

# Using Price Information as an Instrument of Market Discipline in Regulating Bank Risk

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## Abstract

An important trend in bank regulation is greater reliance on market discipline. In particular, information impounded in securities prices is increasingly used to complement supervisory activities of regulators with limited resources. The goal of this paper is to analyze the theoretical foundations of market-based bank regulation. We find that price information only improves the efficiency of the regulator's monitoring function if the banks' risk-shifting incentives are not too large. Further, if the regulator cannot commit to an ex ante suboptimal auditing policy, market-based bank regulation can lead to more risk taking in equilibrium, increasing the expected payments by the deposit insurance agency. Finally, we show that the regulatory use of market information can decrease the investors' incentives to acquire costly information, thereby reducing the informativeness of stock prices.

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Bank regulators have embraced financial markets recently to improve the effectiveness of bank supervision. Feldman and Schmidt (2003) find that 40% of U.S. supervisory reports contain at least some reference to market data (mostly equity prices and market-based ratios). The idea seems simple: since markets are efficient in processing and aggregating information, bank regulators hope to gather information on the bank's financial condition from market indicators that complements their knowledge derived from call reports and on-site bank inspections. In this paper, we analyze how the use of market information by regulators will change incentives for investors to acquire information and thus endogenize the information content of securities prices. Furthermore we examine the incentives for banks' risk shifting and analyze the welfare effects of such a new regulatory approach.

In most developed economies banks are subject to government supervision partly to mitigate risk taking incentives that are introduced by deposit insurance schemes and to preserve financial stability of the banking system, which is of vital importance to the whole economy. A better assessment of a bank's financial soundness enables the regulator to intervene in a timely fashion and may help avoid a collapse of the financial institution. Banks, however, have become increasingly complicated for regulators to evaluate. Large, multinational banks operate in many markets, under many jurisdictions, and often under the supervision of many national regulators. Complex derivatives and other structured securities are a potential source of substantial risks, but fit only poorly in traditional accounting-based rating schemes of bank regulators.

Seeking ways to enhance the effectiveness of bank supervision, bank regulators are actively discussing incorporating information that is generated by financial markets into the regulatory process. One stream of discussion focuses on the value of market information for the off-site assessment of a financial institution's health. Regulators in most countries have automated bank monitoring systems that periodically screen all banks.<sup>1</sup> While most of them currently rely on call report data, recent research

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<sup>1</sup>In the US, for example, the Federal Reserve uses its System for Estimating Examination Ratings (SEER) to regularly estimate a banks current regulatory rating and its probability of failure. Banks with sufficiently bad results are flagged for further review, possible leading to an on-site inspection. King, Nuxoll, and Yeager (2004) provide an overview of models used in the US and Sahajwala and Van den Bergh (2000) review off-site bank monitoring systems used in the US and in several G10 countries.

encourages regulators to include market information.<sup>2</sup> The literature provides evidence that this step will increase the precision of regulatory assessments and thus will allow a more efficient usage of on-site auditing capacity by targeting problem banks.

In a more radical approach, the US Shadow Financial Regulatory Committee (see Herring (2004)) suggests to force banks to issue subordinated debt and to force regulatory action on them when spreads widen too much. However, regardless of the specific implementation of marked based regulation, regulators have set an important step to facilitate information processing by financial markets by defining mandatory disclosure requirements in the third pillar "market discipline" (next to capital requirements and auditing) of the Basel II accord.<sup>3</sup>

The contribution of our paper is to endogenize both, the risk taking behavior of banks as well as the information content of securities prices following a shift in regulatory policy towards incorporating market information into the supervisory process. We find that welfare is increased and the regulator is better off by using market information when the economy is good and risk shifting incentives for banks are low. This is mainly driven by the fact that the regulator can target bad banks more efficiently by learning from financial markets. The increased regulatory effectiveness deters more banks from investing in bad risky projects which reduces the deposit insurance liability and increases welfare. As banks are more likely to invest in safe projects, informed investors find fewer opportunities to trade on their inside information, which decreases investors' incentives to acquire information and market prices become less informative.

When the economy is doing poorly, however, and risk shifting incentives are high,

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<sup>2</sup>Gropp, Vesala, and Vulpes (2002) analyze the information content of stock and bond-based indicators for European banks. They define banks to have a weakened financial condition, whenever the Fitch rating of financial strength is C or below. They find that an equity-based distance to default measure has high predictive power, whereas subordinated debt spreads have signal value only close to default. Krainer and Lopez (2004) find for a sample of U.S. bank holding companies that equity-based expected default frequencies from KMV can predict changes in supervisory ratings for up to four quarters. There is no clear evidence on whether bond or stock prices are more informative. Most previous studies suggest a mix of both (Bliss (2001), Flannery (2001)). See also Bliss and Flannery (2004) for a survey.

<sup>3</sup>Flannery, Kwan, and Nimalendren (2004) provide evidence that markets are able to efficiently process information in the U.S. They find that bank assets (at least for large banks) are not more opaque than assets of other firms. They do not differ in their trading characteristics and analyst forecasts for banks are actually more precise.

the regulator and society might be worse off. To deter banks from excessive risk taking, bank regulators have to audit banks aggressively. On top of auditing the ones with low valuations from financial markets, regulators have to investigate some banks that receive high market valuations. Ex-post however, the regulator has little incentive to audit the latter, because the low likelihood of finding a bad bank hardly justifies the audit costs. Banks will anticipate the commitment problem of the regulator and will more likely invest in the risky project, which increases the deposit insurance liability.

The rest of the paper is structured as follows. Section 1 describes the model. Section 2 analyzes the benchmark case where bank regulation is independent of market information. Section 3 derives the stock market equilibrium. Section 4 derives the regulator's optimal auditing policy. Section 5 analyzes the equilibrium information structure. Section 6 concludes. All proofs are contained in the Appendix.

## 1 The Model

There are three agents in our model: the bank, the regulator, and an informed investor. Figure 1 shows the timing of events.

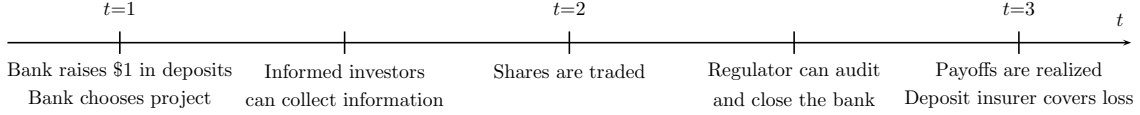
At time 1, the bank collects \$1 in deposits and invests in either a safe or risky asset. The bank's asset choice is not observable to the regulator. Let  $\theta \in \{s, r\}$  denote the asset type and  $q$  the probability that the bank chooses the risky asset, i.e.,  $q = Pr(\theta = r)$ . Deposits are fully insured. The return required by depositors therefore equals the riskless rate, which is normalized to zero.

At time 2, shares of the bank are publicly traded in a stock market as described below. At time 3, the return on the bank's asset is realized and depositors are repaid either by the bank or, if the bank's funds are insufficient, by the regulator. The asset's (gross) return is given by

$$R_\theta = 1 + \mu_\theta + \epsilon \sigma_\theta, \tag{1}$$

where  $\epsilon$  is equally likely to be  $+1$  or  $-1$ . Further,  $\mu_s > \mu_r = 0$ ,  $\sigma_s = 0$ , and  $0 < \sigma_r < 1$ . The bank is risk neutral, has no initial capital, and makes its asset choice to maximize its expected equity payoff.

Figure 1: Timeline.



