_0^{t_B} (R\, I)\ \mathrm{d}t\, f(t_B)\, dt_B - D \\ &= \int_0^\infty (R\, I)\ t_B\, f(t_B)\, dt_B - D = \frac{\gamma + \beta}{(\gamma + \alpha)\, \beta}\, R\, I - D. \end{aligned} \tag{29}$$

Until default at date t_B, the bank earns returns $R\, I$ and pays the reservation wage w_0 and interests on his debt D, with the deteriorating interest rate $r(t) = (26)$. The second line is due to the fact that lenders anticipate the correct default rate, hence in aggregate, they must be repaid exactly D.

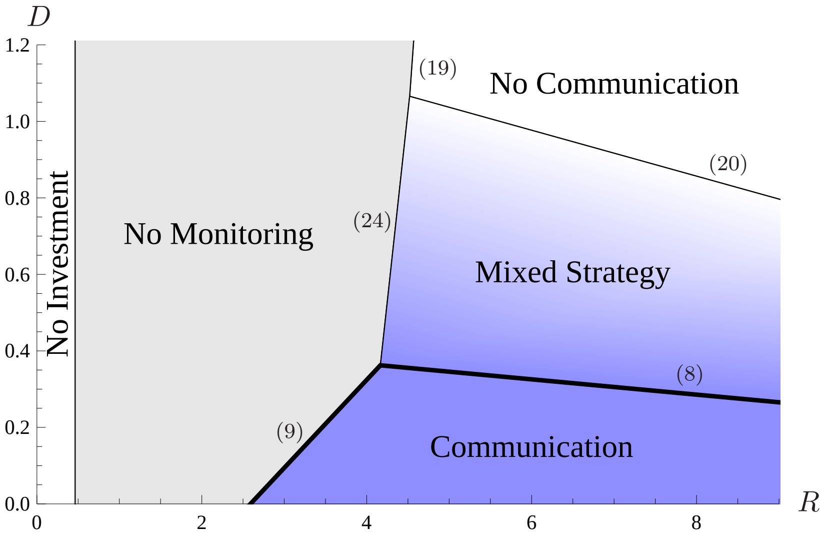
Considering out of equilibrium behavior by the board, we can now derive conditions under which equilibrium 0 exists. The exact condition, together with the proof, is given in the appendix. The condition differs from those in Propositions 2 and 4, there can be multiple equilibria. In this case, we concentrate on the Pareto-dominant equilibrium, which is the communication equilibrium C.

Proposition 4 *Whenever neither C nor NC nor a mixture between them exists, there is either equilibrium 0 (with neither incentive wage nor reward), or the bank does not invest at all.*

3.5 Discussion of Factors Influencing Communication

We have identified four types of equilibria. In the communication equilibrium (C), contracts exhibit a reward and efficiency wages. In the no-communication equilibrium (NC), there is no reward, such that the information about the deterioration does not become public. In the mixed-strategy equilibrium (Mix), both types of contracts C and NC are implemented with positive probability, such that the transmission of information is uncertain. In the no-monitoring equilibrium (0), the manager does not play an active role. The deterioration of project quality is fast. Proposition 4 shows that the parameter space is thus covered completely with equilibria. Figure 2 shows the equilibria for parameters $\alpha = 1/3$, $\beta = 1/2$, $\gamma = 1/8$, $\rho = 9/10$, $\lambda = 1/100$, $c = 1/100$ and $I = 1$ depending on the debt D and the project return R. For very low R, the project is not started at all. For low R, the project is started but not monitored (gray, equilibrium 0). In the remaining parameter space, one of the three equilibria C, Mix or NC is played. The shade of the color in the figure gives the probability of information transmission. Blue means full communication (C), white means no communication (NC), and light blue means some communication (Mix).

Figure 2: Equilibria for different parameter constellations
Numbers in brackets indicate the according inequalities in the propositions.



The conditions in the above propositions show that this figure is independent from parameter choices. The equilibrium with communication exists if D is sufficiently small. If D is high, the board fears the information to become public, because financing costs will then jump up, which is more costly if D is high. Hence for high D, the board does not write a reward into the contract. The same intuition applies for the mixed-strategy equilibrium. The higher D, the lower the equilibrium probability that a warning is communicated. Because $D + E = I$, D also measures the leverage of the bank, hence it is negatively related to the equity ratio. We discuss the implications of capital requirements in Section 5.1.

The effect of R is also intuitive. For extremely low R, the project is not undertaken in the first place. For slightly higher R, the project is carried out, but it is too expensive for the bank to pay the manager an efficiency wage. But if an efficiency wage is paid at all, R influences the probability of communication. For high R, this probability decreases, for the following reason. One benefit of getting the early warning is that the project can be liquidated partially. If it is not liquidated, it continues to pay R. Hence the higher R, the lower the value of the information. In the extreme case of $R = \beta$, the value of liquidation vanishes. The more liquid the project itself, hence the higher the fraction λ that can be liquidated early, the more negative the impact of R. The R measures the income from the project, hence it can be influenced by different factors. For example, R could be higher in economic upswings, or if competition between banks (not explicitly modeled here) is low.

Let us discuss some further comparative statics, although not immediately visible in the figure. The effect on monitoring costs c on the communication probability is positive, for the following reason. The higher the manager's monitoring cost c, the higher the rent that she collects. Because of the manager's discount rate ρ, the bank can economize offering the manager a one-time payment when the effort is less needed. For that reason, c and ρ enter only as a product. The effect of γ is unambiguously negative. The reason is again the manager's rent. For small γ, it is difficult to incentivize the manager, so her rent is extremely small. Hence paying her off early is profitable for the bank. Finally, both α and β influence the communication probability p_{C} through many channels, hence it is more difficult to get an unambiguous intuition.

