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Loan Monitoring, Competition, and Socially Optimal Bank Capital Regulations

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Abstract

This article analyzes socially optimal bank capital regulations that support fairly-priced deposit insurance. Under full information, banks voluntarily choose a socially optimal interior capital structure based on the cost-benefit tradeoff involved in monitoring loans. Capital regulations are, therefore, redundant. Under asymmetric information, incentive-compatible capital regulations together with fairly-priced deposit insurance are possible if and only if the regulator can prevent bank-borrower collusive side-payments and also observe the rate charged and the equity contributed by the bank for a loan. The bank would then again voluntarily choose the socially optimal interior capital structure and bank capital requirements would be redundant. Greater equity contributions by banks with higher loan quality are then socially optimal. These results highlight the critical importance of bank supervision in effective regulatory policy design.

Introduction

It is widely believed that the Federal Deposit Insurance Corporation's (FDIC's) flat-rate deposit insurance premium structure encouraged excessively risky bank lending and thereby contributed to the spate of U.S. bank failures during the 1980s and early 1990s. Several reforms have already been introduced to curb this incentive for bank moral hazard behavior. For instance, the 1991 FDIC Improvement Act (FDICIA) mandates the imposition of risk-adjusted capital standards and deposit insurance premiums and early bank closure policies that would reduce the financial burden on the FDIC.[1] However, the fundamental problem in

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[1] See Chen and Mazumdar (1994) and references listed therein for a discussion of this Act.

implementing any reform is that the regulator may be less informed than the bank about the quality of the bank's loan portfolio. Several authors have therefore analyzed the design of incentive-compatible regulations which would lead the bank to truthfully reveal its loan quality. But there is little consensus about the existence and nature of such regulations.[2]

Furthermore, the regulator's problem is not over if incentive-compatible regulations can be designed. The regulator must next choose one scheme, from an array of incentive-compatible regulations, which will maximize social welfare. However, the welfare implications of regulatory design under asymmetric information have been relatively unexplored in the literature.[3]

This article has two main objectives. First, it examines the existence of incentive-compatible regulations in a framework that explicitly incorporates two important features of banking activity: monitoring services provided by the bank to its clients, and potential collusion between the bank and the borrower (through side-payments) to extract a regulatory subsidy. Second, it analyzes the nature of socially optimal incentive-compatible regulations under full information and asymmetric information.

A bank in our model performs two intermediation functions. First, the bank provides liquidity services to its depositors for an implicit fee. In equilibrium, this fee equals the value of the services provided. Second, the bank monitors its borrower's project to improve its chance of success.[4] Such monitoring is costly and unobservable by outsiders. Therefore, the market and the regulator make inferences about the bank's optimal level of monitoring which influence the competitive loan rate charged, as well as the regulatory capital requirement and deposit insurance premium actually imposed on the bank. In equilibrium, these inferences are correct.

This paradigm yields four main results. First, under full information, banks have an interior optimum capital structure even in the absence of capital regulations. This arises due to the tradeoff between the costs of monitoring and the liquidity service fees foregone and the monitoring benefits earned through increased

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[2] Chan, Greenbaum, and Thakor (1992) argue that banks must be provided a deposit insurance subsidy if regulations are to be incentive-compatible. Yoon and Mazumdar (forthcoming) demonstrate that, when the regulator observes competitive lending rates, incentive-compatible regulations that also allow the FDIC to break even would indeed be possible. Besanko and Kanatas (1990) and Giammarino, Lewis, and Sappington (1993) also demonstrate the existence of incentive-compatible regulations in a model where bank insiders (managers) can affect loan quality through unobservable managerial behavior. However, neither of these studies examines the important effects of loan rate observability and side-payments between banks and borrowers in regulatory design, as we do in this article. Other studies have considered alternative regulatory controls, such as forbearance, to ensure incentive compatibility of bank regulations (see, e.g., Nagarajan and Sealey, 1995).

[3] See Santomero and Watson (1977), Goodman and Santomero (1986), and Flannery and James (1989) for discussions of optimal banking regulations under full information. Giammarino, Lewis, and Sappington (1993) consider optimal regulations under asymmetric information for a monopoly bank. In different contexts, both John, John, and Senbet (1991) and Campbell, Chan, and Marino (1992) address welfare issues of banking regulations.