After observing the bank's stock price  $P$  at time 2, the regulator decides whether to audit the bank. By incurring a cost  $c_A > 0$ , the regulator learns two pieces of information. The first is the bank's asset choice  $\theta$ . The second is an informative signal  $s_A \in \{+1, -1\}$  about the expected return  $R_\theta$ :  $Pr(s_A = +1 | \epsilon = +1) = Pr(s_A = -1 | \epsilon = -1) = (1 + \delta)/2$ , where  $\delta \in (0, 1)$ . Thus,  $E[\epsilon | s_A] = \delta s_A$ . We allow for the possibility of mixed strategy equilibria and let  $a(P)$  denote the probability that the regulator audits the bank when its stock trades at price  $P$ . Based on  $\theta$ ,  $s_A$ , and  $P$ , the regulator then decides whether to close the bank ( $C(\theta, s_A, P) = 1$ ) or leave it open ( $C(\theta, s_A, P) = 0$ ). If the bank is closed, its assets can be sold for  $\$L$ . For simplicity, we assume that the return  $L$  is the same for all types of assets if they are liquidated prematurely. In the event of liquidation, the regulator pays off the bank's depositors thereby incurring a loss  $1 - L$ .

At time 3, the regulator repays depositors when the return of the bank's assets are insufficient. The regulator is risk neutral and chooses  $a(P)$  and  $C(\theta, s_A, P)$  to minimize its own expected total costs  $TC$ , which include the payments to depositors and the cost of auditing the bank.

There is a single risk neutral investor who can collect information on the return of the bank's asset before the stock market opens at time 2. By incurring a cost  $c_I(\phi) = c_I \phi^2$ , the investor observes an informative signal  $s_I \in \{+1, -1\}$  with probability  $\phi$ . With probability  $1 - \phi$ , he does not receive any useful information about  $R_\theta$  (denoted by  $s_I = \emptyset$ ). For simplicity, we assume that the precision of the investor's signal is the same as that of the regulator's signal, but the two signals are not necessarily identical. The signal  $s_I$  equals  $s_A$  with probability  $\rho$ . With probability  $1 - \rho$ , it equals a signal that has the same distribution as  $s_A$ , but is conditionally independent of  $s_A$ . In other

words, the parameter  $\rho \in [0, 1]$  measures the correlation between  $s_A$  and  $s_I$ . If  $\rho = 1$ , the two signals are perfectly correlated, if  $\rho = 0$ , they are conditionally independent.

The investor chooses the quality of his information production technology  $\phi$ , taking the bank's asset choice and the regulator's auditing policy as given, even though his choice affects the other agents' optimal strategies. Based on his information, the investor then submits an order for  $d_I$  shares of the bank's stock to the market maker.

At time 2, there is a chance of  $1 - \phi$  that a liquidity trader arrives and trades in the stock market for exogenous reasons. In that event, the liquidity trader is equally likely to be buying or selling one share. Following Dow and Gorton (1997), we assume that the occurrence of a liquidity shock is perfectly negatively correlated with the arrival of an informed investor (i.e., with the event  $s_I \neq \emptyset$ ). Abstracting from the stylized mechanics, the variable  $\phi$  is simply a convenient device to represent the endogenous information content of market prices.

The bank's stock is traded in a competitive market-making system and a price is formed in a simplified version of the Kyle (1985) model. Investors and liquidity traders submit their demands to a risk neutral market maker who sets the price  $P$  to equal the expected value of a share, conditional on the observed order flow.

## 1.1 Assumptions

The following conditions on the exogenous parameters of the model,  $\mu_s$ ,  $\sigma_r$ ,  $\delta$ ,  $\rho$ ,  $L$ ,  $c_A$ , and  $c_I$ , are intended to restrict attention to the more interesting equilibria in which both the bank and the regulator choose mixed strategies.

### Assumption 1

$$1 - \frac{(2 + \delta - \delta^2) \sigma_r}{2(2 - \delta^2)} < L < 1 - \frac{(2 - \delta - \delta^2) \sigma_r}{2(2 - \delta^2)} \quad (2)$$

Assumption 1 ensures (i) that it is always optimal for the regulator to close a bank with risky assets when the regulator's signal is  $s_A = -1$ , and (ii) that it is never optimal

to close a bank with risky assets when the regulator's signal is  $s_A = +1$ . This holds for all  $\rho \in [0, 1]$  and  $\phi \in [0, \frac{1}{2}]$ .

**Assumption 2**

$$\frac{(1 + \delta) \sigma_r}{4} < \mu_s < \frac{\sigma_r}{2} \tag{3}$$

This assumption implies that the bank prefers to invest in the risky asset when it is never audited, and to invest in the safe asset when it is always audited.

**Assumption 3**

$$c_A < \bar{c}_A = \frac{(1 + \delta) \sigma_r}{4} - \frac{1 - L}{2} \tag{4}$$

This restriction on  $c_A$  ensures that in the case of uninformative stock prices, the expected reduction in deposit insurance payments when auditing a bank with risky assets exceeds the auditing costs.

## 2 Benchmark Case: Optimal Auditing Policy without Stock Price Information

We first analyze the benchmark case, where the regulator's auditing and closure decision is not based on price information. The auditor chooses a constant audit intensity balancing the costs of deposit insurance against the auditing costs.

Without the threat of being liquidated, the bank strictly prefers the risky project. This is not desirable from a welfare perspective.

**Lemma 1** *Under Assumptions 1 and 2, society always prefers the safe asset over the risky asset, i.e.,  $E[R_r^a] < 1 + \mu_s$ , where*

$$R_r^a = \begin{cases} R_r, & \text{if } s_A = +1 \\ L, & \text{if } s_A = -1 \end{cases} . \tag{5}$$

To derive the equilibrium for the benchmark case, we solve for the optimal strategies of the regulator and the bank. The regulator's objective is to minimize the sum of audit costs and deposit insurance losses.

$$\min_a TC = (1 - a) \frac{q}{2} \sigma_r + a \left[ \frac{q}{2} \left( \frac{1 + \delta}{2} (1 - L) + \frac{1 - \delta}{2} (1 - L) + \frac{1 - \delta}{2} \sigma_r \right) + c_A \right] \quad (6)$$

When there is no audit, the regulator loses  $\$ \sigma$  if the bank chooses the risky project and the payoff is low. This happens with probability  $q/2$ . When the supervisor decides to audit, he can detect a bank with a risky project and liquidate it if its payoff is low. This is beneficial to the regulator only if his signal  $s_A$  is correct, which happens with probability  $(1 + \delta)/2$  (first term in the bracket). But since the regulator has only imperfect information on the project outcome, he can make two types of errors. He can incorrectly close a bank with a high expected payoff (second term) or fail to close a bank with a low expected payoff (third term).

The bank chooses its optimal risk level given the regulator's audit frequency  $a$  to maximize the payoff to its equity holders.

$$\max_q (1 - q) \mu_s + \frac{q}{2} \left( (1 - a) + a \frac{1 + \delta}{2} \right) \sigma_r \quad (7)$$

The bank can either choose the safe project and earn a gross return of  $\$ \mu_s$  with certainty or invest in the risky project. In the latter case, the equity holders gain if the project turns out to be successful and the regulator does not audit (first term in the bracket) or if the regulator audits and gets a correct signal (second term). Thus, the probability that the regulator inefficiently closes a risky bank with a positive payoff poses a threat to the bank's equity holders which deters them from always investing in the risky project.