4 Welfare Analysis

In previous sections, we have defined and discussed under which conditions in our model, information may be available for the market. It is not yet clear though, if the communication equilibrium with the feature of communication actually is the most preferred equilibrium of the economy.

We define social welfare as the sum of lenders' profit, bank's profit Π and manager's utility U. As we assume perfect competition in the market, the lenders make zero profits in any equilibrium. Thus welfare is composed by bank's profit and manager's utility only, who may receive positive profits and wages. Welfare in the communication equilibrium is

$$\begin{aligned} W_{\mathrm{C}} &= \Pi_{\mathrm{C}} + U_{\mathrm{C}} \\ &= \Pi_{\mathrm{C}} + \frac{\beta-\alpha}{\beta} \int_0^\infty \left[\int_0^{t_A} (w_A - c\,I)\, e^{-\rho\, t}\, \mathrm{d}t + H\, e^{-\rho\, t_A} \right] \alpha\, e^{-\alpha\, t_A}\, \mathrm{d}t_A + \frac{\alpha}{\beta}\, H \\ &= \frac{R\,I}{\alpha} + \left(1 - \frac{R}{\beta}\right) \lambda\, I - D - \frac{(\beta-\alpha)\,(\gamma\,(\beta+\rho) + \rho\,(\alpha+\beta+\rho))}{\alpha\,\gamma\,\beta^2}\, c\,I. \end{aligned} \tag{30}$$

The manager receives her utility by earning w_A and spending $c\,I$ as long as the loan is in class A. After she communicated the negative signal, she gets reward H. This utility together with the bank's profit results in (30).

In a similar way, we calculate welfare in the no-communication equilibrium as

$$\begin{aligned} W_{\mathrm{NC}} &= \Pi_{\mathrm{NC}} + U_{\mathrm{NC}} \\ &= \Pi_{\mathrm{NC}} + \frac{\beta-\alpha}{\beta} \int_0^\infty \Big[\int_0^{t_A} (w - c\,I)\, e^{-\rho\, t}\, \mathrm{d}t \\ &\quad + \int_{t_A}^\infty \left(\int_{t_A}^{t_B} w\, e^{-\rho\, t}\, \mathrm{d}t \right) \beta\, e^{-\beta\,(t_B - t_A)} \mathrm{d}t_B \Big]\, \alpha\, e^{-\alpha\, t_A}\, \mathrm{d}t_A \end{aligned}$$

$$
\begin{aligned}
&+ \frac{\alpha}{\beta} \int_0^{\infty} \left(\int_0^{t_B} w\, e^{-\rho\, t}\, \mathrm{d}t \right) \beta\, e^{-\beta\, t_B}\, \mathrm{d}t_B \\
&= \frac{R\, I}{\alpha} - D - \frac{\rho\,(\beta+\rho) + \gamma\,(\beta-\alpha+\rho)}{\alpha\,\gamma\,\beta}\, c\, I. \qquad (31)
\end{aligned}
$$

Accordingly, welfare in the mixed-strategy equilibrium is

$$
\begin{aligned}
W_{\text{Mix}} &= p_{\text{C}}\,(\Pi_{\text{C}} + U_{\text{C}}) + (1-p_{\text{C}})\,(\Pi_{\text{NC}} + \Pi_{\text{NC}}) \\
&= \frac{R\, I}{\alpha} + \frac{\beta - R}{\alpha}\, \lambda\, I - \frac{\beta}{\alpha}\, D - \frac{(\beta-\alpha)\,(\gamma+\rho)}{\alpha\,\gamma\,\beta}\, c\, I. \qquad (32)
\end{aligned}
$$

By calculating the difference between (30) and (31), one can show that W_{C} is greater than W_{NC} for all parameters,

$$
W_{\text{C}} - W_{\text{NC}} = \left(1 - \frac{R}{\beta}\right) \lambda\, I + \frac{\rho\,(\alpha+\gamma+\rho)}{\gamma\,\beta^2}\, c\, I. \qquad (33)
$$

Using the assumption that $\beta > R$, we do find that communication is always preferred from a welfare perspective if there are positive wages w_A to set monitoring incentives for the manager. This is intuitive, as the lenders make no profits at all and the manager is indifferent between those equilibria, because the incentive compatible wage w_A^* is just chosen by setting $U_{\text{C}} = U_{\text{NC}}$. Therefore, the difference between W_{C} and W_{NC} only results from the difference of the bank's profits in both equilibria. The bank owners receive a higher profit in the communication equilibrium, as they are able to reduce the costly debt and as they have to pay the cheaper one-time payment H^* in equilibrium C instead of the higher sum of wages w_A^* from date t_A to t_B in equilibrium NC because of the manager's discount rate. Thus, W_{C} is always higher than W_{NC}.

Welfare in equilibrium 0, the no-monitoring equilibrium, is

$$
W_0 = \Pi_0 + U_0 = \frac{\gamma+\beta}{(\alpha+\gamma)\,\beta} R\, I - D. \qquad (34)
$$

The manager receives neither incentive wage nor reward. Therefore her utility equals 0 and the welfare is identical to the bank's profit. Whether the welfare in the communication equilibrium is greater than W_0 depends on the exogenous parameters, as we can see by calculating the difference between (30) and (34),

$$
W_{\text{C}} - W_0 = \frac{\gamma\,(\beta-\alpha)}{\alpha\,\beta\,(\alpha+\gamma)}\, R\, I - \frac{(\beta-\gamma)\,\big(\gamma\,(\beta+\rho) + \rho\,(\alpha+\beta+\rho)\big)}{\alpha\,\gamma\,\beta^2}\, c\, I. \qquad (35)
$$

If the costs for monitoring loans are very high, clearly there is a level when it is too expensive to set incentives for monitoring. With costs

$$
c \le \frac{\gamma}{\gamma\,(\beta+\rho) + \rho\,(\alpha+\beta+\rho)} \Big(\frac{\beta\,\gamma}{\alpha+\gamma} \cdot R + \frac{\beta\,\alpha}{\beta-\alpha} \cdot \lambda\,(\beta - R) \Big), \qquad (36)
$$

the equilibrium with communication realizes a higher welfare than the equilibrium without monitoring. In summary, it may be possible that no monitoring is better than communication from a welfare perspective depending on the parameters, for example the costs c. With monitoring and low costs c, though, incentives for information are always welfare optimal.