[4] It is generally acknowledged that a bank helps its borrower realize better returns by providing financial expertise, monitoring the management, or standing by to provide emergency funds (e.g., Diamond, 1984; Fama, 1985; James, 1987; and Berlin, 1987).

equity financing. Bank equityholders have a larger residual claim on the loan's payoff and thus have an incentive to increase monitoring effort to improve the loan's probability of success. Optimally, banks use greater equity financing for higher quality loans which are more sensitive to bank monitoring. This result offers a new and empirically testable rationale for the existence of depository institutions. It also provides an explanation of regulatory policy introduced by FDICIA whereby banks with high *risk-adjusted* capital standards are subject to less regulatory supervision since they are believed to be safer.[5]

Second, under full information, social welfare is maximized if the regulator does not impose any capital requirements, when the loan and liability markets are both competitive. There are currently two opposing views in the literature on the effects of capital requirements on bank loan portfolio risk. Koehn and Santomero (1980) and Kim and Santomero (1988) argue that stricter capital requirements would not necessarily lower bank risk, whereas Keeley and Furlong (1990) and Yoon and Mazumdar (forthcoming) support conventional wisdom that they could. This article adds a third view to this debate, arguing that capital requirements are redundant from a social welfare perspective.

Third, analysis of the design of incentive-compatible regulations when the regulator cannot observe bank loan quality shows that previous results concerning the impossibility of incentive-compatible fairly-priced insurance schemes obtained by Chan, Greenbaum, and Thakor (1992) extend to different and more general settings. Specifically, we demonstrate that incentive-compatible capital regulations and fairly-priced deposit insurance can coexist if and only if the regulator can observe the capital structure and the loan rate that the bank actually employs in the competitive loan market, and can prevent collusive bank-borrower side-payments. However, in practice, the regulatory supervision costs necessary to prevent such collusion may be very high. Thus, incentive-compatible regulatory design involves a tradeoff, between such regulatory supervision costs and the deposit insurance subsidy, that has hitherto not been discussed in the literature. The regulator would optimally supervise banks, and design an incentive-compatible fairly-priced deposit insurance policy, only if the deposit insurance subsidy saved exceeds the cost of bank supervision.

Finally, we demonstrate that, even under asymmetric information, the incentive-compatible and socially optimal capital requirement schedule is the *laissez-faire* one. However, this is valid only if the regulator can costlessly observe and prevent any bank-borrower side-payments. Thus, our analysis highlights the importance of close bank monitoring and supervision of bank management activities. Such regulatory supervision may ultimately be of greater importance than capital regulations in reducing the deposit insurer's loss and in maximizing

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[5] The issue of bank's optimal capital structure has been addressed by several authors (e.g., Pringle, 1974; Taggart and Greenbaum, 1978; Buser, Chen, and Kane, 1981; Orgler and Taggart, 1983; Chen and Mazumdar, 1994, 1995; and Mazumdar, forthcoming). These studies suggest that the bank's optimal capital structure may be determined by factors such as taxes, agency costs, bankruptcy costs, regulatory interactions, and the production function for financial services. We argue that the influence of equity financing on the bank's loan monitoring effort will be an additional factor in determining its optimal capital structure.

social welfare. This result thus offers support for stricter bank supervisory measures recently introduced through FDICIA.[6]

The next section describes the model and analyzes the bank's monitoring behavior. Then, we analyze the bank loan contract and socially optimal bank capital regulations under full information. Subsequently, we discuss incentive-compatible and socially optimal bank capital regulations when side-payments can and cannot be observed. Finally, the last section provides some concluding remarks. All proofs are found in the Appendix.

THE MODEL

Consider a capital market with many risk-neutral banks and firms. A firm must finance its investment project entirely through a bank loan. A bank finances its loan with equity capital, E, and deposits, D. This capital market is competitive. So, in equilibrium, the bank breaks even. One plus the economy's risk-free interest rate is denoted by r. We assume that $r > 1$.

We consider a one-period model with two event dates, $t = 0$ and $t = 1$. Firms have investment projects, all of which require a capital outlay of one dollar at $t = 0$ and yield either α dollars if successful or 0 if unsuccessful at $t = 1$, where α is a known constant greater than r. These investment projects are classified according to an *a priori* quality index, $\theta \in [0,1]$.[7] In determining a loan contract, both the firm and the bank are assumed to costlessly observe the project's quality index.