We can now solve for the equilibrium in the benchmark case, which is summarized in the following proposition:

**Proposition 1** *If the regulator ignores the information content of the stock price  $P$ ,*

then there exists a unique equilibrium with the bank's asset choice given by

$$\hat{q}_{bm} = \frac{4c_A}{(1+\delta)\sigma_r - 2(1-L)},$$

and the regulator's auditing policy given by

$$\hat{a}_{bm} = \frac{2(\sigma_r - 2\mu_s)}{(1-\delta)\sigma_r}.$$

The regulator's expected total costs (payments to depositors and auditing costs) are

$$TC_{bm} = \frac{\hat{q}_{bm}\sigma_r}{2}.$$

### 3 Stock Market Equilibrium

We begin our analysis of the stock market equilibrium by deriving the investor's optimal trading strategy  $d_I(s_I)$  and the market maker's pricing rule  $P(d)$ , taking as given the bank's asset choice  $q$ , the regulator's auditing policy  $a(P)$ , and the quality of the investor's information production technology  $\phi$ .

Since the order submitted by liquidity traders is either  $d_L = +1$  or  $d_L = -1$ , the investor can profitably trade on his information only by buying one share when he receives good news ( $s_I = +1$ ) and selling one share when he receives bad news ( $s_I = -1$ ). Indeed, a buy or sell order for any amount other than one share would be identified by the market maker as originating from the investor, thus revealing his information and destroying his opportunity to make a trading profit. Further, buying (selling) shares when  $s_I = -1$  ( $s_I = +1$ ) or submitting an order when the signal is uninformative ( $s_I = \emptyset$ ) would generate a loss.<sup>4</sup> Thus, the investor's profit-maximizing

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<sup>4</sup>This is supported by the following out-of-equilibrium beliefs: If the market maker observes two buy (sell) orders, he updates his probability of state  $\epsilon = +1$  ( $\epsilon = -1$ ) to  $(1+\delta)/2$ .

trading strategy can be summarized as follows:

$$d_I(s_I) = \begin{cases} +1, & \text{if } s_I = +1 \\ -1, & \text{if } s_I = -1 \\ 0, & \text{if } s_I = \emptyset \end{cases} \quad (8)$$

The market maker sets the price  $P$  equal to the expected asset value, conditional on the observed order flow. When the investor follows the trading strategy specified by (8), there are generally two possible prices, one for a buy order and one for a sell order. This is a consequence of our assumption that the occurrence of a liquidity shock is perfectly negatively correlated with the arrival of an informed investor. A buy order could originate from either an informed investor with favorable information or from liquidity traders, and the equilibrium price will reflect the chances of each. Similarly, a sell order could be caused by either liquidity needs or unfavorable information. The following lemma characterizes the equilibrium prices as a function of the observed order flow.

**Lemma 2** *For a given asset choice  $q$ , auditing policy  $a(P)$ , and intensity of informed trading  $\phi$ , the date 2 stock prices are given by*

$$P(d = +1) = (1 - q) \mu_s + q \left( \frac{1}{2}(1 + \phi \delta) - \frac{1}{4} a^+(1 - \delta)(1 + \phi(\delta - \rho(1 + \delta))) \right) \sigma_r \equiv P^+,$$

$$P(d = -1) = (1 - q) \mu_s + q \left( \frac{1}{2}(1 - \phi \delta) - \frac{1}{4} a^-(1 - \delta)(1 - \phi(\delta - \rho(1 + \delta))) \right) \sigma_r \equiv P^-,$$

where  $a^+ = a(P^+)$  and  $a^- = a(P^-)$ .

Based on these prices and the trading strategy specified by (8), we can now calculate the investor's expected trading profit and his optimal choice of  $\phi$ , balancing the gains from trade and the cost of information collection:

**Lemma 3** *For a given asset choice  $q$  and auditing policy  $a(P)$ , the investor's expected profit from producing information and trading on it is equal to*

$$\pi_I = \phi(1 - \phi) q \left( \frac{1}{2} \delta - \frac{1}{8} (a^+ + a^-)(1 - \delta)(\delta - \rho(1 + \delta)) \right) \sigma_r - c_I \phi^2. \quad (9)$$

The optimal quality of the information production technology is given by

$$\hat{\phi} = \frac{1}{2} - \frac{c_I}{q\left(\delta - \frac{1}{4}(a^+ + a^-)(1 - \delta)(\delta - \rho(1 + \delta))\right)\sigma_r + 2c_I} < \frac{1}{2}. \quad (10)$$

**Corollary 1** *The optimal quality of the investor's information,  $\hat{\phi}$ , is increasing in the probability  $q$  that the bank invests in the risky asset, the variance  $\sigma_r$  of the asset return, the signal precision  $\delta$ , the correlation  $\rho$  of the investor's information with the auditor's information, and is decreasing in the information production cost  $c_I$ . Further,  $\hat{\phi}$  is increasing (decreasing) in the audit frequency, if the correlation between  $s_I$  and  $s_A$  is sufficiently high (low) in that*

$$\frac{\partial \hat{\phi}}{\partial a^+} > (<) 0, \quad \frac{\partial \hat{\phi}}{\partial a^-} > (<) 0, \quad \text{if} \quad \rho > (<) \rho_{crit} = \frac{\delta}{1 + \delta}. \quad (11)$$

Most of these comparative statics are intuitive. When the bank invests in the risk-free asset, there are no trading opportunities for the informed trader. Thus, it is not surprising that he invests more in information acquisition when the bank is more likely to invest in the risky project. Information also becomes more valuable when the variation  $\sigma_r$  of the project's payoff increases.

The optimal amount of information acquisition of the informed trader also increases in the signal precision  $\delta$ . Recall that, for algebraic convenience, we assume that  $\delta$  is the precision of both the informed trader's signal and of the regulator's signal. The ability to get more precise signals clearly allows the investor to trade more effectively. However, when the regulator's auditing technology improves, he is more likely to close down "bad banks" (i.e., banks that invested in the risky project where the conditional expected payoff is low). This effectively increases the difference between the high and the low stock price. To understand this intuition, consider the case where the regulator always audits and the signal always reveals the true state. Then we know for sure that the bank will be closed in the bad state and will survive in the good state. As the regulator's signal becomes noisier, the probability that the regulator closes a bank with a high (low) expected payoff increases (decreases). This causes the expected value of

the bank in the good (bad) state to decrease (increase). Thus, the difference between the high and the low stock price decreases and the informed trader's profit declines.

The investor is also concerned about the correlation of the auditor's signal with his own signal. Since the investor's payoff is affected by both his ability to identify the true state as well as the regulator's action, he has a strong interest in learning the regulator's information. When the correlation of the two signals is high, the regulator's closure policy can be predicted by the informed investor, which makes inside information more valuable to him. When the correlation is low, the regulator is more likely to make a mistake from the informed investor's perspective, which decreases his incentives for information collection.

The same logic applies for the sensitivity of the optimal amount of information collection with respect to the auditing intensity. When the correlation is high, i.e. above the critical threshold  $\rho_{crit}$ , the informed investor can benefit from higher auditing, because her ability to predict the regulators action is sufficiently high. When the correlation is low, the incentives to collect information decrease as the audit intensity increases, because more auditing increases the risk that the regulator will close the bank when the informed investor receives a favorable signal.

