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.

Bank regulators have recently embraced financial markets to improve the effectiveness of bank supervision. The idea seems simple: since markets are efficient in processing and aggregating information, bank regulators hope to gather information on the banks 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.

Im 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. The main information source for bank regulators apart from inspections are periodic reports that banks have to file and that contain detailed information on banks assets and liabilities broken down in various categories. 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 who only see part of the whole bank. 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. Even when regulators place permanent auditing teams with large banks, they cannot supervise all departments and not all international operations.

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 institutions health. Regulators in most countries have automated bank monitoring systems that periodically screen all banks.[1] While most of them currently rely on call report data, recent research

[1] In the US, for example, the Federal Reserve uses its System for Estimating Examination Ratings

encourages regulators to include market information.[2] Most studies ecourage the use of market information arguing that regulatory assessments will become more precise 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.[3]

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. It is important to analyze the optimal strategies of the regulator, the bank, and the informed trader simultaneously as multiple feedback effects characterize the equilibrium outcome. Using price information will alter the regulators effectiveness, its closure policy, and thus the value of the securities and the potential profit from informed trading.

(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. 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).

[2]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.

[3]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.

Regulatory efficiency and the threat of regulatory action will also change the banks optimal risk taking and thus again securities payoffs and the incentives to acquire information. The information content of securities prices and the banks risk taking strategy will in turn determine regulatory effectiveness.

We find using market information is in the regulators interest and increases welfare as longs as risk shifting incentives for banks are not too high. The regulator can target bad banks more efficiently by learning from financial markets and thus 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, partly offsetting the regulators gain.

When risk shifting incentives are high, which we interpret as the economy being in a poor state, however, the regulator and society might be worse off. To deter banks from excessive risk taking in this scenario, 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.

Our paper is related to several recent papers that address endogeneity in the information content of securities prices and regulation. Faure-Grimaud (2002) studies the use of stock market information for electricity regulation. In his model the regulator can not commit to lower price caps which reduce the ex-ante investment incentives of the company. Our paper detail the regulators learning function by allowing stock price contingent auditing strategies and models the feedback effect of market information, firms investment choices and auditing policy. Bond, Goldstein, and Prescott (2007) look at the feedback effect assuming the banks investment strategy as exogenously given. In their model the regulator can intervene and thereby increase the banks value by a fixed amount. Prices then partially reveal the banks value but also the value of the regulatory intervention, which might lead to a breakdown of the regulators intervention strategy.

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 extends the basic model along several lines and 7 concludes. All proofs are contained in the Appendix.

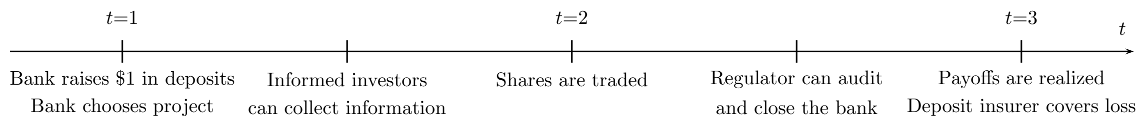
1 The Model

Our model is comprised of three agents: the bank, the regulator, and a potentially informed investor. The bank collects \$1 in deposits at time 1 and invests in either a safe or a risky asset. Deposits are fully insured and thus offer a return equal to the riskless rate, which is normalized to zero. The bank has access to a safe, positive NPV project with a payoff of $R_s = 1 + \mu$, where $\mu > 0$. The risky project yields a terminal cash flow of either $R_r = 1 + \sigma$ or $R_r = 1 - \sigma$, where $0 < \sigma < 1$. The probability distribution of the payoff depends on the asset's quality q, such that the probability of realizing the high payoff is equal to q: $Pr(R_r = 1 + \sigma) = q$. The quality can be good $(q = g)$ or bad $(q = b)$. For simplicity, we assume that $g = (1 + \delta)/2$ and $b = (1 - \delta)/2$, with $\delta \in (0, 1)$.[4] The quality of the risky asset is not known at $t = 1$. The common prior belief of all agents is that the bank is equally as likely to have a good and a bad risky asset. The parameter δ determines the difference in quality of the two projects.[5] The risky project is chosen with probability θ and the bank's asset choice, denoted by $\omega \in \{s, r\}$, is not observable to investors and to the regulator at this time.

[4]Thus, from a welfare perspective, the risky project is worth undertaking when the quality is good, but not when it is bad: $E[R_r \mid q = g] = 1 + \delta\,\sigma > 1 > 1 - \delta\,\sigma = E[R_r \mid q = b]$.

[5]In Section 6.2 we will extend the model and derive an alternative interpretation of the project quality. Assume that the ex-ante probability for each payoff equals one half and that investors and the regulator can get informative signals on the project realization. The quality parameter q can then also be interpreted as a signal on the risky asset's payoff and delta can be seen as a measure of signal quality.

Figure 1: Timeline.



At $t = 2$, shares of the bank are publicly traded in a stock market as described below. At $t = 3$, 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 bank is risk neutral, has no initial capital, and makes its asset choice to maximize its expected return to shareholders.

After observing the bank's stock price P at $t = 2$, the regulator decides whether or not to audit the bank. By incurring a cost $c_A > 0$, the regulator learns the bank's asset choice and, if the bank invested in a risky asset, observes the asset's quality q. 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 the asset choice, the quality q, and the stock price P, the regulator then decides whether to close the bank or not. If the bank is closed, its assets can be sold for a liquidation value of $\$L$. For simplicity, we assume that the return L is the same for all assets if they are liquidated prematurely.[6] As a consequence of limited liability, the equiyholders would always want to keep the bank open. At $t = 3$, the regulator repays depositors when the value of the bank's assets is insufficient to cover their claims. The regulator is risk neutral and minimizes its own expected costs, 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 $t = 2$. By incurring a cost $c_I(\phi) = c_I\,\phi^2$, the investor observes an informative signal $s_I = q$ with probability ϕ.