5 Policy Implications

We can now use the model to discuss policy implications. Out of a variety of possible applications, we concentrate on two: capital regulation as the fundamental form of banking regulation, and convertible bonds as an innovative regulatory approach implemented in Basel III.

5.1 Capital Regulation

When discussing potential policy measures in banking, discussing capital adequacy standards is always a good start. We need to slightly reinterpret the original model. Originally, the initial investment into the project was I, whereof the debt D was inserted by lenders, the remaining $E = I - D$ was the equity stake. Let us now assume that E is fixed, that the maximum investment is given by $E = \kappa\, I$, thus $I = \frac{1}{\kappa}\, E$. The parameter κ identifies the (required) equity ratio. We assume that bank owners cannot reinvest profits, therefore equity does not increase over time. The profits of the bank are distributed to the equity owners, however equity invested in the current project of the bank remains fixed. We can now discuss the role of an increase in κ. The question of interest is if communication can be obtained by introducing capital regulation and if the welfare can be enhanced by stricter capital requirements. Therefore, we do start our analysis in the mixed strategy region to see if the probability of communication increases.

Here, we concentrate on the mixed-strategy equilibrium because within any of the other equilibria, a marginal increase in capital regulation can only reduce welfare. The reason is that project size is reduced, but the probability of communication is not changed. In the mixed-strategy equilibrium, the probability for choosing contract C is changed from equation (22) to

$$p_{\mathrm{C}} = \frac{\beta}{\alpha}\left(1 - \frac{(\beta - \alpha)\,(1 - \kappa)}{\rho\,\frac{\alpha+\gamma+\rho}{\gamma\,\beta}\,c + \lambda\,(\beta - R)}\right). \tag{37}$$

It can directly be seen that an increase in κ leads to a higher value of p_{C}. Hence, higher capital regulation leads to a higher probability of communication. Welfare in the mixed-strategy equilibrium under capital regulation is

$$W_{\text{Mix}} = \Big(\frac{R}{\alpha\,\kappa} + \frac{\beta - R}{\alpha\,\kappa}\,\lambda - \frac{\beta\,(\frac{1}{\kappa} - 1)}{\alpha} - \frac{(\beta-\alpha)\,(\gamma+\rho)}{\alpha\,\gamma\,\beta\,\kappa}\,c\Big)\,E. \tag{38}$$

The summands in the bracket can be interpreted. The first term gives the income from the project as long as it is in class A, depending negatively on κ. The second term is the value of early liquidation, which is also bigger when the project is larger. The third part stems from refinancing costs. The last term is the cost of incentivizing the manager, including savings from paying her off early. Taking the derivative,

$$\frac{\partial W_{\text{Mix}}}{\partial \kappa} = \Big(\frac{1-\lambda}{\alpha\,\kappa^2}\,(\beta - R) + \frac{(\beta-\alpha)\,(\gamma+\rho)}{\alpha\,\gamma\,\beta\,\kappa^2}\,c\Big)\,E. \tag{39}$$

Depending on the relative size of α, β and R, this term could be positive or negative. In our model, though, we have assumed that $\beta > R$, otherwise the bank would not want to liquidate the project early, and $\beta > \alpha$, otherwise the transition probability from B to default would be lower than from A to B. Consequently, the above derivative is positive. The welfare effect of capital requirements is positive despite the fact that aggregate investment ins reduced. The benefit of increased transparency overcompensates the detriment of reduced investment. Summing up, a marginal increase of capital requirements is welfare-positive in the mixed-strategy equilibrium. It is welfare-negative in all other equilibria because it reduces investment volume.

With this setting, it would also be possible to discuss risk-sensitive capital requirements, as introduced in Basel II and not dropped in Basel III. The asset portfolio of the bank would have to be rated, but this rating could depend only on the available information. Hence, in equilibrium C, the rating would be high (A) before the transition, and lower (B) afterwards. In other equilibria, the rating would be somewhere in between because of the lack of available information. So let us assume that the better the rating, the lower κ. This would imply that part of the project would have to be sold after a deterioration (deleveraging), possibly at fire sale prices.[4] The implications for a bank's incentive to implement an informative contract (C) are detrimental. When reacting upon a warning from a manager, not only will markets realize and react, raising refinancing costs. Also will rating agencies react by downgrading the bank, which forces it to deleverage, at unfavorable prices. Summing up, capital regulation is good for the system's informativeness, but requirements must be risk-insensitive.

[4] These prices are difficult to endogenize in our setting without further assumptions. That is why we have left this discussion informal.

5.2 Convertible Bonds

We have assumed that the bank can finance its loan portfolio only with debt and inside equity. Allowing for more general financial tools, equilibria might look different. Let us, for example, discuss the role of contingent convertible bonds (cocos) as a rather innovative source of finance, considered also in Basel III. We show that equilibrium C can be reached when it is welfare-optimal, with the following reason. The coco debt is converted into shares at a predefined conversion rate after the value of equity has dropped below some threshold. The original reason why the board may not want to implement a contract with communication is the negative market reaction after a bad signal. In other words, there is a positive externality on investors that is not internalized by the bank. However, adjusting the conversion rate of the cocos to the right level, this externality can be taken into account.

Without loss of generality, assume there is no straight debt, only contingent convertible bonds. The volume that needs to be financed by lenders is $D = I - E$ as before. We show that the face value can be different, debt may have to be issued below par. Let us call $\bar{D}$ the face value, and r the short-term interest rate. For exposition, set $\lambda = 0$. We can now discuss the model outcome.