## 4 Optimal Auditing Policy with Stock Price Information

Given the stock market equilibrium in Section 3, we can now derive the optimal strategy of the regulator and the bank. Assumption 1 assures that the regulator, once he has conducted an audit, will always base his closure decision only on his own signal.<sup>5</sup>

Making the audit decision dependent on the observed stock price, the regulator will always find it optimal to audit the bank more frequently (i.e., with a higher probability) when the stock price is low. The reason is that the probability of finding a bank with a low expected project payoff is higher for low stock prices. The regulator will only audit

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<sup>5</sup>That is, he always (never) finds it optimal to close the bank when he receives a bad (good) signal, even if the stock price is high (low).

the bank after observing a high stock price if (always) auditing the bank following a low stock price does not suffice to prevent excessive risk taking. The optimal auditing policy with stock price information will therefore depend on the bank's risk-shifting incentives.

**Proposition 2** *Suppose stock prices are informative (i.e.,  $\phi > 0$ ) and let*

$$\mu_s^c = \left( \frac{1}{2} - \frac{1}{8}(1 - \delta)(1 - \phi(\delta - \rho(1 + \delta))) \right) \sigma_r.$$

*If  $\mu_s \geq \mu_s^c$ , there exists a unique equilibrium with the bank's asset choice given by*

$$\hat{q}_l = \frac{4c_A}{(1 + \delta)(1 + \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 + \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L)},$$

*and the regulator's auditing policy given by*

$$\hat{a}_l^+ = 0 \quad \text{and} \quad \hat{a}_l^- = \frac{4(\sigma_r - 2\mu_s)}{(1 - \delta)(1 - \phi(\delta - \rho(1 + \delta))) \sigma_r}.$$

*If  $\mu_s < \mu_s^c$ , the unique equilibrium is characterized by*

$$\hat{q}_h = \frac{4c_A}{(1 + \delta)(1 - \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 - \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L)},$$

$$\hat{a}_h^+ = \frac{(3 + \delta + \phi(\delta(1 - \delta) - \rho(1 - \delta^2))) \sigma_r - 8\mu_s}{(1 - \delta)(1 + \phi(\delta - \rho(1 + \delta))) \sigma_r}, \quad \text{and} \quad \hat{a}_h^- = 1,$$

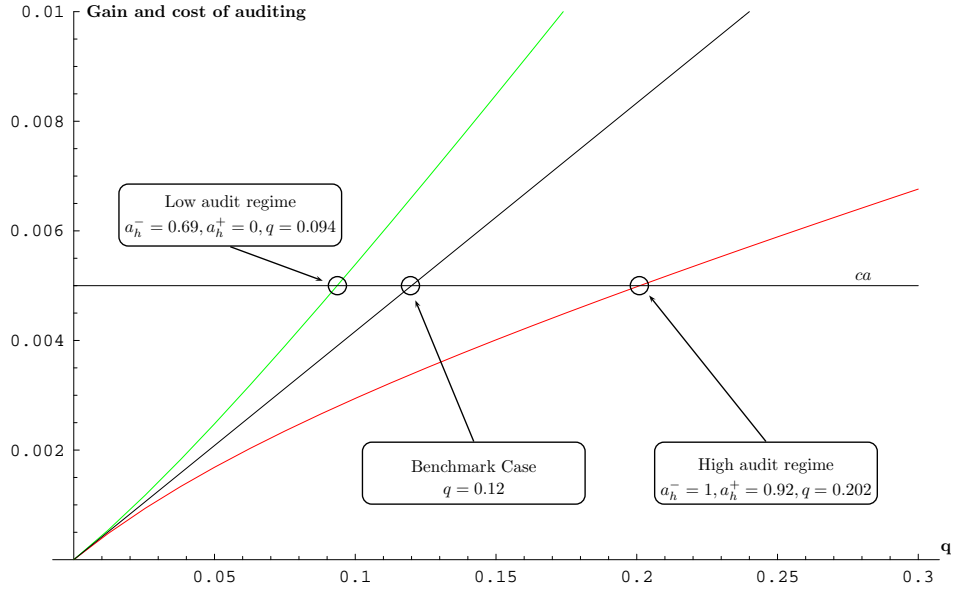
*when auditing costs are low ( $c_A < c_A^c$ ), and by*

$$\hat{q}_h = 1, \quad \hat{a}_h^+ = 0, \quad \text{and} \quad \hat{a}_h^- = 1,$$

*when auditing costs are high ( $c_A^c < c_A < \bar{c}_A$ ), where  $c_A^c$  is a function of  $\delta$ ,  $\rho$ ,  $\phi$ ,  $\sigma_r$ , and  $L$ .*

Which of the two auditing regimes occurs depends on the risk-shifting incentives of the bank. When risk taking is not very attractive (i.e., the return on the safe project is high relative to that on the risky project,  $\mu_s \geq \mu_s^c$ ), the regulator audits the bank only

Figure 2: Gains and costs from auditing.



when the stock price is low. In other words, if the expected benefit from investing in the risky project does not outweigh the potential loss bank equity holders incur when the regulator closes a solvent bank by mistake, a low audit frequency suffices to prevent excessive risk taking. We refer to this case as the *low-audit regime*. In equilibrium, the bank will be indifferent between choosing the safe and the risky project.

When risk shifting is attractive (i.e., if  $\mu_s \leq \mu_s^c$ ), the regulator can only deter the bank from always investing in the risky project by auditing the bank more frequently, in some cases even when the stock price is high. We call this case the *high-audit regime*.

Auditing at high stock prices is very costly for the regulator, since the probability of finding a “bad bank” is very low in this case. When the auditing costs are too high ( $c_A \geq c_A^c$ ), the regulator will not find it worthwhile to audit the bank when the stock price is high, even if the bank always chooses the risky project. The bank anticipates that the regulator can not commit to such a high audit frequency and therefore always invests in the risky project.

The goal of market discipline is to create incentives for banks to behave prudently.

We next compare the bank's optimal investment strategy to the benchmark case where the regulator does not condition the audit decision on stock prices.

**Proposition 3** *The bank is less likely to invest in the risky asset in case the regulator's auditing policy takes price information into account, if and only if the return on the safe asset is high in that  $\mu_s \geq \mu_s^c$ . Thus, the probabilities of investing in the risky asset in the low-audit, high-audit and benchmark equilibria are ordered  $\hat{q}_l < \hat{q}_{bm} < \hat{q}_h$ .*

Surprisingly, an auditing strategy based on price information does not always induce banks to reduce their risk. When the risky project is very attractive, banks are more likely to choose the risky project under a market-based auditing scheme than in the benchmark case.

Figure 2 illustrates the intuition behind this result by means of a numerical example. When risk shifting is not particularly attractive, we are in the low-audit regime. The regulator has to provide little auditing and can therefore concentrate on auditing when the stock price is low. The regulator can thereby take advantage of information contained in stock prices and perform bank audits more efficiently in those states in which the bank is more likely to realize a low payoff. The three increasing lines in Figure 2 show the benefit to the regulator of conducting an audit for different levels of  $q$  in the low-audit regime, the high-audit regime, and the benchmark case, respectively. Of course, auditing is not beneficial when the bank always chooses the safe project ( $q = 0$ ). We find that auditing is very efficient in the low-audit regime as the benefit increases steeply in the probability that the bank picks the risky project. In equilibrium, the bank chooses  $q$  such that the regulator is indifferent between auditing and not auditing. In other words, the benefits from auditing must equal the auditing costs  $c_A$ . In equilibrium, the bank is less likely to choose the risky project than in the benchmark case because the regulator's auditing strategy is more effective.