[6] We assume that the full value of the assets can only be realized when the bank remains operational, because of e.g. necessary monitoring which can best be done by the bank, a liquidity discount that the regulator faces when selling the assets on the secondary market, or because of asymmetric information on the quality of the banks loan portfolio.

With probability $1-\phi$, he does not receive any useful information (denoted by $s_I = \emptyset$). The investor chooses the quality of his information production technology ϕ, 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 $t = 2$, 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 as 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 $s_I \neq \emptyset$). 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. Figure 1 summarizes the timing of events.

1.1 Assumptions

To restrict the model to the case of interest we impose several conditions on the exogenous parameters of the model. In Assumption 1 we restrict the liquidation value L so that (i) it is always optimal for the regulator upon an audit to close a bank with a bad risky asset, and (ii) it is never optimal to close a bank with a good risky asset. The bounds equal the expected deposit insurance payments given a bad and a good risky project, respectively. When this assumption is violated, the regulator will find it optimal to either always or never close the bank.

Assumption 1

$$1 - \frac{(1+\delta)\,\sigma}{2} < L < 1 - \frac{(1-\delta)\,\sigma}{2}$$

To create some tensions between the banks equityholders and the regulator we restrict the payoff from the safe project to be lower than the expected payoff to the shareholders from the risky project. This assumption creates an incentive for risk-shifting and implies that the bank prefers to invest in the risky asset when it is never audited. When this assumption is violated, the bank will always choose the safe project and there is no need for bank supervision. Likewise we assume that the safe project yields a higher return to shareholders than the risky project given that the bank is always audited. Violating this bound would result in a less interesting equilibrium where the bank always chooses the risky project and the auditor always audits the bank and closes it when the quality of the project is bad.

Assumption 2

$$\frac{(1+\delta)\,\sigma}{4} < \mu < \frac{\sigma}{2}$$

Finally we intend to make sure that auditing is not prohibitively expensive for the regulator. The 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, i.e. the benefit of auditing, exceeds the auditing costs. When audit costs are higher than $\overline{c}_A$ the regulator would be forced to only audit when the stock price is low, limiting the analysis to a borderline case.

Assumption 3

$$c_A < \overline{c}_A = \frac{(1+\delta)\,\sigma}{4} - \frac{1-L}{2}$$

2 Benchmark Case: Optimal Auditing Policy without Stock Price Information

We begin by analyzing the benchmark case, where the regulator's auditing and closure decision is not dependent on price information. 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.

$$\min_a \; TC = (1-a)\frac{\theta}{2}\,\sigma + a\left[\frac{\theta}{2}(1-L) + \frac{\theta}{2}\left(\frac{1-\delta}{2}\right)\sigma + c_A\right] \tag{1}$$

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 $\theta/2$. Upon an audit the regulator can observe the project choice and the quality of the risky project and liquidate it. This is beneficial to the regulator only if the risky prject is chosen and the quality is low, which happens with probability $\theta/2$. In this case the regulator suffers a small loss of $(1-L)$ because the liquidation value is less than the face value of deposits (first term in square brackets). When the project is of good quality, the regulator will allow the bank to continue and only repay depositors when the payoff is low, which occurs with probability $(1-\delta)/2$ and realize a loss of σ (second term). In the case of an audit, the regulator must bear the audit cost c_A.

The bank chooses its optimal probability of investing in the risky project θ given the regulator's audit frequency a to maximize the payoff to its equity holders.

$$\max_{\theta}\,(1-\theta)\,\mu+\theta\left((1-a)\frac{\sigma}{2}+\frac{a}{2}\,\frac{1+\delta}{2}\sigma\right) \tag{2}$$

The bank can either select the safe project and earn a gross return of \$$\mu$ with certainty or invest in the risky project. In the latter case, the equity holders will 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 the project is of high quality (which occurs with probability $a/2$). In this situation they get a gross return of \$$\sigma$ with probability $(1+\delta)/2$ (second term). A bank with a bad quality project will be closed upon an audit even though it is still of positive value for equityholders.[7] This potential loss deters the bank 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*

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

[7] The high payoff occurs with probability $(1-\delta)/2>0$

and the regulator's auditing policy given by

$$\hat{a}_{bm} = \frac{2(\sigma - 2\,\mu)}{(1-\delta)\,\sigma}.$$

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

$$TC_{bm} = \frac{\hat{\theta}_{bm}\,\sigma}{2}.$$

3 Stock Market Equilibrium

We commence 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 θ, the regulator's auditing policy $a(P)$, and the quality of the investor's information production technology ϕ.

Since the order submitted by liquidity traders is either $d_L = 1$ or $d_L = -1$, the investor can profitably trade on her information only by buying one share when she receives good news ($s_I = g$) and selling one share when she receives bad news ($s_I = b$). 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 her information and destroying her opportunity to make a trading profit. Furthermore, buying (selling) shares when $s_I = b$ ($s_I = g$) or submitting an order when the signal is uninformative ($s_I = \emptyset$) would generate a loss.[8] Thus, the investor's profit-maximizing trading strategy can be summarized as follows:

$$d_I(s_I) = \begin{cases} 1, & \text{if } s_I = g \\ -1, & \text{if } s_I = b \\ 0, & \text{if } s_I = \emptyset \end{cases} \tag{3}$$

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

[8] 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 $q = g$ ($q = b$) to 1.

by (3), 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 order from the 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 1 *For a given asset choice θ, auditing policy $a(P)$, and intensity of informed trading ϕ, the date 2 stock prices are given by*

$$\begin{aligned} P(d=1) &= (1-\theta)\,\mu + \theta\left(\tfrac{1}{2}(1+\phi\,\delta) - \tfrac{1}{4}\,a^{+}(1-\delta)(1-\phi)\right)\sigma \;\equiv\; P^{+}, \\ P(d=-1) &= (1-\theta)\,\mu + \theta\left(\tfrac{1}{2}(1-\phi\,\delta) - \tfrac{1}{4}\,a^{-}(1-\delta)(1+\phi)\right)\sigma \;\equiv\; P^{-}, \end{aligned}$$