After the negative signal, the project is in class B, hence the aggregate value is

$$\int_0^\infty R\,I\,t_B\,\beta\,e^{-\beta\,t_B}\,\mathrm{d}t_B = \frac{R\,I}{\beta}. \tag{40}$$

A fraction $1/(1+\eta)$ goes to the bank, the fraction $\eta/(1+\eta)$ goes to lenders. Now remember that the project can be in class B right away, with probability α/β. The lender then loses part of his investment immediately, he wants to be compensated for that, hence

$$\begin{aligned} D &= \frac{\beta-\alpha}{\beta}\,\bar{D} + \frac{\alpha}{\beta}\cdot\frac{R\,I}{\beta}, \\ \bar{D} &= \frac{\beta}{\beta-\alpha}\,D - \frac{\eta}{1+\eta}\,\frac{\alpha}{\beta-\alpha}\,\frac{R\,I}{\beta}. \end{aligned} \tag{41}$$

After this initial period, the interest rate r adjusts such that lenders break even,

$$\begin{aligned} \bar{D} &= \alpha\,\mathrm{d}t\,\frac{\eta}{1+\eta}\cdot\frac{R\,I}{\beta} + (1-\alpha\,\mathrm{d}t)\,(1+r\,\mathrm{d}t)\,\bar{D}, \\ r &= \alpha\Big(1 - \frac{\eta}{1+\eta}\,\frac{R\,I}{\beta\,n}\Big). \end{aligned} \tag{42}$$

The second line obtains by solving for r and taking the limit $\mathrm{d}t \to 0$. We can now calculate the bank's expected profit within equilibrium C, i. e., the equilibrium with reward and efficiency wage. This consists of two parts, the expected profits before the negative signal, and the profits after the signal.

$$\begin{aligned}\Pi_\mathrm{C} &= \frac{\beta-\alpha}{\beta}\int_0^\infty (R\,I - w - r\,\bar{D})\,t_A\,\alpha\,e^{-\alpha\,t_A}\,\mathrm{d}t_A - H + \frac{1}{1+\eta}\,\frac{R\,I}{\beta}\\ &= \frac{R\,I}{\alpha} - D - \frac{(\alpha+\gamma+\rho)\,(\beta^2+\rho\,\big(\beta-\alpha)\big)}{\gamma\,\alpha\,\beta^2}\,c.\end{aligned} \tag{43}$$

The second line obtains by inserting the optimal w^* and H^* from (5) and (6), and the equilibrium $\bar{D}$ from (41). Note that this equilibrium profit is identical to that in the informative equilibrium with debt financing only, see (7). This comes at no surprise, as the expected profits of lenders are always zero, and those of the manager are unchanged. Especially, η drops out of the equation. A higher η is exactly compensated by lower interest rates r. We now need to check when the board wants to drop the reward. Out of equilibrium, his expected profit is

$$\begin{aligned}\Pi'_\mathrm{C} &= \frac{\beta-\alpha}{\beta}\int_0^\infty (R\,I - w - r\,\bar{D})\,t_A\,\alpha\,e^{-\alpha\,t_A}\,\mathrm{d}t_A + \int_0^\infty (R\,I - w - r\,\bar{D})\,t_B\,\alpha\,e^{-\alpha\,t_B}\,\mathrm{d}t_B\\ &= \frac{1}{\beta-\alpha}\Big((\frac{\beta}{\alpha}-\frac{1}{1+\eta})\,R\,I - \beta\,D\Big) - \frac{(\beta+\rho)(\alpha+\gamma+\rho)}{\gamma\,\beta}\,c.\end{aligned} \tag{44}$$

Now for a given η, the board chooses to implement the reward if $\Pi_\mathrm{C} \geq \Pi'_\mathrm{C}$, hence if

$$D \leq \frac{\eta}{1+\eta}\,\frac{R\,I}{\alpha} - \frac{\beta-\alpha}{\beta}\,\frac{\rho\,(\alpha+\gamma+\rho)}{\alpha\,\beta\,\gamma}\,c. \tag{45}$$

In Section 4, we have learned that the equilibrium with reward always dominates the equilibrium with monitoring only. Hence, in order to achieve the communication equilibrium C, one needs to set η high enough such that (45) is binding. Taking the limit of $\eta \to \infty$, the reward is implemented if $D \leq R/\alpha$. But R/α is the expected return from the project; a project with $D > R/\alpha$ would not be financed in the first place. As a result, the communication equilibrium can always be obtained. The following proposition sums up these arguments.

Proposition 5 *Starting from the no-communication equilibrium (NC), finance with appropriate contingent convertible bonds induces the board to implement contracts with a reward, such that the communication equilibrium obtains.*

Also in the no-monitoring equilibrium, one can show that finance through coco bonds can lead to the communication equilibrium. For a given η, the profit without efficiency wage is

$$\Pi''_\mathrm{C} = \frac{\beta+\gamma}{\beta-\alpha}\Big(\frac{\beta\,(1+\eta)-\alpha}{\beta\,(1+\eta)\,(\alpha+\gamma)}\,R - \frac{\alpha}{\alpha+\gamma}\,D\Big). \tag{46}$$

The board chooses to implement efficiency wages and reward if $\Pi_{\mathrm{C}} > \Pi''_{\mathrm{C}}$, hence if

$$D \leq \frac{(\beta-\alpha)\,(\alpha+\gamma)}{\alpha^2+\gamma\,(2\,\alpha-\beta)} \left(\left(\frac{(\beta+\gamma)\,(\beta\,(1+\eta)-\alpha}{(\beta-\alpha)\,\beta\,(\alpha+\gamma)\,(1+\eta)} - \frac{1}{\alpha} \right) R \right. \\ \left. + \frac{(\alpha+\gamma+\rho)\,(\beta^2+(\beta-\alpha)\,\rho)}{\alpha\,\beta^2\,\gamma}\, c \right). \tag{47}$$

The derivative of this term with respect to η is positive. This means that, the higher η, the more debt the bank can take without destroying the communication channel.