As the risky project becomes more attractive, the regulator has to increase his level of auditing. Once he has reached the critical level of always auditing the bank after observing a low stock price, a further increase in bank risk leads to a commitment problem for the regulator. Ex ante, he would like to commit to a higher audit frequency

in order to prevent excessive risk taking. Ex post, however, he does not find it optimal to audit the bank when a high stock price indicates that the bank is solvent. Knowing that the regulator cannot commit to an ex post suboptimal auditing policy, the bank will increase its project risk to a level at which the regulator finds it worthwhile to audit the bank even at high stock prices. Thus bank risk is dramatically increasing once we move from the low-audit regime to the high-audit regime.

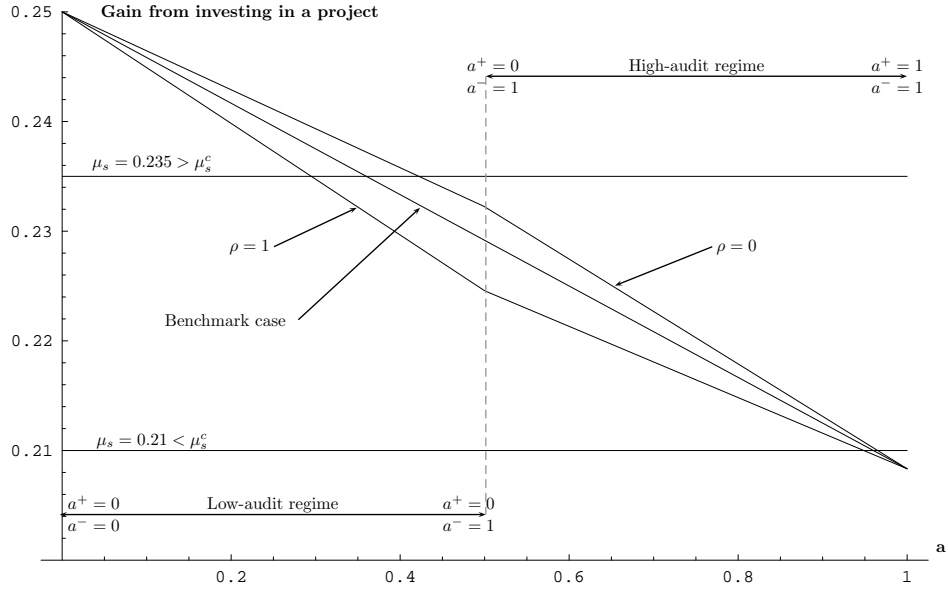
**Proposition 4** *The regulator's expected total costs (payouts to depositors and auditing costs) in case the regulator's auditing policy takes price information into account are lower than in the benchmark case, if and only if the return on the safe asset is high in that  $\mu_s \geq \mu_s^c$ . Thus, the regulator's total costs in the high-audit, low-audit and benchmark equilibria are ordered  $TC_l < TC_{bm} < TC_h$ .*

Proposition 4 shows that the regulator is not always better off when his auditing strategy is based on price information. When risk shifting is not very attractive, we are in the low-audit regime and market information can enhance the effectiveness of bank supervision. In the high-audit regime, however, the bank regulator is worse off. This has some interesting policy implications. While incorporating market information might save costs during normal times, it might amplify the regulator's cost during a financial crisis. At the brink of a banking crisis, such as the savings and loan crisis, when risk shifting becomes more attractive, the regulator might not be able to commit to audit banks enough and banks' risk as well as the crisis resolution costs will increase.

**Proposition 5** *Suppose auditing costs are sufficiently low so that the regulator finds it optimal to audit a bank with risky assets even after a high stock price has been observed (i.e.,  $c_A < c_A^c$ ). Then the audit frequency in case the regulator takes price information into account is lower (higher) than in the benchmark case, if the correlation between the investor's signal  $s_I$  and the regulator's signal  $s_A$  is high (low), i.e.,*

$$\frac{\hat{a}^+ + \hat{a}^-}{2} \underset{(>)}{<} \hat{a}_{bm}, \quad \text{iff} \quad \rho \underset{(<)}{>} \frac{\delta}{1 + \delta}.$$

Figure 3: Project payoffs or the bank for different levels of auditing.



Proposition 5 compares the equilibrium audit frequency of the regulator to the benchmark case. Figure 3 illustrates the intuition behind this result. The graph shows the expected bank stock payoff given the safe and risky projects for different levels of auditing. The regulator optimally performs as many audits as necessary in order to make the bank indifferent between the safe project (horizontal lines) and the risky project (downward sloping lines). When risk shifting is not very attractive (i.e., when  $\mu_s > \mu_s^c$ ), the necessary audit frequency is low and the regulator has to audit the bank only when the stock price is low (low-audit regime). When risk shifting becomes more attractive for the bank (e.g., because the return on the safe project is low,  $\mu_s < \mu_s^c$ ), excessive risk taking by the bank can only be prevented by conducting more frequent audits.

The driving factor for the optimal auditing policy is the correlation between the regulator's signal  $s_A$  and the investor's signal  $s_I$ . With highly correlated signals, fewer audits compared to the benchmark case suffice to deter the bank from always investing in the risky project. The opposite is true for a low correlation. In this case, more audits are necessary to prevent risk shifting than in the benchmark case. The key to

understanding this result is very simple. Equity holders do not care whether the regulator closes a bank with a low payoff from the risky project, because their profit would be zero anyway. The equity holders' main concern is that the regulator accidentally closes a bank with a high payoff. For given risk-shifting incentives, we therefore need a certain level of inefficient bank closures to convince equity holders that investing in the safe project is more profitable for them. Thus, the disciplining mechanism for banks is the regulator's threat to close a solvent bank by mistake, thereby destroying the option value of a continued operation to equity holders. When the correlation is high, it is very likely that the regulator will get a bad signal when the stock price is low. Thus, less auditing is required to achieve this target level of bank closures. When the correlation is low, the regulator is less likely to receive an unfavorable signal following a low stock price and therefore has to audit banks more often than in the benchmark case. In the two extreme cases when the regulator never audits or always audits the bank, price information is not important. In these cases, the regulator's behavior only depends on his own information and the bank's gain from investing in the risky project does not depend on the correlation between  $s_A$  and  $s_I$ .

## 5 Equilibrium Information Structure

Most empirical studies explore the possible use of information contained in market prices for bank supervision assuming that the amount of informed trading is exogenous. However, using price information in a market-based auditing process can increase or, potentially, decrease the endogenous informativeness of stock prices.

**Proposition 6** *In the low-audit regime (i.e., when  $\mu_s \geq \mu_s^c$ ), the intensity of informed trading in case the regulator takes price information into account is lower than in the benchmark case, i.e.,  $\hat{\phi}_l = \hat{\phi}(\hat{q}_l, \hat{a}_l) < \hat{\phi}_{bm}$ . In the high-audit regime, however, there exist parameter values such that  $\hat{\phi}_h = \hat{\phi}(\hat{q}_h, \hat{a}_h) > \hat{\phi}_{bm}$ .*

The informed trader's profits are mainly driven by the bank's willingness to invest in the risky project. Thus, if the bank's risk-taking incentives decrease because of

more effective auditing, so does the investor's informational advantage over the market maker and, hence, his expected profit.

Proposition 7 highlights the importance of the correlation between the investor's and the regulator's signal.

**Proposition 7** *The investor's expected profit,  $\pi_I$ , is strictly increasing in  $\rho$ , the correlation of her signal,  $s_I$ , and the regulator's signal,  $s_A$ . The regulator, on the other hand, benefits from an increase in the correlation  $\rho$  if and only if  $(\mu_s - \mu_s^c)(L - (1 - \sigma_r/2)) > 0$ .*

The investor always benefits from a high correlation, because this makes the regulator's actions more predictable from his perspective. Consider for example an investor who short sells the stock. He does not only gain when the risky project has a bad outcome, but also when the regulator closes the bank. The latter case is more likely to occur when the signal correlation is high.