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

Based on these prices and the trading strategy specified by (3), we can now calculate the investor's expected trading profit and her optimal choice of ϕ, balancing the gains from trade and the cost of information collection:

Lemma 2 *For a given asset choice θ and auditing policy $a(P)$, the investor's expected profit from producing information and trading on it is equal to*

$$\pi_I = \phi\,(1-\phi)\,\theta\left(\tfrac{1}{2}\,\delta + \tfrac{1}{8}\,(a^{+}+a^{-})(1-\delta)\right)\sigma - c_I\,\phi^2.$$

The optimal quality of the information production technology is given by

$$\hat{\phi} = \frac{1}{2} - \frac{c_I}{\theta\big(\delta + \frac{1}{4}\,(a^{+}+a^{-})(1-\delta)\big)\,\sigma + 2\,c_I} < \frac{1}{2}. \tag{4}$$

Even in the absence of costs, the informed investor only wants to get informed with a probability of one half to maximize the uncertainty of the market maker of whether to deal with an informed or a noise trader. The comparative statics are summarized in the following corollary:

Corollary 1 *The optimal quality of the investor's information, $\hat{\phi}$, is increasing in the probability θ that the bank invests in the risky asset, the variance σ of the asset return, the difference in asset quality δ, the auditing frequencies a^{+} and a^{-}, and is decreasing in the information production cost c_I.*

The value of information increases in both, the probability of the bank investing in the risky asset and in the change in valuation given a good or bad signal which is driven by σ and δ. In the basic model the informed investor always benefits from tougher auditing. This result is driven by the implicit assumption that there is only one piece of information whether the assets are high or low quality – that can be learned by the informed investor as well as the regulator. When both players are informed, either through a signal or an audit, they will have the same information. The investor therefore implicitly not only learns about the asset payoff but can also predict the actions of the regulator. An increase in auditing results in more banks with bad projects being closed, which lowers the expected value of the bank given a bad signal whereas the value of banks with good projects is not affected. The spread in valuations given an informative signal increases, as does the trading profit, and the informed trader buys more information in equilibrium. In Section 6.2 we extend our basic model to allow for correlated signals where both the regulator and the investor get a signal on the risky asset's payoff. The signals have the same precision but are not necessarily identical. We will find that additional auditing can also lead to a decline in information production in the extended model.

4 Bank regulation with Stock Price Information

4.1 The optimal audit decision

Given the stock market equilibrium in Section 3, we can now derive the optimal strategy of the regulator and the bank. The auditor's objective is twofold. First, he has to set the audit intensity high enough to deter the bank from always investing in the risky project. In equilibrium he will provide enough auditing to make the bank indifferent between the safe and the risky project. Second, given a certain level of auditing, he will try to allocate costly auditing resources as efficiently as possible by targeting banks with bad risky projects. Since these banks are more likely to have low stock prices, the regulator will always find it optimal to audit the bank with a higher probability when the stock price is low. The optimal auditing policy and the banks optimal risk taking strategy is summarized in the following proposition:

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

$$\mu_c = \left(\tfrac{1}{2} - \tfrac{1}{8}(1-\delta)(1+\phi)\right)\sigma.$$

If $\mu \geq \mu_c$, there exists a unique equilibrium with the bank's asset choice given by

$$\hat{\theta}_l = \frac{4\, c_A}{(1+\phi)\big((1+\delta)\,\sigma - 2(1-L)\big)},$$

and the regulator's auditing policy ("low audit regime") given by

$$\hat{a}_l^+ = 0 \qquad \textit{and} \qquad \hat{a}_l^- = \frac{4(\sigma - 2\,\mu)}{(1+\phi)(1-\delta)\,\sigma}.$$

If $\mu < \mu_c$, the unique equilibrium ("high audit regime") is characterized by

$$\hat{\theta}_h = \frac{4\, c_A}{(1-\phi)\big((1+\delta)\,\sigma - 2(1-L)\big)},$$

$$\hat{a}_h^+ = 1 - \frac{2(4\mu - (1+\delta)\,\sigma)}{(1-\phi)(1-\delta)\,\sigma}, \qquad \textit{and} \qquad \hat{a}_h^- = 1,$$

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

$$\hat{\theta}_h = 1, \qquad \hat{a}_h^+ = 0, \qquad \textit{and} \qquad \hat{a}_h^- = 1,$$

when auditing costs are high ($c_A^c < c_A < \overline{c}_A$), where c_A^c is a function of δ, ϕ, σ, and L.

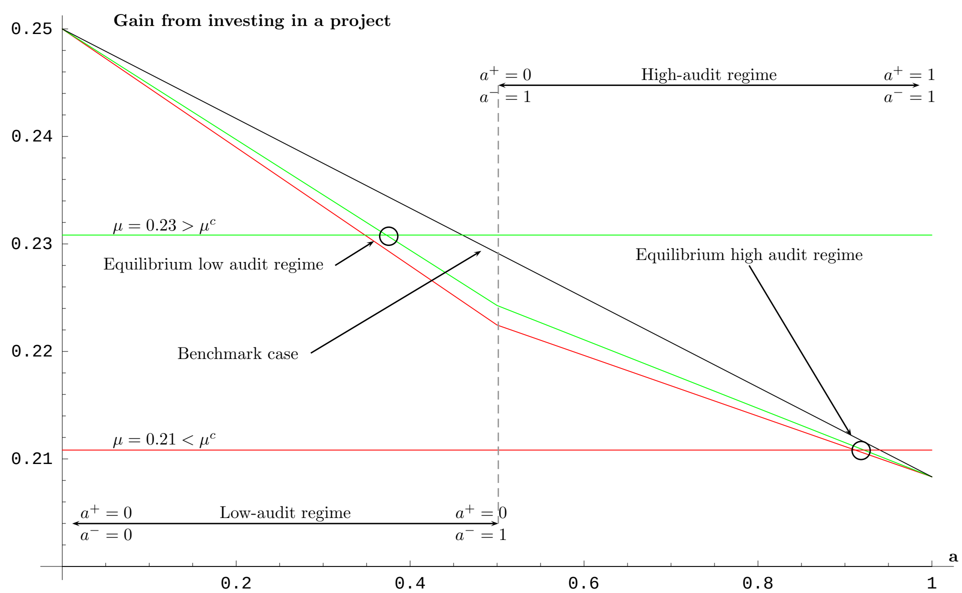
The overall level of auditing depends on the risk-shifting incentives of the bank. When risk taking is not very attractive (i.e., the return on the safe project is high relative to that on the risky project, $\mu \geq \mu^c$), the regulator will provide a low level of overall auditing. We refer to this case as the *low-audit regime.* To maximize the effectiveness of the auditing the regulator only audits the bank when the stock price is low. In equilibrium, the bank will be indifferent between choosing the safe and the risky project.