6 Conclusion

We have constructed a microeconomic model of a bank in which communication of negative information plays a crucial role. The board would like to react upon bad news by downsizing both the project and the manager's duties. But it first needs to persuade the manager to tell him. In any case, the refinancing markets take notice of the board's reaction to the news, hence the news are incorporated into market prices. This means higher refinancing costs for the bank. From a welfare perspective, the board has insufficient incentives to implement an informative contract. In the wording of Eugene Fama, financial markets are always semi-strongly efficient, and they become strongly efficient when the informative contract is chosen. The degree of efficiency is endogenous to the model.

The model matches a number of stylized facts from the recent financial crisis. First and foremost, it explains how it is possible that crucial information could remain hidden such a long time. Because many financial institutions were highly leveraged, the effect on refinancing costs would have been disastrous. So even if individuals within financial institutions would have foreseen the crisis, the institutions would not have wanted to incentivize them to talk freely. Looking again at Figure 2, this is specific for highly leveraged institutions. Furthermore, many assets of financial institutions (e. g., mortgage loans) seemed to be highly liquid before the crisis, but proved to be illiquid in the crisis. It was impossible to cancel or reverse housing loans, because then borrowers would just default. In our model, a low liquidity of assets entails a low level of information.

We have modeled the bank as a single institution, there are no systemic effects. Modeling a banking system would have consequences into different directions. For example, the information about the deterioration of the loan portfolio may trigger further allocative decisions. In the communication equilibrium, the capital market is strongly information efficient. In the other equilibria, it is not. This implies that financial markets serve their informational function less well in the uninformative equilibria. As another example, if the loan portfolios of several banks are stochastically dependent, a manager's contract will contain information from other banks. If one bank gets into trouble, the probability that another bank's project deteriorates increases. Consequently, the optimal reward decreases. This might induce some form of competition between managers to be the first to report the deterioration.

Already when abstracting from systemic effects, we can discuss some implications. A higher equity ratio means that the bank fears the deterioration of credit conditions less, hence it is incentivized to implement a communicative contract, giving early warnings to the markets. Capital requirements force banks to deleverage and thus reduce aggregate investment. But the benefits of increased transparency, including the responses taken by banks themselves, overcompensate for reduced investment. In other words, it is better to invest less if this enables banks to optimally react upon negative news, which would otherwise have been suppressed. Introducing risk-sensitive capital requirement is detrimental. Contingent convertible bonds can also increase welfare if the conversion rate is fixed low enough, reducing pressure from refinancing markets. In all applications, we stress that policies should be designed such that communication channel does not choke.

A Proofs

Proof of Proposition 1. When does the board prefer to (out of equilibrium) implement contracts with lower wages or lower reward? We calculate his expected profits for these strategies. If, out of equilibrium, the board would write the manager a contract without reward, then he would have to pay the manager until the project defaults. On the other hand, refinancing costs would never adjust from r_A to r_B. Consequently, the aggregate payoff to the bank would be

$$\begin{aligned}\Pi'_{\mathrm{C}} = {} & \frac{\beta-\alpha}{\beta}\int_0^\infty \Big[\int_0^{t_A}(R\,I - r_A\,D - w_A)\,\mathrm{d}t \\ & \qquad + \int_{t_A}^\infty \Big\{\int_{t_A}^{t_B}(R\,I - r_A\,D - w_A)\,\mathrm{d}t\Big\}\,\beta\,e^{-\beta\,(t_B-t_A)}dt_B\Big]\,\alpha\,e^{-\alpha\,t_A}\,dt_A \\ & + \frac{\alpha}{\beta}\Big[\int_0^\infty\Big\{\int_0^{t_B}(R\,I - r_A\,D - w_A)\,\mathrm{d}t\Big\}\,\beta\,e^{-\beta\,t_B}\,dt_B\Big] \\ = {} & \frac{R\,I - w_A^* - r_A\,D}{\alpha} \\ = {} & \frac{R\,I}{\alpha} - \frac{(\beta+\rho)\,(\gamma+\alpha+\rho)}{\gamma\,\beta\,\alpha}\,c\,I. \end{aligned} \tag{48}$$

The last line is obtained by inserting w_A^* and by setting $r_A = 0$.

The board chooses reward plus positive wage only if $\Pi'_{\mathrm{C}} \leq \Pi_{\mathrm{C}}$, hence if

$$\begin{aligned}
\frac{R\,I}{\alpha} - \frac{(\beta+\rho)\,(\gamma+\alpha+\rho)}{\gamma\,\beta\,\alpha}\,c\,I \leq{} & \frac{R\,I}{\alpha} + (1-\frac{R}{\beta})\,\lambda\,I - D \\
& - \frac{(\alpha+\gamma+\rho)\,\big(\beta^2+\rho\,\big(\beta-\alpha\big)\big)}{\gamma\,\alpha\,\beta^2}\,c\,I \\
D \leq{} & \left(1-\frac{R}{\beta}\right)\,\lambda\,I + \frac{\rho\,(\alpha+\gamma+\rho)}{\gamma\,\beta^2}\,c\,I. \qquad (49)
\end{aligned}$$