The regulator does not always prefer a high signal correlation. On the one hand, when the correlation is low, the regulator can learn more about the true state from observing a second signal, which is incorporated in securities prices. On the other hand, when the correlation is high, the regulator is more likely to close a solvent bank by mistake conditional on observing a low stock price. This increases the liquidation threat for the bank and thus makes an investment in the risky project more costly for equity holders.

## 6 Conclusion

Market-based bank auditing seeks to improve the regulatory process by incorporating information contained in market prices. Encouraged by recent empirical studies showing that financial markets can provide valuable information to regulators, bank supervisors hope to increase the efficiency of their monitoring activities and to enhance financial stability. However, including market information in the supervisory process changes investors' incentives to acquire information in the first place and also affects

the banks' optimal risk choice. In this paper we analyze the interaction between the banks' risk-taking incentives, the regulator's optimal auditing policy, and the investors' incentives to collect information.

We find that market-based bank regulation makes regulators better off only if banks' risk shifting incentives are not too large. In this case, the regulator is able to extract information from financial markets and can induce banks to invest more prudently by auditing more efficiently. Lower bank risk makes it less attractive for investors to trade on information and security prices become less informative.

In crisis situations, however, when risk shifting is very attractive, regulators are worse off than they would be by ignoring information from financial markets. The main intuition for this result is that regulators hardly find "bad banks" when financial markets give positive signals, which makes auditing very costly in these states of the world. Thus, regulators cannot commit to a strict auditing policy that is suboptimal ex post. Banks anticipate this invest in riskier portfolios, which increase the regulator's cost from deposit insurance payments.

Caution has to be applied when implementing mechanisms of market discipline in bank regulation. While regulators can be better off in times of a stable banking system in which banks have incentives to invest prudently, bank supervisors can be worse off when bank supervision is needed most, namely when the banking sector is fragile and incentives for banks to take excessive risks are high.

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## A List of Variables

$\theta$	bank's asset type, $\theta \in \{s, r\}$
$q$	probability that the bank chooses the risky asset, i.e., $q = Pr(\theta = r)$
$R_\theta$	asset return: $R_\theta = 1 + \mu_\theta + \epsilon \sigma_\theta$ , $\epsilon \in \{-1, +1\}$
$\mu_\theta$	expected (net) return on the bank's asset
$\sigma_\theta$	standard deviation of the return on the bank's asset
$P$	stock price, $P \in \{P^+, P^-\}$
$c_A$	auditing costs of the regulator
$s_A$	signal about $\epsilon$ observed by the regulator, $s_A \in \{+1, -1\}$
$s_I$	signal about $\epsilon$ observed by the investor, $s_I \in \{+1, -1\}$
$\delta$	informativeness of the regulator's and investor's signal
$a(P)$	audit probability of the regulator as a function of the stock price $P$
$L$	liquidation value of the bank's assets when the regulator closes the bank
$c_I(\phi)$	costs of information production for the investor, $c_I(\phi) = c_I \phi^2$
$\phi$	probability that the informed investor observes an informative signal
$\rho$	correlation of the regulator's and the investor's signal
$d_I$	market order submitted by the investor
$d_L$	market order submitted by liquidity traders
$TC$	expected total costs of the regulator

## B Proofs

### Proof of Lemma 1

Assuming that the regulator always audits the bank and closes it when her signal indicates a low return (i.e., when  $s_A = -1$ ), the expected return on the risky asset is

equal to

$$\begin{aligned}
E[R_r^a] &= Pr(\epsilon = +1)(Pr(s_A = +1 | \epsilon = +1)(1 + \sigma_r) + Pr(s_A = -1 | \epsilon = +1)L) \\
&\quad + Pr(\epsilon = -1)(Pr(s_A = +1 | \epsilon = -1)(1 - \sigma_r) + Pr(s_A = -1 | \epsilon = -1)L) \\
&= \frac{1}{2} \left( \frac{1 + \delta}{2} (1 + \sigma_r) + \frac{1 - \delta}{2} L \right) + \frac{1}{2} \left( \frac{1 - \delta}{2} (1 - \sigma_r) + \frac{1 + \delta}{2} L \right) \\
&= (1 + \delta \sigma_r + L)/2.
\end{aligned} \tag{12}$$

This is less than the return on the safe asset,  $1 + \mu_s$ , since  $L < 1$  by Assumption 1 and  $(1 + \delta) \sigma_r/4 < \mu_s$  by Assumption 2.  $\square$

## Proof of Proposition 1

First, note that under Assumptions 2 and 3, a pure-strategy equilibrium does not exist. If the bank is never audited, it prefers to invest in the risky asset (Assumption 2). But in this case, the optimal strategy for the regulator is to audit the bank (Assumption 3). On the other hand, if the bank is always audited, it is better off investing in the safe asset (Assumption 2). But then performing a costly audit is not optimal for the regulator. Thus, there is no pure-strategy equilibrium.

In a mixed-strategy equilibrium, the following two conditions have to hold: (1) the bank's equity holders have to be indifferent between investing in the safe and the risky asset, and (2) the regulator has to be indifferent between auditing and not auditing the bank.

If the bank invests in the safe asset, the return to its equity holders is  $\mu_s$ . If it invests in the risky asset, then its equity holders receive a non-zero payoff of  $\sigma_r$  only if  $\epsilon = +1$  (which happens with probability  $\frac{1}{2}$ ) *and* the bank is not audited or, if it is audited, the regulator observes a positive signal  $s_A = +1$  (which happens with probability  $(1 + \delta)/2$ ). Thus, condition (1) can be written as

$$\mu_s = \frac{1}{2} \left( 1 - a + a \left( \frac{1 + \delta}{2} \right) \right) \sigma_r.$$

Solving this equation for  $a$  yields the regulator's equilibrium auditing policy

$$\hat{a}_{bm} = \frac{2(\sigma_r - 2\mu_s)}{(1 - \delta)\sigma_r}.$$

Condition (2) requires the regulator to be indifferent between auditing and not auditing the bank. For a given asset choice  $q$ , the regulator's expected deposit insurance payments are equal to  $q\sigma_r/2$  in case she does not audit the bank. If the regulator decides to audit the bank, she will receive a negative signal  $s_A = -1$  and consequently close a bank with risky assets with probability  $\frac{1}{2}$ . In this case, her deposit insurance payments are equal to  $1 - L$ . In addition, there is chance that the regulator does not liquidate an insolvent bank based on an incorrect signal  $s_A = +1$  (which happens with probability  $(1 - \delta)/2$ ), in which case the regulator has to repay depositors  $\sigma_r$ . Condition (2) therefore translates to

$$\frac{q\sigma_r}{2} = \frac{q}{2} \left( (1 - L) + \frac{1 - \delta}{2} \sigma_r \right) + c_A,$$

which can be solved for the bank's equilibrium asset choice

$$\hat{q}_{bm} = \frac{4c_A}{(1 + \delta)\sigma_r - 2(1 - L)}.$$

Since in equilibrium, the regulator is indifferent between auditing and not auditing the bank, her expected total costs (payments to depositors and auditing costs) must be equal to the expected payments to depositors in the no-auditing case, i.e.,

$$TC_{bm} = \frac{\hat{q}_{bm}\sigma_r}{2}.$$

□

## Proof of Lemma 2

For a given asset choice  $q$  and auditing policy  $a(P)$ , the expected payoff to the bank's equity holders conditional on a liquidity buy order is given by

$$E[R \mid d_L = +1] = (1 - q) \mu_s + q \left( \frac{1}{2} \left( 1 - a^+ + a^+ \left( \frac{1 + \delta}{2} \right) \right) \sigma_r \right)$$

If the bank invests in the safe asset, the return to its equity holders is  $\mu_s$ . If it invests in the risky asset, then its equity holders receive a non-zero payoff of  $\sigma_r$  only if  $\epsilon = +1$  (which happens with probability  $\frac{1}{2}$ ) and the bank is not audited or, if it is audited, the regulator observes a positive signal  $s_A = +1$  (recall that  $Pr(s_A = +1 \mid \epsilon = +1) = (1 + \delta)/2$ ).