When risk shifting is appealing (i.e., if $\mu \leq \mu^c$), 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 bank with a low quality project 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 its stock price is high, even if the bank always chooses the risky project. The bank anticipates that the regulator will not audit at a high enough frequency and therefore always invests in the risky project.

Figure 2 illustrates the auditor's optimal auditing strategy. 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 $\mu > \mu^c$), the necessary audit frequency is low (below 0.5 overall) 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, $\mu < \mu^c$), excessive risk taking by the bank can only be prevented by conducting more frequent audits (high-audit regime).

Looking at the stock price allows the regulator to employ his resources more efficiently by incorporating the market information in the decision on whether or not to audit the bank. Thus, as we can see from the graph, the extent of auditing that the regulator has to provide to deter banks from always taking the risky project is lower when the regulator uses market information for bank regulation. The reduction in nec-

Figure 2: Gains and costs from auditing.



essary auditing when using market information is largest at an overall audit probability of one half. In this case only information from markets determines whether or not the bank will be audited. This intuition is summarized in the following Proposition:

Proposition 3 *The audit frequency in case the regulator takes price information into account is lower than in the benchmark case, i.e.,*

$$\frac{\hat{a}^+ + \hat{a}^-}{2} < \hat{a}_{bm}.$$

4.2 The bank's investment choice

In equilibrium, the bank will set the probability of investing in the risky asset just high enough set the regulator's benefit of an audit auditing equal to the audit costs. The regulator's benefit comes from finding and closing a bank with a bad risky project. The size of the benefit is driven by two effects: First, the probability of finding the bank to have a bad risky project increases as the bank is more likely to go for the risky project (increasing θ). Second, the probability of finding a bad bank also depends on the information that the regulator has learned from the stock market.

When risk shifting is not particularly attractive, we are in the low-audit regime. The regulator has to provide little overall 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 have a low quality project. While the probability of finding the risky project of a bank to be bad is one half in the benchmark case, this probability has now increased to $(1+\phi)/2$.[9] This learning effect makes an audit more beneficial for the regulator. Banks will anticipate the regulators advantage of learning and reduce the probability θ of choosing the risky project to set the auditor's expected benefit equal to the audit cost. This positive effect for the regulator is slightly mitigated by an adjustment in the optimal information production in financial markets relative to the benchmark case. When the bank is more likely to invest in the safe asset, the trading opportunities of the informed investor are reduced and so are the incentives to buy information on the bank. When markets are less informative, the gains to the regulator are partly offset because there is now less to learn from low stock prices.[10]

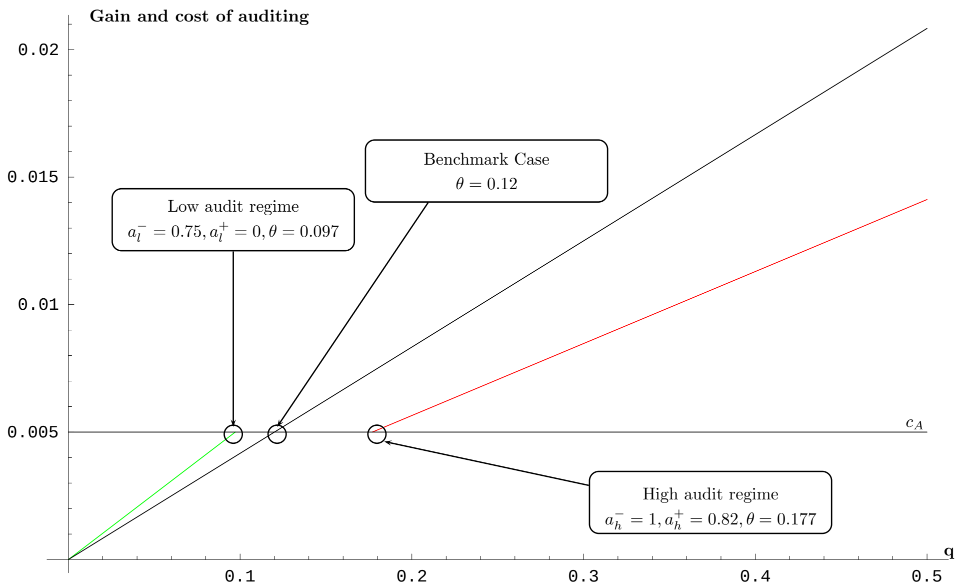
Figure 3 illustrates the intuition behind the banks optimal investment choice by means of a numerical example. The upward sloping lines depict the regulator's expected benefit from auditing for different probabilities of the bank investing in the risky project (θ). The benefit of auditing increases as the bank is more likely to invest in the risky project. In the low audit regime (left line), benefits of auditing are higher than in the benchmark case for any given θ because of the learning effect.

In the high audit regime the regulator always audits banks with low stock price and the audit probability is determined by balancing the marginal benefit of auditing a bank with a high stock price with the audit cost. Auditing at a high stock price is disadvantageous for the regulator because the probability of finding a bank with a bad project that is worth closing is low. The only case where a bank with a bad risky project would have a high stock price is when a noise trader submits a buy order. The

[9] Assume that the bank's project is bad. A sell order could come from a noise trader that just got it "right" by accident (w.p. $(1-\phi)/2$) or from an informed trader (w.p. ϕ).