Banks have a loan monitoring technology given by the following Cobb-Douglas function:

$$P = \theta^{\frac{1}{2}} M^{\frac{1}{2}}. \tag{1}$$

In other words, if a bank spends loan monitoring effort, M, for a loan project of *a priori* quality θ, then the project's success probability would ultimately be $P \in [0,1]$. That is, the marginal impact of monitoring effort on the loan's success probability is assumed to be greater for loans with better *a priori* quality.[8] Al-

[6] The basic framework of our model is generally applicable to any insurance contract where the insured party's unobservable actions (like monitoring effort by the bank in our model) influence its outcome. For instance, this framework could also be employed to analyze the optimal design of government loan guarantees to corporations, credit insurance provided by the government to exporters, and implicit loan guarantees provided by a parent corporation to its subsidiary. Although the firm's credit risk is, in general, dependent on its efforts, the guarantor may require the insured party to maintain a certain level of equity in order to provide it with an incentive to increase its efforts. Given information asymmetry regarding the innate quality of the insured project, the optimal incentive-compatible loan guarantee contract would balance the cost of smaller tax shields with the effort-enhancing effects of additional equity financing.

[7] For simplicity, our model assumes that each bank's risk originates from the quality of its single loan, θ, which is viewed as uncorrelated across firms. However, a more detailed structure could be envisaged where a bank holds a portfolio of loans and each firm's θ represents a systematic risk factor. In such a case, the firms' risk would be correlated and the bank would price each loan according to its systematic risk factor.

[8] Thus, monitoring technology is similar in spirit to that of Boyd and Prescott (1986), who develop a model in which banks, in equilibrium, monitor only good type firms. There is, however, no consensus in the literature regarding the nature of a bank's monitoring technology. Berlin and Loeys

though this specification is admittedly ad hoc, it appears quite plausible, for it basically assumes that banks would find it more difficult to increase the success probability of a loan that has a lower quality to begin with. Thus, in our framework, bank monitoring effort merely complements the loan's *a priori* quality in determining its ultimate probability of success.

Since our results will critically depend on the nature of the monitoring technology assumed, two additional clarificatory comments are in order at this juncture. First, although the Cobb-Douglas monitoring technology is adopted for analytical convenience, our fundamental result that the bank's optimal equity schedule is an increasing function of quality θ follows because monitoring effort and θ are complementary to each other. Second, the equity schedule *may* be decreasing in θ for alternative monitoring technologies such as $P = \theta + (1-\theta)M$ under certain technical conditions. However, because comparative statics results are generally ambiguous in such a framework, such a technology function is not considered in our analysis.

The cost of the bank's monitoring effort is expressed as $C(M) = \frac{cM}{2}$, where c is a positive constant. This monitoring effort cannot be observed by any party other than the bank. The borrower can, however, infer this effort using his or her knowledge of θ, as discussed below.

Banks are subject to deposit-related government regulations. First assume that neither the *a priori* loan quality nor the success probability is observed by the regulator. In this situation, the regulator must rely on a bank's report of its loan quality, $\hat{\theta}$, to make inferences about the bank's monitoring effort, $\hat{M}$, and, in turn, about the loan's success probability $\hat{P} = \hat{\theta}^{1/2}\hat{M}^{1/2}$. Based on the bank's report and these inferences, the regulator will require the bank to pay a deposit insurance premium of $\pi(\hat{\theta})$ per dollar deposit and to additionally contribute a minimum equity of $e(\hat{\theta})$ per dollar loan. The deposit insurance is assumed to provide full coverage.[9] When the regulator imposes these regulations, it is assumed to costlessly observe the contractual loan rate that the bank actually charges its loan customer as well as the bank's capital structure variables.

At this juncture, it is important to highlight the equilibrium implications of the competitive nature of the loan market in our model. Because the loan market is competitive and all banks have the same monitoring technology, in equilibrium, no bank can extract any rent from any corporate borrower. Thus, in equilibrium, all banks break even and earn zero net present value and are *indifferent* between loans of differing quality, as long as they satisfy a certain minimum acceptable quality.