Similarly, if the investor follows the trading strategy defined by (8), the expected payoff conditional on an informed buy order is equal to

$$E[R \mid d_I = +1] = (1 - q) \mu_s + q \left( \frac{1 + \delta}{2} \left( 1 - a^+ + a^+ \left( \rho + (1 - \rho) \frac{1 + \delta}{2} \right) \right) \sigma_r \right)$$

If an informed investor buys a share, the probability that  $\epsilon = +1$  is equal to  $(1 + \delta)/2$ , and the probability that the regulator's signal is positive as well is equal to  $\rho + (1 - \rho)(1 + \delta)/2$ .

From the market maker's perspective, the expected value of the bank's equity conditional on observing a buy order is therefore given by

$$\begin{aligned} P(d = +1) &= \phi E[R \mid d_I = +1] + (1 - \phi) E[R \mid d_L = +1] \\ &= (1 - q) \mu_s + q \left( \frac{1}{2} (1 + \phi \delta) - \frac{1}{4} a^+ (1 - \delta) (1 + \phi(\delta - \rho(1 + \delta))) \right) \sigma_r. \end{aligned}$$

Similarly, upon observing a sell order, the market maker sets the price equal to

$$\begin{aligned} P(d = -1) &= \phi E[R \mid d_I = -1] + (1 - \phi) E[R \mid d_L = -1] \\ &= (1 - q) \mu_s + q \left( \frac{1}{2} (1 - \phi \delta) - \frac{1}{4} a^- (1 - \delta) (1 - \phi(\delta - \rho(1 + \delta))) \right) \sigma_r. \end{aligned}$$

□

### Proof of Lemma 3

For a given asset choice  $q$  and auditing policy  $a(P)$ , the investor's expected profit from buying (selling) one share after observing the signal  $s_I = +1$  ( $s_I = -1$ ) is given by  $E[R | d_I = +1] - P(d = +1)$  ( $P(d = -1) - E[R | d_I = -1]$ ). Her expected trading profit net of information production costs is therefore equal to

$$\begin{aligned}\pi_I &= \frac{1}{2} \phi (E[R | d_I = +1] - P(d = +1)) + \frac{1}{2} \phi (P(d = -1) - E[R | d_I = -1]) - c_I \phi^2 \\ &= \phi (1 - \phi) q \left( \frac{1}{2} \delta - \frac{1}{8} (a^+ + a^-) (1 - \delta) (\delta - \rho(1 + \delta)) \right) \sigma_r - c_I \phi^2.\end{aligned}$$

From the first-order condition, the optimal quality of the investor's information production technology is found to be

$$\hat{\phi} = \frac{1}{2} - \frac{c_I}{q \left( \delta - \frac{1}{4} (a^+ + a^-) (1 - \delta) (\delta - \rho(1 + \delta)) \right) \sigma_r + 2 c_I}.$$

Note that  $0 < \hat{\phi} < \frac{1}{2}$ . □

### Proof of Corollary 1

These comparative static results follow immediately from equation (10). □

### Proof of Proposition 2

To be written.

### Proof of Proposition 3

In the low-audit equilibrium, the bank's probability of investing in the risky asset,  $\hat{q}_l$ , is given by

$$\frac{4 c_A}{(1 + \delta) (1 + \phi (\delta + \rho (1 - \delta))) \sigma_r - 2 (1 + \phi (\delta^2 + \rho (1 - \delta^2))) (1 - L)},$$

which is lower than the probability in the benchmark case,  $\hat{q}_{bm}$ , since

$$(1 + \delta)(1 + \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 + \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L) > (1 + \delta) \sigma_r - 2(1 - L),$$

or, equivalently, since

$$(1 + \delta) \sigma_r (\delta + \rho(1 - \delta)) > 2(1 - L) (\delta^2 + \rho(1 - \delta^2)).$$

A sufficient condition for the above inequality to hold is

$$(1 + \delta) \sigma_r > 2(1 - L),$$

which is ensured by Assumption 1, since

$$L > 1 - \frac{(2 + \delta - \delta^2) \sigma_r}{2(2 - \delta^2)} > 1 - \frac{(1 + \delta) \sigma_r}{2}.$$

In the high-audit equilibrium, the bank's probability of investing in the risky asset,  $\hat{q}_h$ , is 1 when auditing costs are high, and

$$\frac{4c_A}{(1 + \delta)(1 - \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 - \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L)}$$

when auditing costs are low. Thus,  $\hat{q}_h$  exceeds the probability in the benchmark case, since  $\hat{q}_{bm} < 1$  and

$$(1 + \delta)(1 - \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 - \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L) < (1 + \delta) \sigma_r - 2(1 - L),$$

which can again be rewritten as

$$(1 + \delta) \sigma_r (\delta + \rho(1 - \delta)) > 2(1 - L) (\delta^2 + \rho(1 - \delta^2)).$$

This proves that the bank's probabilities of investing in the risky asset are ordered as

follows:  $\hat{q}_l < \hat{q}_{bm} < \hat{q}_h$ . □

## Proof of Proposition 4

In the low-audit equilibrium, the regulator never audits the bank after observing a high stock price, and is indifferent between auditing and not auditing the bank after observing a low stock price. This implies that her expected total costs (payments to depositors and auditing costs) have to be equal to the expected payments to depositors in the no-auditing case, i.e.,  $TC_l = \hat{q}_l \sigma_r / 2$ . Thus, the regulator's total costs in the low-audit equilibrium are lower than in the benchmark case,  $TC_{bm} = \hat{q}_{bm} \sigma_r / 2$ , because  $\hat{q}_l < \hat{q}_{bm}$  (see Proposition 3).

In the high-audit equilibrium, on the other hand, the regulator always audits the bank after observing a low stock price, and is indifferent between auditing and not auditing the bank after observing a high stock price. In the latter case, her expected total costs (payments to depositors and auditing costs) are therefore equal to  $\hat{q}_h \sigma_r / 2$ . In the former case (i.e., when  $P = P^-$ ), her expected costs, denoted by  $TC^-(a^- = 1, q = \hat{q}_h)$ , exceed  $TC^-(a^- = 1, q = \hat{q}_{bm})$ , the costs the regulator would incur if the bank chose the risky asset only with probability  $\hat{q}_{bm}$ , since  $TC$  is strictly increasing in  $q$  and since  $\hat{q}_{bm} < \hat{q}_h$  (see Proposition 3). Moreover, since  $TC(a = 1, q = \hat{q}_{bm}) = \frac{1}{2} TC^+(a^+ = 1, q = \hat{q}_{bm}) + \frac{1}{2} TC^-(a^- = 1, q = \hat{q}_{bm})$  and since the bank is more likely to be insolvent when the stock price is low<sup>6</sup>, we have

$$TC^-(a^- = 1, q = \hat{q}_h) > TC(a = 1, q = \hat{q}_{bm}) = \frac{\hat{q}_{bm} \sigma_r}{2}.$$

This implies that the regulator's total costs in the high-audit equilibrium,  $TC_h$ , are bounded below by

$$\frac{1}{2} \left( \frac{\hat{q}_h \sigma_r}{2} \right) + \frac{1}{2} \left( \frac{\hat{q}_{bm} \sigma_r}{2} \right),$$

which clearly exceeds the costs in the benchmark case,  $TC_{bm} = \hat{q}_{bm} \sigma_r / 2$ , because  $\hat{q}_h > \hat{q}_{bm}$ . □

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<sup>6</sup>Note that  $Pr(\epsilon = -1 | P = P^-) = (1 + \phi \delta) / 2 > (1 - \phi \delta) / 2 = Pr(\epsilon = -1 | P = P^+)$ , implying that  $TC^+(a^+ = 1, q = \hat{q}_{bm}) < TC^-(a^- = 1, q = \hat{q}_{bm})$ .