[10] The equilibrium information structure will be discussed in more detail in Section 5.

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



regulator therefore learns something from the market that he would prefer not to know, namely that the expected benefit of auditing the bank is very low.[11] Figure 3 illustrates the reduced benefit of auditing for a given θ relative to the benchmark case (rightmost line). Banks anticipate the regulator's dilemma and are more likely to invest in the risky asset than in the benchmark case. The information content of securities prices will change as well. The latter effect can go both ways in the high audit regime (see also proposition 6). In this numerical example the higher probability of investing in the risky project increases the trading opportunities for the informed trader and leads to higher information production. The regulator therefore, learns more in a situation where he is not interested in learning. We summarize our findings in the following proposition:

Proposition 4 *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*

[11]This intuition is similar to Cremer (1995) who shows that a better informed principal may find it harder to commit to threats and may thus be worse off.

safe asset is high in that $\mu \geq \mu_c$. Thus, the probabilities of investing in the risky asset in the low-audit, high-audit and benchmark equilibria are ordered $\hat{\theta}_l < \hat{\theta}_{bm} < \hat{\theta}_h$.

Thus, 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. The auditor's overall cost will be driven by the bank's optimal risk taking strategy, the overall level of auditing and the associated auditing costs, and the effectiveness of auditing, i.e. the likelihood that banks with bad projects will be closed early. The results are expressed in the following proposition:

Proposition 5 *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 $\mu \geq \mu_c$. Thus, the regulator's total costs in the high-audit, low-audit and benchmark equilibria are ordered $TC_l < TC_{bm} < TC_h$.*

Proposition 5 illustrates that the regulator is not always better off when the auditing strategy is based on price information. When risk shifting is an unattractive prospect, 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, which has some interesting policy implications. Incorporating market information into the supervisory process might save costs during normal economic conditions when safe projects are attractive relative to risky ones and risk shifting incentives are therefore low. In economic downturns, however, it might amplify the regulator's cost. At the brink of a banking crisis, such as the savings and loan crisis for example, when risk shifting becomes more attractive and effective bank supervision is of utmost importance, the regulator might not be able to commit to audit banks enough and banks' risk as well as the crisis resolution costs will increase. Thus the volatility of the deposit insurance funds liability over the business cycle will increase when market information is incorporated into bank supervision.

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. Using price information in a market-based auditing process, however, will certainly change the information content of securities prices. Such a policy change can increase or, potentially, decrease the endogenous informativeness of stock prices partially offsetting the gains from market based auditing.

The amount of information that the informed trader optimally acquires increases in the audit probability a and the probability of the bank investing in the risky project θ (see Corollary 1). In the low audit regime, both a and θ decrease and so does the probability of an order by the informed trader. In the high audit regime a decreases and θ increases. The combined effect can go either way, increasing or decreasing the information in the stock market.

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

In the low-audit regime the regulators gains from using market information are partly offset by the losses in information content. The decrease in the market information is disadvantageous for the regulator in two ways: firstly, it directly decreases the effectiveness of the market based auditing mechanism; secondly, it increases μ_c and thus the chances of a switch to the high-audit regime, thereby reducing the area in the parameter space where the regulator benefits from market based regulation. Empirical studies that look at the predictive power of market based indicators for predicting bank failures should therefore be approached with a little caution because actually using these indicators for bank supervision might greatly reduce their predictive power and effectiveness.

6 Extensions

In this Section we propose several extensions of our model. We introduce regulatory commitment to an audit strategy in Section 6.1, relax the assumption that regulator and informed investor observe the same signal in Section 6.2, and analyze incentives for voluntary disclosure in section 6.3.

6.1 Commitment

One of the reasons why the regulator is worse off in the high-audit regime is his inability to commit ex ante to an audit strategy. One can argue that a government sponsored regulator can credibly commit by passing a law that requires each bank to be audited with a certain frequency. Specifically in our model we allow the regulator to set an ex-ante audit probability a_{co}. We do not allow this audit probability to be contingent on the stock price as we do not believe that such a law would be feasible in practice for several reasons: First, stock prices outside of our model are influenced my macroeconomic forces which would have to be netted out. Second, changes in the economic environment would require the law to be re-calibrated. Given the length of the legislative process, a mandatory state contingent audit policy might not be implemented in time for it to be effective. Leaving the calibration outside of the law, e.g. with the regulator, might weaken the credibility of the commitment.

Proposition 7 *If the regulator can commit to an ex post inefficient audit policy, he optimally chooses the minimum audit frequency a_{co} that prevents the bank from ever investing in the risky asset, i.e., $\hat{a}_{co} = \min\{a : a > \hat{a}_{bm}\}$.*

By setting the audit probability high enough, the regulator can always deter banks from investing in the risky asset. In cases when banks invest in the safe asset with certainty, there is no incentive for the informed investor to buy information and stock prices become uninformative. The model collapses to the benchmark case and the regulator has to provide a level of auditing which is slightly above $\hat{a}_{bm}$. As we can see from Proposition 3, the regulator will face higher auditing costs with commitment than without. In the high-audit regime these additional costs are more than offset by the savings in deposit insurance payments. Being able to commit is beneficial for the regulator in the high-audit regime, where a lack of commitment creates incentives for banks to engage in excessive risk shifting. In the low audit regime without commitment, however, deposit insurance payments are relatively low and the benefit of no bank failures and hence zero deposit insurance liability under commitment can be outweighed by the increase in audit costs. The regulator can therefore be worse off when committing to an audit strategy. This intuition is summarized in the following proposition.