If, again out of equilibrium, the board would set up a contract with neither reward nor efficiency wage, the aggregate payoff to the board would be

$$\begin{aligned}
\Pi''_{\mathrm{C}} ={} & \frac{\beta-\alpha}{\beta}\int_0^\infty \Big[\int_0^{t_A} (R\,I - r_A\,D)\,\mathrm{d}t \\
& + \int_{t_A}^\infty \Big\{\int_{t_A}^{t_B} (R\,I - r_A\,D)\,\mathrm{d}t\Big\}\,\beta\,e^{-\beta\,(t_B-t_A)}dt_B\Big]\,(\alpha+\gamma)\,e^{-(\alpha+\gamma)\,t_A}\,dt_A \\
& + \frac{\alpha}{\beta}\Big[\int_0^\infty \Big\{\int_0^{t_B} (R\,I - r_A\,D)\,\mathrm{d}t\Big\}\,\beta\,e^{-\beta\,t_B}\,dt_B\Big] \\
={} & \frac{(R\,I - r_A\,D)\,(\gamma+\beta)}{\beta\,(\alpha+\gamma)} = \frac{(\gamma+\beta)}{\beta\,(\alpha+\gamma)}\,R\,I. \qquad (50)
\end{aligned}$$

The manager chooses reward plus positive wage only if $\Pi''_{\mathrm{C}} \leq \Pi_{\mathrm{C}}$, hence if

$$\begin{aligned}
\frac{(\gamma+\beta)}{\beta\,(\alpha+\gamma)}\,R\,I \leq{} & \frac{R\,I}{\alpha} + (1-\frac{R}{\beta})\,\lambda\,I - D - \frac{(\alpha+\gamma+\rho)\,\big(\beta^2+\rho\,\big(\beta-\alpha\big)\big)}{\gamma\,\alpha\,\beta^2}\,c\,I \\
D \leq{} & \frac{\gamma\,(\beta-\alpha)}{\alpha\,(\alpha+\gamma)\,\beta}\,R\,I - + \left(1-\frac{R}{\beta}\right)\,\lambda\,I - \frac{(\alpha+\gamma+\rho)\,\big(\beta^2+\rho\,(\beta-\alpha)\big)}{\gamma\,\alpha\,\beta^2}\,c\,I. \qquad (51)
\end{aligned}$$

We have to prove one more thing. Up to now, we have implicitly assumed that the board implements the contract one and for all. However, given that all contracts are only short-term, he may change the contract at any time. For example, he may start with a low wage, but increase the wage after some time. However, one can show that the reward does not depend on the probability with which the board expects the project to be in class A or B, because both reward and reduced wage costs apply only under the condition that a transition occurs, hence the probability cancels out. Furthermore, because the board is always informed about the project's class, the efficiency wage does not change over time. Therefore, when (49) and (51) hold, the board writes a contract with efficiency wage and positive reward. ■

Proof of Proposition 2. The board can deviate from the equilibrium in two ways. First, he can pay zero wages. The manager then shirks. The expected return to the board is then

$$\Pi'_{\mathrm{NC}} = \frac{\beta-\alpha}{\beta}\int_0^\infty \Big[\int_0^{t_A} (RI - rD)\,\mathrm{d}t$$

$$
\begin{aligned}
&+ \int_{t_A}^{\infty} \Big(\int_{t_A}^{t_B} (RI - rD)\mathrm{d}t \Big) \beta e^{-\beta(t_B - t_A)} dt_B \Big] (\alpha+\gamma) e^{-(\alpha+\gamma)t_A} dt_A \\
&+ \frac{\alpha}{\beta} \int_0^{\infty} \Big(\int_0^{t_B} (RI - rD)\mathrm{d}t \Big) \beta e^{-\beta t_B} dt_B \\
&= \frac{(RI - \alpha\, D)(\gamma+\beta)}{\beta\,(\gamma+\alpha)}. \qquad (52)
\end{aligned}
$$

Comparing with (18), the board implements the efficiency wage if $\Pi_{\text{NC}} > \Pi'_{\text{NC}}$, thus if

$$
D \leq \frac{R\,I}{\alpha} - \frac{(\alpha+\gamma)\,(\beta+\rho)\,(\gamma+\alpha+\rho)}{\gamma^2\,\alpha\,(\beta-\alpha)}\,c\,I. \qquad (53)
$$

Second, the board can deviate by not only paying the wage but also the reward. The manager then monitors and communicates all news. In this case, bank's expected profit is

$$
\Pi''_{\text{NC}} = \frac{RI}{\alpha} + \left(1 - \frac{R}{\beta}\right) \lambda\, I - \frac{2\beta-\alpha}{\beta}\, D - \frac{(\gamma+\alpha+\rho)(\beta^2+\rho\,(\beta-\alpha))}{\gamma\alpha\beta^2}\, c\, I. \qquad (54)
$$

The board pays efficiency wages but no reward only if $\Pi_{\text{NC}} > \Pi''_{\text{NC}}$, thus if

$$
D \geq \frac{\beta-R}{\beta-\alpha}\,\lambda\, I + \frac{\rho\,(\gamma+\alpha+\rho)}{\gamma\,\beta\,(\beta-\alpha)}\, c\, I. \qquad (55)
$$

Hence when (53) and (55) hold, there is an equilibrium with payments of positive wage and zero reward. ■

Proof of Proposition 3. The boundaries of the mixed-strategy equilibrium are defined by the conditions under which the board would deviate from it. Instead of playing a mixed strategy, the board could definitely decide to implement a contract with incentive wage and reward. The expected return to the board is then

$$
\begin{aligned}
\Pi'_{\text{Mix}} &= \frac{R\,I}{\alpha} - \frac{(R-r_B)\,\lambda\, I}{\beta} - H^* - \frac{\alpha\, r_B\, D + (\beta-\alpha)\,(w_A^* + r\, D)}{\alpha\,\beta} \\
&= \frac{R\,I}{\alpha} + \left(1 - \frac{R}{\beta}\right) \lambda\, I - D - \frac{(\alpha+\gamma+\rho)\,\big(\beta^2+\rho\,\big(\beta-\alpha\big)\big)}{\gamma\,\alpha\,\beta^2}\, c\, I. \qquad (56)
\end{aligned}
$$