## Proof of Proposition 5

In the low-audit equilibrium, the (unconditional) probability that the regulator audits the bank is

$$\frac{\hat{a}_l^+ + \hat{a}_l^-}{2} = \frac{2(\sigma_r - 2\mu_s)}{(1 - \delta)(1 - \phi(\delta - \rho(1 + \delta))) \sigma_r},$$

which is lower than the probability in the benchmark case,

$$\hat{a}_{bm} = \frac{2(\sigma_r - 2\mu_s)}{(1 - \delta) \sigma_r},$$

if and only if

$$1 - \phi(\delta - \rho(1 + \delta)) > 1,$$

or, equivalently, if and only if  $\rho > \delta/(1 + \delta)$ .

If the regulator's auditing costs are below  $c_A^c$ , the audit probability in the high-audit equilibrium is given by

$$\frac{\hat{a}_h^+ + \hat{a}_h^-}{2} = \frac{2(\sigma_r - 2\mu_s) + (1 - \delta)\phi(\delta - \rho(1 + \delta)) \sigma_r}{(1 - \delta)(1 + \phi(\delta - \rho(1 + \delta))) \sigma_r}.$$

This probability is lower than  $\hat{a}_{bm}$  if and only if

$$((1 + \delta) \sigma_r - 4\mu_s)(\delta - \rho(1 + \delta)) > 0.$$

Since  $(1 + \delta) \sigma_r - 4\mu_s < 0$  by Assumption 2, the above inequality holds if and only if  $\rho > \delta/(1 + \delta)$ .

This proves that the audit probability in case the regulator takes price information into account is lower (higher) than in the benchmark case, if the correlation between the investor's signal and the regulator's signal is higher (lower) than  $\delta/(1 + \delta)$ .  $\square$

## Proof of Proposition 6

In the low-audit equilibrium, the probability that the bank invests in the risky asset,  $\hat{q}_l$ , is lower than that in the benchmark case,  $\hat{q}_{bm}$  (Proposition 3). Further, if  $\rho > \delta/(1 + \delta)$ ,

the audit probability  $\hat{a}_l = (\hat{a}_l^+ + \hat{a}_l^-)/2$  is lower than  $\hat{a}_{bm}$  as well (Proposition 5). It therefore follows from Corollary 1, which shows that  $\hat{\phi}$  is strictly increasing in  $q$  and  $a$  if the above condition on  $\rho$  is satisfied, that the intensity of informed trading in the low-audit equilibrium,  $\hat{\phi}_l$ , is lower than in the benchmark case. If, on the other hand,  $\rho < \delta/(1 + \delta)$ , we have  $\hat{a}_l > \hat{a}_{bm}$  (Proposition 5). However, under this condition, Corollary 1 shows that  $\hat{\phi}$  is strictly decreasing in  $a$ , again implying a lower intensity of informed trading than in the benchmark case.

In the high-audit regime, the effects are not clear. The higher probability that the bank chooses the risky asset leads to an increase in  $\hat{\phi}$ , whereas the change in audit probability ( $\hat{a}_h < \hat{a}_{bm}$  if  $\rho > \delta/(1 + \delta)$ , and  $\hat{a}_h > \hat{a}_{bm}$  if  $\rho < \delta/(1 + \delta)$ ) reduces  $\hat{\phi}$ . Depending on the parameter values, the intensity of informed trading in the high-audit equilibrium can be either higher or lower than in the benchmark case. For example, for the parameter values  $\mu_s = 0.2, \sigma_r = 0.5, \delta = 0.5, \rho = 1, L = 0.7, c_A = 0.01, c_I = 0.01$ , we find that  $\hat{\phi}_{bm} = 0.41$ , while  $\hat{\phi}_h = 0.44$ .

## Proof of Proposition 7

The first part of Proposition 7 relating the investor's expected profit,  $\pi_I$ , to the correlation  $\rho$  follows immediately from equation (10).

In the low-audit equilibrium, the regulator's total costs are given by  $TC_l = \hat{q}_l \sigma_r/2$  (see the proof of Proposition 4). Thus, the regulator benefits from a higher correlation  $\rho$  if and only if

$$\frac{\partial \hat{q}_l}{\partial \rho} = \frac{4c_A(1 - \delta^2)\phi(2(1 - L) - \sigma_r)}{((1 + \delta)(1 + \phi(\delta + \rho(1 - \delta)))\sigma_r - 2(1 + \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L))^2} < 0,$$

or, equivalently, if and only if  $L > 1 - \sigma_r/2$ .

If the auditing costs  $c_A$  are below  $c_A^c$ , the regulator's total costs in the high-audit equilibrium are given by  $TC_h = \frac{1}{2}(\hat{q}_h \sigma_r/2) + \frac{1}{2}TC^-(a^- = 1, q = \hat{q}_h)$  (see the proof of Proposition 4), where  $TC^-(a^- = 1, q = \hat{q}_h)$  denotes the expected costs when the stock price is low (i.e., when  $P = P^-$ ) and the regulator audits the bank. These costs are

given by

$$\begin{aligned}
TC^-(a^- = 1, q = \hat{q}_h) = & \hat{q}_h \left( (Pr(\epsilon = +1 | P = P^-) Pr(s_A = -1 |, \epsilon = +1, P = P^-) \right. \\
& + Pr(\epsilon = -1 | P = P^-) Pr(s_A = -1 |, \epsilon = -1, P = P^-)) (1 - L) \\
& \left. + Pr(\epsilon = -1 | P = P^-) Pr(s_A = +1 |, \epsilon = -1, P = P^-) \sigma_r \right) + c_A
\end{aligned}$$

Tedious but straightforward calculations show that  $TC_h$  can be written as

$$TC_h = \frac{(2\phi(\delta^2 + \rho(1 - \delta^2))(1 - L) - ((1 + \delta)\phi(\delta + \rho(1 - \delta)) - 2)\sigma_r) c_A}{(1 + \delta)(1 - \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 - \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L)}.$$

Differentiating  $TC_h$  with respect to  $\rho$  yields

$$\frac{\partial TC_h}{\partial \rho} = \frac{-(1 - \delta^2)\phi(2(1 - L) + (1 - \delta)\sigma_r)(2(1 - L) - \sigma_r)c_A}{\left( (1 + \delta)(1 - \phi(\delta + \rho(1 - \delta))) \sigma_r - 2(1 - \phi(\delta^2 + \rho(1 - \delta^2)))(1 - L) \right)^2}$$

which shows that in the high-audit equilibrium, the regulator benefits from an increase in  $\rho$  if and only if  $L < 1 - \sigma_r/2$ . □