Proposition 8 *If the return on the safe asset is high in that $\mu \geq \mu_c$, there exist parameter values such that the regulator's expected total costs in case he commits ex ante to an audit policy $\hat{a}_{co}$ exceed those he incurs without commitment, i.e., $TC_{co} > TC_l$.*

Committing to an audit strategy is not always optimal for the regulator. Especially in the low-audit regime, where market based regulation dominates the benchmark case, commitment might be counterproductive because of the high audit cost. In the region of the parameter space where commitment is helpful, it is not optimal to introduce market based regulation in the first place. We also have some doubts on how implementable a commitment strategy is in reality. When bank regulators spend significant amounts of taxpayer money to provide a high level of auditing $\hat{a}_{co}$ while all banks seem to be very safe, there might be political pressure to cut back the budget of the bank supervisor.

So far we assumed that the regulator can make commitment conditional on μ. To point out another potential problem with an ex-ante commitment one could think of extending our model one step further. Assume that risk shifting incentives vary with the state of the economy and that the legislative process is slow enough that the committed audit probability cannot be fine-tuned to the current state of the business cycle. After the regulator's commitment, nature chooses the state of the economy, i.e. the return μ of the safe project. The regulator will optimally commit to an audit probability which minimizes the ex-ante expected deposit insurance liability over all possible μs. In doing so, there will be states of the economy where the auditor deters the bank from investing in the risky project but potentially over audits the bank while in other states the committed audit probability will be too low and the bank will always choose the risky project. The additional costs associated with over auditing in the states with low risk shifting incentives and the losses from deposit insurance payments in the states of high risk shifting incentives makes the commitment strategy less advantageous for the regulator.

6.2 Correlated signals

Until now we have assumed that both the regulator and the informed investor can observe the same signal. That implicitly assumes that they both use the same information set and processing technology so that they both end up with the same conclusion when they get informed. In reality there are, however, different pieces of information that can be learned that are relevant for the economic condition of the bank. While the regulator might do a thorough investigation his focus might be, for example, on the loan book, whereas an informed trader could learn something about the competitive situation or the derivatives book. In this Section we want to relax this important assumption and allow for two separate signals that are potentially correlated. For this extension we have to interpret the quality of the risky asset as a signal about its payoff with precision δ.[12] In other words, both the regulator and the informed investor now observe imperfect and potentially different signals about the risky asset's return.

While both signals s_A and s_I have the same precision, the signals need not be identical. To model correlation, we assume that the regulator and the informed investor observe the same signal with probability ρ and that both signals are independent but from the same distribution with probability $1 - \rho$. The previously analyzed model is the special case where $\rho = 1$.

When allowing imperfect correlation we need to place tighter restrictions on the liquidation value L in order to ensure that the regulator's optimal closure decision only depends on his own signal and not on the observed stock price, i.e. while the decision

[12] Assume that the risky assets payoff is high with probability one half. The investor, upon receiving a signal, and the regulator, upon conducting an audit, get signals about the assets payoff where the probability that the payoff is high, given the signal is high, equals $(1 + \delta)/2$.

whether or not to audit is based on the stock price, the closure decision is solely based on the regulators signal.

Assumption 4

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

Imperfect correlation will change the regulators auditing technology which also impacts the optimal information acquisition by informed traders and bank risk taking in equilibrium. In summary it can make the regulator better or worse off. We start our analysis by looking at the regulators optimal auditing policy.

As the correlation decreases, so does the likelihood that both the informed trader and the regulator get a wrong signal when the actual payoff will be high. Thus, the regulator learns more about the true state of the bank, can make a better informed closure decision, and benefits as he is less likely to close a bank inefficiently. While along this line of reasoning lower correlation is beneficial for the regulator there is also a disadvantageous effect as more efficient bank closures change the incentives for the bank to invest in the risky project.

With lower correlation banks will find the risky project more attractive for two reasons: First, for a given auditing intensity a better informed regulator is less likely to close the bank[13]. Bank closures have a disciplining effect because the regulator closes a bank which still has positive value for the equityholders. With fewer disciplining closures, the risky asset becomes more attractive. Second, the punitive effect of a closure is lower as the value of the bank to the equity holders upon closure is lower. The regulator is better informed and closes the bank when the payoff of the risky project is likely to be low. In this case the equity value of the bank is also low and the disciplining effect of a closure is therefore less pronounced.[14] To deter the bank from

[13]Intuitively one can think of an example where the bank will only be closed when capital markets as well as the regulator get a negative signal. As the correlation decreases banks are more likely to be closed when the payoff of the risky project will be low (more informed regulator) but for a given audit intensity the event of a closure is less likely.

[14]It is straightforward to show that for a given audit intensity the value of the banks equity conditional on closure is increasing in ρ.

always investing in the risky project the regulator has to increase the overall auditing frequency. The equilibrium audit frequency increases as the correlation decreases. In at one point the regulator even has to provide more auditing than in the benchmark case. This intuition is summarized in the first part of the following proposition:

Proposition 9 *If the regulator and the investor observe imperfect and potentially different signals about the bank's expected return, the audit frequency in case the regulator takes price information into account is lower than in the benchmark case if and only if the correlation between the signals s_I and s_A exceeds $\delta/(1+\delta)$, i.e.,*

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

Further, if $\rho \underset{(<)}{>} \delta/(1+\delta)$, the optimal quality of the investor's information is increasing (decreasing) in the audit frequency, i.e.,

$$\frac{\partial \hat{\phi}}{\partial a^{+}} \underset{(<)}{>} 0, \ \frac{\partial \hat{\phi}}{\partial a^{-}} \underset{(<)}{>} 0, \qquad if \qquad \rho \underset{(<)}{>} \frac{\delta}{1+\delta}.$$

In the basic model the information content of securities prices always increases ceteris paribus with the audit probability. With perfect correlation the investor can not only predict the payoff, he can also predict the action of the regulator. The latter is most relevant when the informed investor falsely gets a low signal (i.e. a bad risky project will have a high payoff realization). With perfect correlation, the regulator will also be wrong and close the bank which benefits the informed investor who has shorted the shares. This advantage of predicting the regulator's action fades away as correlation decreases and the trader faces a higher risk of being on the wrong side of the market when he is wrong and the regulator gets it right or the other way around. When the correlation is below $\delta/(1+\delta)$ the risk that arises from differences in signals dominates and the informed investor prefers less auditing by the regulator. An example in Appendix B illustrates the intuition.