The second line is obtained by inserting w_A^*, H^* and setting $r = r_{\text{Mix}}$, $r_B = \beta$. Because strategy C is definitely chosen, $p_{\text{C}} = 1$. The board plays the mixed strategy only if $\Pi_{\text{Mix}} > \Pi'_{\text{Mix}}$, thus if

$$
D \geq \left(1 - \frac{R}{\beta}\right) \lambda\, I + \frac{\rho\,(\alpha+\gamma+\rho)}{\gamma\beta^2}\, c\, I. \qquad (57)
$$

Contrary, the board could directly decide to play strategy NC and pay only an incentive wage but no reward to the borrower. In that case, its profit would be

$$\begin{aligned}\Pi''_{\text{Mix}} &= \frac{R\,I - r\,D - w_A}{\alpha} \\ &= \frac{R\,I}{\alpha} - D - \frac{(\gamma+\alpha+\rho)\,(\beta+\rho)}{\gamma\,\alpha\,\beta}\,c\,I. \end{aligned} \tag{58}$$

Again, the second line is obtained by inserting w_A^* and setting $r = r_{\text{Mix}}$. In this case, strategy NC is definitely chosen, therefore $p_{\text{C}} = 0$. The board plays the mixed strategy only if $\Pi_{\text{Mix}} > \Pi''_{\text{Mix}}$, thus if

$$D \leq \frac{\beta - R}{\beta - \alpha}\,\lambda\,I + \frac{\rho\,(\alpha+\gamma+\rho)}{\gamma\,\beta\,(\beta-\alpha)}\,c\,I. \tag{59}$$

The above conditions (57) and (59) are identical to the equations (8) and (20) from Propositions 1 and 2. Thus, the mixed-strategy equilibrium is located exactly between equilibrium C and equilibrium NC.

There is one more possibility to deviate from the mixed-strategy equilibrium. If the board decides to pay neither incentive wage nor reward, its profit would be

$$\begin{aligned}\Pi'''_{\text{Mix}} &= \int_0^\infty \int_0^{t_B} \big(R\,I - r\,D\big)\text{d}t\, f(t_B)\,dt_B \\ &= \frac{\beta+\gamma}{\alpha+\gamma}\left(\frac{R\,I}{\beta} + \left(1 - \frac{R}{\beta}\right)\lambda\,I - d + \frac{\rho\,(\alpha+\gamma+\rho)}{\beta^2\,\gamma}\,c\,I\right). \end{aligned} \tag{60}$$

Inserting p_{C} and setting $r = r_{\text{Mix}}$ leads to the second line. The board prefers the mixed strategy to a contract without incentive wage and reward if $\Pi_{\text{Mix}} > \Pi'''_{\text{Mix}}$, thus if

$$D \leq \frac{R\,I}{\beta} + \left(1 - \frac{R}{\beta}\right)\lambda\,I - \left(\alpha+\gamma+\frac{\alpha\,(\beta+\gamma)\,\rho}{\beta^2}\right)\frac{\alpha+\gamma+\rho}{(\beta-\alpha)\,\gamma^2}\,c\,I. \tag{61}$$

If equations (57), (59) and (61) hold, an equilibrium with mixed strategies C and NC exists. ■

Proof of Proposition 4. We need to discuss for which parameters a behavior out of equilibrium may be optimal for the board. For example, he may want to pay the manager an efficiency wage, in which case the deterioration of the project is not as fast. We have to calculate the expected profits in this case. The density function of the default date t_B is then simply

$$\hat{f}(t_B) = \alpha\,e^{-\alpha\,t_B}. \tag{62}$$

The bank's expected profit consists of three parts: expected returns from the project, expected wages, and expected refinancing costs. The first two parts are simply

$$\int_0^\infty \big(R\,I - w_A\big)\, t_B\, \hat{f}(t_B)\, dt_B = \frac{R\,I - w_A}{\alpha}. \tag{63}$$

The third part is

$$\begin{aligned}
&\int_0^\infty \Big[\int_0^{t_B} r(t)\, D\, \mathrm{dt}\Big]\, \hat{f}(t_B)\, dt_B \\
&= D\cdot \int_0^\infty \Big[\int_0^{t_B} \frac{(\alpha+\gamma)\,(\beta-\alpha) - \beta\,\gamma\, e^{-(\beta-\alpha-\gamma)\,t}}{(\beta-\alpha) - \gamma\, e^{-(\beta-\alpha-\gamma)\,t}}\, \mathrm{dt}\Big]\, \alpha\, e^{-\alpha\, t_B}\, dt_B \\
&= D\cdot \int_0^\infty \Big[(\alpha+\gamma)\, t_B - \log\Big(\frac{\beta-\alpha-\gamma\, e^{-(\beta-\alpha-\gamma)\,t_B}}{\beta-\alpha-\gamma}\Big)\Big]\, \alpha\, e^{-\alpha\, t_B}\, dt_B \\
&= D\cdot \int_0^\infty \Big[(\alpha+\gamma)\, t_B + \log(\beta-\alpha-\gamma) - \log\big(\beta-\alpha-\gamma\, e^{-(\beta-\alpha-\gamma)\,t_B}\big)\Big]\, \alpha\, e^{-\alpha\, t_B}\, dt_B \\
&= D\cdot \Big[\frac{\alpha+\gamma}{\alpha} + \log(\beta-\alpha-\gamma) - \int_0^\infty \log\big(\beta-\alpha-\gamma\, e^{-(\beta-\alpha-\gamma)\,t_B}\big)\, \alpha\, e^{-\alpha\, t_B}\, dt_B\Big] \\
&= D\cdot \Big[\frac{\alpha+\gamma}{\alpha} - \frac{\gamma}{\beta-\alpha}\cdot \Phi\Big(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\gamma}{\beta-\alpha-\gamma}\Big)\Big],
\end{aligned} \tag{64}$$