(1988), for instance, argue that monitoring is only valuable for poorer type firms. See Best and Zhang (1993) for an empirical analysis of this debate.

[9] In general, deposit insurance is intended to protect depositors from ruin and increase the stability of the banking sector by preventing bank runs. Even if banks are sufficiently diversified, they face systematic risks and, thus, uninsured depositors remain at risk. Although it is frequently argued that the government can bear both systematic and unsystematic risks as well as, or better than, any other party in the economy, we simply assume that private insurance is not available, and government deposit insurance is mandatory.

All banks will reject any loan application that does not satisfy a minimum quality and fund *any* loan of acceptable quality, θ, at the same market-determined loan rate, $R(\theta)$, and with the same level of deposits, $D(\theta)$. Because a borrowing firm knows that in equilibrium it will get the same offer and monitoring service from all banks, it chooses a bank randomly. Concomitantly, banks do not compete for loans of better quality.

We view a sequence of activities to occur in the following order at $t = 0$. First, a firm applies for a loan from a bank to finance its project of quality θ. The bank evaluates this loan application by observing θ and taking into consideration its subsequent choice of monitoring effort. The bank next determines the appropriate level of deposit financing, D, it would use as well as the contractual loan rate, R, it would charge if it granted the loan. A loan contract will indeed be made if the bank can earn non-negative profits and if the firm sees it as the best offer in the loan market. In this context, the interest rate on insured deposits, $\rho - 1$, is assumed to be less than the risk-free interest rate, $r - 1$. The interest rate differential, $r - \rho$, is viewed as an implicit fee charged by the bank for providing depositors with liquidity services in a competitive deposit market. Such a fee provides the bank with an incentive to use deposit financing. Second, if the bank makes a loan, it then reports a loan quality, $\hat{\theta}$, to the regulator. Based on the two schedules e and π, the regulator then imposes the appropriate capital requirement and deposit insurance premium on the bank. Third, given $\hat{\theta}$, $e(\hat{\theta})$, $\pi(\hat{\theta})$, R, and D, the bank optimally chooses its monitoring effort and hence will realize P.

At $t = 1$, if the project is successful, the firm pays off R to the bank which then uses this proceed to meet its deposit liabilities and pay its shareholders a liquidating dividend. However, if the project fails, the firm defaults completely and the bank, which receives nothing, is then declared bankrupt. The deposit insurance agency then pays off the bank's depositors.

The Optimal Loan Monitoring Effort

Once R and D are chosen for a loan project of quality θ, the bank pays its equity contribution, E, as well as the deposit insurance premium, π D. At this stage, the bank maximizes the net present value of its equity, V^B, by choosing a monitoring effort level, M, as follows:

$$\max_{M \geq 0} V^B = \frac{P(R - \rho D)}{r} - \frac{cM}{2} - E - \pi D, \tag{2}$$

where P is given by equation (1). The first-order condition is

$$\frac{\partial V^B}{\partial M} = \theta^{\frac{1}{2}} M^{-\frac{1}{2}} \frac{R - \rho D}{2r} - \frac{c}{2} = 0. \tag{3}$$

The bank's optimal monitoring effort level is given by[10]

$$M(\theta) = \theta\left(\frac{R-\rho D}{rc}\right)^2. \tag{4}$$

Note that, given θ, M is increasing in R but decreasing in D. Also, since both R and D will in turn depend on θ, the impact of a change in θ on $M(\theta)$ will, in general, be ambiguous. Using equations (1) and (4), the loan's success probability is

$$P = \theta^{\frac{1}{2}} M(\theta)^{\frac{1}{2}} = \theta\left(\frac{R-\rho D}{rc}\right). \tag{5}$$

Here we assume that $rc > \alpha$ in order to sufficiently guarantee that the probability measure P lies in the range [0,1].

Given the observability of R and D, it is easy to see that the borrower can perfectly infer M and hence P given his or her knowledge of θ. On the other hand, based on the bank's loan quality report, $\hat{\theta}$, the regulator must infer the bank's monitoring effort, $M(\hat{\theta})$, as well as the loan's success probability, $\hat{P}$. These inferences are made by substituting $\hat{\theta}$ in place of θ in equations (4) and (5), respectively.