For any given audit intensity, the informed investor benefits from a higher correlation because she can then learn more about the regulators decisions, which influence her trading profit. The benefit of high correlation for the informed trader has some interesting policy implications on what kind of information the market is looking for. Left with a choice whether to learn information that is currently been used by regulators or something outside the scope of the regulatory process, informed investors prefer the former. The market will not only try to learn about the state of the bank but rather figure out the regulatory mechanism. Most current empirical studies are done in a regime where market information is not central to the supervisory process. Some of them like find that market information contributes additional explanatory power to existing regulatory models like CAMEL ratings. These findings might go away as soon as market information is incorporated into bank regulation because informed investors might shift their attention to learn the same information that existing regulatory assessment models produce.

Proposition 10 *The investor's expected profit π_I is strictly increasing in ρ, the correlation of her signal s_I with the regulator's signal s_A. The regulator, on the other hand, benefits from a high correlation ρ if and only if $(\mu - \mu_c)(\sigma/2(1-L)) > 0$.*

The regulator will not necessarily benefit from higher correlation that the market is seeking. In the low audit regime ($\mu > \mu_c$), banks are audited when the stock price is low, i.e. the informed trader gets a bad signal. Higher correlation will result in more bad signals for the regulator and thus in more bank closures, which will cost $(1 - L)$. The regulator is less likely to receive a good signal and leave the bank open, which could cost him σ if the project's cash flow realization is low, which happens with probability 1/2. When bank closure costs are low relative to the cost of paying off a failing bank's depositors, the regulator can benefit from higher correlation. In the high audit regime the reverse reasoning applies: the marginal bank is audited when the market is high. Thus higher correlation results in more positive signals for the auditor which reduces the number of bank closures. This is only optimal when the cost of letting the bank stay open and potentially pay off depositors is less than the cost of bank closure.

An efficient bank regulator in a developed financial market who can liquidate assets of closed banks effectively ($\sigma/2(1-L) > 0$) might be tempted to increase correlation in good times (low audit regime). The regulator could, for example, release information on her auditing technology and since investors strictly prefer high correlation they have an incentive to acquire information that is similar to the regulator's information. Everyone is better off as long as the bank's return on the safe project remains attractive. In a straightforward extension of our model, one could allow the banks investment opportunities to vary with the business cycle. A dramatic decrease in the attractiveness of the safe project and the associated switch to the high audit regime hits a regulator who has sought high correlation twice: first deposit insurance costs increase due to increased risk taking; second the regulator is worse off with high correlation in this state. A proprietary, opaque auditing technology might therefore reduce the variability in the deposit insurance cost over the business cycle.

6.3 Voluntary disclosure

In this section we want to discuss the bank's incentive to facilitate more informed trading by, e.g., voluntarily disclosing information to the market or investing in more transparent assets that can be evaluated by market participants at lower cost.

Proposition 11 *In the high-audit regime (i.e., when $\mu < \mu_c$), the regulator's expected total costs are increasing in the intensity of informed trading ϕ. Further, the range of auditing costs $[0, c_A^c]$, for which the regulator finds it optimal to audit the bank with positive probability after observing a high stock price is decreasing in ϕ.*

The regulator faces higher costs as informed trading increases in the high audit regime. The marginal bank that will be audited in this case has a high stock price. When the intensity of informed trading is high, a high stock price is more likely to result from a good signal of the informed trader, which implies in turn that the risky project is likely to yield the high payoff. This reduces the benefit of auditing because upon auditing the regulator will most likely get a good signal, leave the bank open, and pay the audit cost. Banks understand the disincentive for the regulator and engage in more risk shifting, which increases the deposit insurance cost of the regulator.

While more informative stock prices can hurt the regulator, the bank can in some cases be better off. With more informed trading the critical audit cost c_A^c, beyond which the regulator will find it more cost effective to not monitor banks with high stock prices at all (third case in Proposition 2), increases. In this case banks will always choose the risky project and can realize a higher profit. The intuition works as follows: the regulator tries to set the auditing intensity to make the bank indifferent between the safe and the risky project. The bank's ex-ante value is therefore always equal to μ. When auditing costs are above c_A^c, however, the regulator's benefit of auditing given a high stock price is below the auditing costs. Banks, knowing that they will be under-audited, always invest in the risky project and can realize an ex-ante value greater of μ_c greater than μ.

Thus, banks have a strong incentive to disclose information when risk shifting incentives are high, at the time that is most uncomfortable to the regulator. One possible strategy for a bank to decrease information acquisition costs is to invest in more transparent assets. Assume that there are two types of risky projects: an idiosyncratic and a systematic one. Assuming that outsiders have more information about systematic risk factors, market based regulation will create an incentive for all banks in the economy to invest in the systematic project in a situation where risk shifting is attractive. Banks portfolios will become more correlated which in turn might cause financial stability to deteriorate and increases the banking systems vulnerability to a systemic crisis.