where the Lerch transcendent Φ is defined by $\Phi(z,1,a) = \sum_{n=0}^{\infty} z^n/(a+n)$. The aggregate expected profit consists of (63) net of (64), hence

$$\Pi_0' = \frac{R\,I - w_A^*}{\alpha} - D\cdot \Big[\frac{\alpha+\gamma}{\alpha} - \frac{\gamma}{\beta-\alpha}\cdot \Phi\Big(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\gamma}{\beta-\alpha-\gamma}\Big)\Big] \tag{65}$$

with w^* as defined in (5). The board implements the naked contract (without efficiency wage or reward) only if $\Pi_0 \geq \Pi_0'$, hence if

$$D \geq \frac{\beta-\alpha}{\gamma^2\,(\gamma+\alpha)\,\beta}\cdot \frac{\gamma^2\,(\beta-\alpha)\,R\,I - (\gamma+\alpha)(\beta+\rho)(\gamma+\alpha+\rho)\,c\,I}{\beta-\alpha\,\big[1+\Phi(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\gamma}{\beta-\alpha-\gamma})\big]}. \tag{66}$$

Finally, we need to calculate potential out of equilibrium profits if the board wants to implement a contract with both efficiency wage and reward. As long as the manager does not blow the whistle, lenders believe they finance a project of mixed quality, hence they demand the loan rate $r(t)$ as defined in (26). Once the negative signal is communicated, lenders learn they have had wrong beliefs; they then charge the rate $r = \beta$, according to the correct instantaneous probability of default. The profit function consists thus of several parts. First, with probability $(\beta-\alpha)/\beta$, the project starts in class A and the interest rate is $r(t)$. The date of the transition to class B is exponentially distributed with parameter α. The profit is

$$\int_0^\infty \Big[\int_0^{t_A} (R\,I - w_A - r(t)\,D)\, \mathrm{dt}\Big]\alpha\, e^{-\alpha\, t_A}\, dt_A$$

$$= \frac{R\,I - w_A^*}{\alpha} - D \cdot \Big[\frac{\alpha+\gamma}{\alpha} - \frac{\gamma}{\beta-\alpha} \cdot \Phi\Big(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\alpha}{\beta-\alpha-\gamma}\Big)\Big], \tag{67}$$

in analogy to (64). Then at date t_A, the reward H is paid, and the project continues with reduced investment size until it defaults completely. This happens with instantaneous probability β, hence the interest rate is also β.

$$\begin{aligned} &\int_0^\infty \Big[\int_0^{t_B} (R\,I\,(1-\lambda) - r_B\,(D - \lambda\,I))\,\mathrm{d}t\Big]\alpha\,e^{-\alpha\,t_B}\,dt_B \\ &= \frac{R\,I}{\beta} + \left(1 - \frac{R}{\beta}\right)\lambda\,I - D. \end{aligned} \tag{68}$$

With probability α/β, the loan starts in class B right away, and the profit as in (68). The aggregate expected profit is then $1 \cdot (68) + (\beta-\alpha)/\beta \cdot (67)$, which is

$$\begin{aligned} \Pi_0'' &= \frac{R\,I}{\beta} + \left(1 - \frac{R}{\beta}\right)\lambda\,I - D \\ &\quad + \frac{\beta-\alpha}{\beta} \cdot \Big[\frac{R\,I - w_A^*}{\alpha} - D \cdot \Big[\frac{\alpha+\gamma}{\alpha} - \frac{\gamma}{\beta-\alpha} \cdot \Phi\Big(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\alpha}{\beta-\alpha-\gamma}\Big)\Big]\Big] \\ &= \frac{\beta}{\alpha\,\beta}\,R\,I + \left(1 - \frac{R}{\beta}\right)\lambda\,I - \left(1 + \frac{(\beta-\alpha)\,(\alpha+\gamma)}{\alpha\,\beta}\right) D \\ &\quad + \frac{(\alpha\,\beta - (\beta-\alpha)\,(\beta+\rho))\,(\alpha+\gamma+\rho)}{\gamma\,\alpha\,\beta^2}\,c\,I + \frac{\gamma}{\beta}\,D\,\Phi\Big(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\gamma}{\beta-\alpha-\gamma}\Big). \end{aligned} \tag{69}$$

Hence, the board implements the naked contract only if $\Pi_0 \geq \Pi_0''$, thus

$$\frac{D}{I} \geq \frac{(\beta-\alpha)\gamma^2\beta R + \gamma\alpha\beta(\alpha+\gamma)(\beta-R)\lambda - (\alpha+\gamma)\big((\beta-\alpha)(\beta+\rho) - \alpha\beta\big)(\alpha+\gamma+\rho)c}{\gamma(\alpha+\gamma)\beta\Big[(\beta-\alpha)\,(\alpha+\gamma) - \alpha\,\gamma\,\Phi\Big(\frac{\gamma}{\beta-\alpha}, 1, \frac{\beta-\alpha}{\beta-\alpha-\gamma}\Big)\Big]}. \tag{70}$$

The board only conducts the project if the bank's profit suffices to pay back at least the invested equity. Therefore, the returns of the project must be high enough,

$$\Pi_0 \geq I - D \qquad \Longrightarrow \qquad R \geq \frac{\beta\,(\alpha+\gamma)}{\beta+\gamma}. \tag{71}$$

As can be seen from (66) and (70), the board does not deviate at the same points from a 0 contract to a C or NC contract where he does deviate from a C or a NC contract to the 0 contract. That means that the boundaries of the different equilibria are not congruent which leads to a small region of multiple equilibria where we do have either 0 and C equilibria or 0 and NC equilibria. We then concentrate on the Pareto-dominating equilibrium with monitoring. ■

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