The deposit insurance premium is said to be fairly priced if

$$\pi(\hat{\theta})D = (1-\hat{P})\frac{\rho}{r}D = (1-\hat{\theta}^{\frac{1}{2}} M(\hat{\theta})^{\frac{1}{2}})\frac{\rho}{r}D. \tag{6}$$

In equation (6), the insurance premium equals the insurer's expected liability, which is based on the regulator's estimation of the loan's failure probability. This deposit insurance premium becomes *actuarially* fair, that is, the insurer breaks even contract-by-contract if $\hat{\theta} = \theta$.[11]

Bank Loan Contract and Capital Regulations Under Full Information

In this section, we assume that the regulator has full information regarding θ. The objective is to find the socially optimal capital requirement schedule that should be imposed on banks when the deposit insurance system breaks even contract-by-contract. First, in a situation where the regulator charges each bank the fairly-priced insurance premium but does not impose any capital requirement, we

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[10] The expression for bank monitoring effort given by equation (4) is similar to the one analyzed by Besanko and Kanatas (1990), except that, in their model, monitoring effort is independent of the loan's quality.

[11] Although there could exist many deposit insurance premium schedules that are risk-adjusted, only the one in equation (6) allows the insurer to break even contract-by-contract. In an alternative paradigm where the insurer breaks even only on an aggregate basis, the risk-adjusted deposit insurance premium schedules may subsidize a particular group of firms on the basis of θ at the expense of others. However, whether such a deposit insurance scheme, which must also be incentive-compatible, would be socially optimal depends on the nature of the social welfare function. This issue is discussed in greater detail below.

determine the optimal capital structure a bank chooses to finance a loan. In the competitive loan market, such a capital structure would result in a market loan rate that leads the bank to break even and also maximizes the borrower's profits. Next, we examine the socially optimal bank capital regulation that also ensures fairly-priced deposit insurance. This discussion serves as a benchmark for the analysis of the regulator's problem under asymmetric information in the next section.

Let the pair of regulatory schedules $\{e(\theta), \pi(\theta)\}$ be such that, for all $\theta \in [0,1]$, $e(\theta)$ equals zero and $\pi(\theta)$ satisfies equation (6). Given the regulator's full information, $\pi(\theta)$ will lead each deposit insurance contract to break even.

Consider a firm with a project of quality θ which applies for a loan from a bank in the competitive loan market. Upon receiving such a loan application, the bank will choose a deposit level, D, and a loan rate, R, such that the value of the borrowing firm, V^F, is maximized, and the value of the bank's equityholders, V^B, is non-negative.[12] It is possible that $V^B < 0$ for some $\theta \in [0,1]$, in which case the loan contract will not be made. Therefore, our analysis is restricted to $\Theta \subset [0,1]$, that is, the set of θ such that $V^B(\theta) \geq 0$ and $V^F(\theta) \geq 0$.

Given $\theta \in \Theta$, the bank's problem can be stated as follows:

$$\max_{\{R,D\}} V^F = \frac{P(\alpha - R)}{r} \tag{7}$$

subject to

$$V^B = \frac{P(R-\rho D)}{r} - \frac{cM}{2} - E - \pi D \geq 0, \tag{8a}$$

$$1 + \pi D = E + D + E^a, \tag{8b}$$

$$E \geq 0, \tag{8c}$$

$$E^a = \pi D, \tag{8d}$$

where M, P, and π are given by equations (4), (5), and (6), respectively. Condition (8a) is the bank's participation constraint in the loan market. Condition (8b) is its budget constraint, where the sources and uses of funds are described by the right-hand side and left-hand side of the equation, respectively. Condition (8c) specifies that the bank's minimum capital requirement for the loan is zero in this particular scenario. Condition (8d) requires the bank to pay its total deposit insurance premium, πD, through additional equity capital, E^a. Capital requirements are assumed to be calculated in terms of the bank's equity net of the deposit insurance premium, that is, E.[13]

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[12] The bank's capital structure is an integral part of the lending decision for two reasons. First, as we have already seen, it influences the firm's profits through its effects on the bank's optimal monitoring effort and consequently on the project's success probability. Second, it also influences the bank's profits through its effects on the deposit insurance premium, the bank's overall cost of capital, and the loan rate charged to the firm.