7 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

θ	bank's asset type, $\theta \in \{s, r\}$
q	probability that the bank chooses the risky asset, i.e., $q = Pr(\theta = r)$
R_θ	asset return: $R_\theta = 1 + \mu_\theta + \epsilon\,\sigma_\theta$, $\epsilon \in \{-1, +1\}$
μ_θ	expected (net) return on the bank's asset
σ_θ	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 ϵ observed by the regulator, $s_A \in \{+1, -1\}$
s_I	signal about ϵ observed by the investor, $s_I \in \{+1, -1\}$
δ	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, $c_I(\phi) = c_I\,\phi^2$
ϕ	probability that the informed investor observes an informative signal
ρ	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 Example correlated signals and information acquisition

This simple numerical example illustrates how expected trading profits are linked to audit frequency and correlation in signals. Assume for simplicity that the bank always invests in the risky asset, which is pays 32 in the good state and 0 in the bad state. The informed trader trades with probability 1/2 and the precision of all signals is 3/4.

	never audit	always audit	
		$\rho = 1$	$\rho = 0$
$E[R_r \mid s_I = 1]$	24	24	18
P^+	20	18	15
$E[R_r]$	16	12	12
P^-	12	6	9
$E[R_r \mid s_I = -1]$	8	0	6
Expected profit	4	6	3

Let us first look at the case when the bank is never audited: Conditional on a good signal the bank is worth $E[R_r \mid s_I = 1] = 3/4 \cdot 32 + 1/4 \cdot 0 = 24$ for the informed investor. Similarly, the bank is worth $E[R_r \mid s_I = -1] = 3/4 \cdot 0 + 1/4 \cdot 32 = 8$ after receiving a bad signal. The unconditional value of the bank, which also represents the value conditional on a noise trader submitting an order is equal to 16. The market maker, when seeing a buy order does not see whether the order comes from an informed trader, in which case the bank would be valued at 24, or from a noise trader, in which case the banks value would be 16, and sets the price at 20. Following a similar logic, the price given a sell order is 12. The expected profit for the informed trader is $1/2 \cdot (24 - 20) + 1/2 \cdot (12 - 8) = 4$.

Assume now that the bank is always audited and that the correlation is equal to one. The informed trader knows that when he gets a good signal, the regulator will also get a good signal, let the bank continue and therefore the value stays the same. When the informed trader gets a bad signal, however, he knows that the regulator will get the same and close the bank, reducing its value to zero. Thus the spread between the valuations of the informed trader conditional on his signal increases and so does the expected trading profit.

When the correlation is equal to zero, the situation is quite different for the informed trader: Upon receiving a good signal, it could still be the case that the regulator gets a false signal and closes the bank. This probability is 25%. This risk of the regulator and the informed trader having divergent views lowers the valuation of the informed trader given the good signal to $0.25 \cdot 24 + 0.25 \cdot 0 = 18$, reflecting the fact that the regulator might get the same good signal as the informed trader with 75% probability and a bad signal with a 25% probability in which case she would close the bank. Similar reasoning leads to a valuation of 6 for a bad signal. The difference between valuations given a good and a bad signal, respectively, shrinks and so does the profit of the informed trader.

Some general results that we can take away from this example are that the informed trader prefers more auditing only when the correlation between signals is sufficiently high and that for a given level of auditing, the informed traders profit always increases in signal correlation.

C Proofs (preliminary)

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 μ. If it invests in the risky asset, then its equity holders receive a non-zero payoff of σ_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

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

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

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

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 σ_r. Conditions (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

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

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 1

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

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

If the bank invests in the safe asset, the return to its equity holders is μ. If it invests in the risky asset, then its equity holders receive a non-zero payoff of σ_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 (3), the expected payoff conditional on an informed buy order is equal to

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

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

$$\begin{aligned} P(d=+1) &= \phi\, E[R \mid d_I = +1] + (1-\phi)\, E[R \mid d_L = +1] \\ &= (1-q)\,\mu + q\Big(\tfrac{1}{2}(1+\phi\,\delta) - \tfrac{1}{4}\,a^+(1-\delta)\big(1+\phi(\delta - \rho(1+\delta))\big)\Big)\sigma_r. \end{aligned}$$

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

$$\begin{aligned} P(d=-1) &= \phi\, E[R \mid d_I = -1] + (1-\phi)\, E[R \mid d_L = -1] \\ &= (1-q)\,\mu + q\Big(\tfrac{1}{2}(1-\phi\,\delta) - \tfrac{1}{4}\,a^-(1-\delta)\big(1-\phi(\delta - \rho(1+\delta))\big)\Big)\sigma_r. \end{aligned}$$

□

Proof of Lemma 2

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 $E[R \mid d_I = +1] - P(d = +1)$ ($P(d = -1) - E[R \mid d_I = -1]$). Her expected trading profit net of information production costs is therefore equal to

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

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

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

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

Proof of Corollary 1

These comparative static results follow immediately from equation (4). □

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

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

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

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

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

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

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

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

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

Proof of Proposition 5

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 4).

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 4). 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[15], 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 $\hat{q}_h > \hat{q}_{bm}$. $\square$

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

Proof of Proposition 3

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

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

which is lower than the probability in the benchmark case,

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

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

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

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

$$\big((1+\delta)\,\sigma_r - 4\mu\big)\big(\delta - \rho(1+\delta)\big) > 0.$$

Since $(1+\delta)\,\sigma_r - 4\mu < 0$ 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 4

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 4). 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 3). It therefore follows from Corollary 1, which shows that $\hat{\phi}$ is strictly increasing in q and a if the above condition on ρ 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 3). 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 $\mu = 0.2, \sigma_r = 0.5, \delta = 0.5, \rho = 1, L = 0.7, c_A = 0.01, c_I = 0.01$, we find that $\hat{\phi}_{bm} = 0.41$, while $\hat{\phi}_h = 0.44$.

Proof of Proposition 10

The first part of Proposition 10 relating the investor's expected profit, π_I, to the correlation ρ follows immediately from equation (4).

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 5). Thus, the regulator benefits from a higher correlation ρ if and only if

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

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 5), 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

$$TC^{-}(a^{-}=1, q=\hat{q}_h) = \hat{q}_h\Big(\big(Pr(\epsilon=+1 \mid P=P^{-})Pr(s_A=-1 \mid, \epsilon=+1, P=P^{-})$$
$$+Pr(\epsilon=-1 \mid P=P^{-})Pr(s_A=-1 \mid, \epsilon=-1, P=P^{-})\big)(1-L)$$
$$+Pr(\epsilon=-1 \mid P=P^{-})Pr(s_A=+1 \mid, \epsilon=-1, P=P^{-})\sigma_r\Big) + c_A$$

Tedious but straightforward calculations show that TC_h can be written as

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

Differentiating TC_h with respect to ρ yields

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

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