[13] Alternatively, the deposit insurance premium can be paid using deposits. Although our approach is chosen for analytical simplicity, the main results of this article would remain unchanged if the alternative approach was employed.

We now analyze the bank's problem in equation (7) and conditions (8a) through (8d) in two stages. In the first stage, given $\theta \in \Theta$, we determine R as a function of D which would yield $V^B = 0$ in equilibrium. In the second stage, we substitute this loan rate into equation (7) to find the optimum value of D given θ. This value establishes the bank's optimum capital structure and, in turn, yields the competitive market loan rate, R.

Using equations (4), (5), and (6), we rewrite V^B in condition (8a) as

$$V^B(\theta,D)=\frac{\theta(R-\rho D)^2}{2r^2c}-(1-D)-(1-\frac{\theta(R-\rho D)}{rc})\frac{\rho}{r}D. \tag{9}$$

Letting the right-hand side of equation (9) equal zero gives rise to a quadratic equation in R. Solving this equation for R yields

$$R(\theta,D)=\sqrt{(\rho D)^2+\frac{2rc}{\theta}(r-(r-\rho)D)}. \tag{10}$$

Differentiating this loan rate schedule with respect to D yields

$$\frac{\partial R}{\partial D}=\frac{\rho^2 D-\dfrac{rc(r-\rho)}{\theta}}{R}. \tag{11}$$

Differentiating this derivative again with respect to D and rearranging terms yields

$$\frac{\partial^2 R}{\partial D^2}=\frac{r^2c\rho^2[2\theta-\dfrac{c(r-\rho)^2}{\rho^2}]}{\theta^2R^3}. \tag{12}$$

The relationship between the loan rate, R, and the deposit financing, D, critically hinges on the impact of deposit financing on the bank's expected profit. On one hand, a *ceteris paribus* increase in deposit financing would decrease the bank's monitoring effort and thus its monitoring cost. Such an increase would also increase the bank liquidity service fee and lower its average cost of capital. These two factors would lead the bank to decrease the loan rate in the competitive loan market. On the other hand, the decrease in the bank's monitoring effort would also decrease the loan's success probability. To compensate for the associated decrease in the bank's expected profits, the loan rate must increase. The net impact of these countervailing influences determines the change in the loan rate (for a loan of quality θ) necessary to allow the bank to break even due to an increase in its deposit financing. This tradeoff is formally expressed by the following lemma.

Lemma 1

Define $D^m(\theta) = \dfrac{rc(r-\rho)}{\theta\rho^2}$. *Then we have*

(1) $\dfrac{\partial R}{\partial D} \lesseqgtr 0$ *for* $D \lesseqgtr D^m(\theta)$ *and* $\dfrac{\partial^2 R}{\partial D^2} > 0$ *at all* $D \leq 1$ *and for* $\theta^a \leq \theta$,

(2) $\frac{\partial R}{\partial D}<0$ *and* $\frac{\partial^2 R}{\partial D^2}\geq 0$ *at all* $D \leq 1$ *and for* $\theta^b \leq \theta < \theta^a$*, where the equality holds only for* $\theta = \theta^b$*, and*

(3) $\frac{\partial R}{\partial D}<0$ *and* $\frac{\partial^2 R}{\partial D^2}<0$ *at all* $D \leq 1$ *and for* $\theta < \theta^b$*;*

where $\theta^a = \frac{rc(r-\rho)}{r^2}$, $\theta^b = \frac{c(r-\rho)^2}{2r^2}$*, and* $D^m(\theta) \gtrless 1$ *for* $\theta \lesseqgtr \theta^a$ *and for* $\theta > \theta^b$*, and min* $[1,D^m(\theta)]$ *is the level of deposits at which* $R(\theta,D)$ *reaches its minimum.*

Figure 1 illustrates the relationship between R and D. In Panel A with a relatively large θ (or $\theta^a \leq \theta$), we have $D^m(\theta) \leq 1$. In this case, the second effect dominates the first in the above-mentioned tradeoff if $D < D^m(\theta)$, while the reverse is true if $D > D^m(\theta)$. The two effects exactly offset each other at $D^m(\theta)$. Thus, the loan rate schedule $R(\theta,D)$ is decreasing in D, reaches its minimum at $D^m(\theta)$, and is then increasing. Furthermore, the schedule is convex. In Panel B with a relatively small θ (or $\theta^b \leq \theta < \theta^a$), the schedule is decreasing throughout in $D \leq 1$ as the first effect dominates. In this case, R reaches its minimum at $D = 1$ as $D^m(\theta) > 1$. The schedule is again convex (weakly convex for $\theta = \theta^b$) in D. Finally, in Panel C with a very small θ (or $0 < \theta < \theta^b$), the schedule is again decreasing throughout in D for the same reason. However, the function is now concave in D. In this case, R again reaches its minimum at $D = 1$. These three relationships reflect the nature of the monitoring technology in equation (1); they imply that the bank's loan monitoring is less effective for a smaller θ and only minimally effective for a very small θ.

We now use equation (5) and $R(\theta,D)$ in equation (10) to rewrite the bank's problem in equations (7) and (8a) through (8d) given $\theta \in \Theta$ as

$$\max_{D\in[0,1]} V^F(\theta,D)=\frac{\theta(R(\theta,D)-\rho D)(\alpha-R(\theta,D))}{r^2 c}. \tag{13}$$

The first-order condition is

$$\frac{\partial V^F}{\partial D}=\frac{\theta}{r^2 c}\left[\frac{\partial R}{\partial D}(\alpha-2R+\rho D)-\rho(\alpha-R)\right]=0, \tag{14}$$

where R and $\frac{\partial R}{\partial D}$ are given by equations (10) and (11), respectively. The second-order condition is

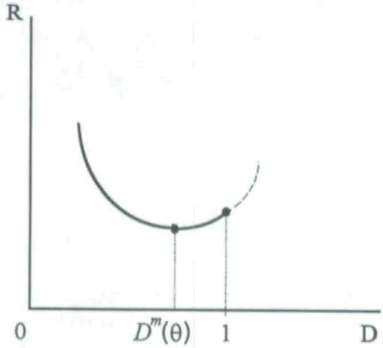
$$\frac{\partial^2 V^F}{\partial D^2}=\frac{\theta}{r^2 c}\left[\frac{\partial^2 R}{\partial D^2}(\alpha-2R+\rho D)-2\frac{\partial R}{\partial D}(\frac{\partial R}{\partial D}-\rho)\right]<0, \tag{15}$$

where $\frac{\partial^2 R}{\partial D^2}$ is given by equation (12).

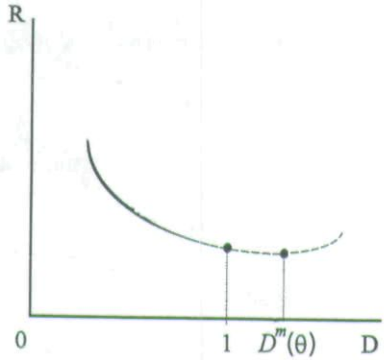
Figure 1

The Relationship Between Loan Rate, R, and Deposit Financing, D

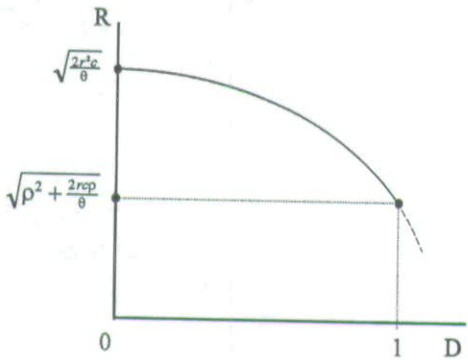
A: The Case of $\theta^a \leq \theta \leq 1$



B: The Case of $\theta^b \leq \theta < \theta^a$



C: The Case of $0 < \theta < \theta^b$



We refer to the solution to the maximization problem in equation (13) as the bank's optimal capital structure when the deposit insurance is fairly priced but no capital requirements are imposed. We denote it by $D^{\Delta}(\theta) \equiv 1 - E^{\Delta}(\theta)$, where $E^{\Delta}(\theta)$ denotes the bank's optimal equity contribution to the loan. In order to solve the maximization problem in equation (13), and for our subsequent analysis, the following condition is imposed on the parameters of our model:[14]

$$\alpha \leq \rho\left(\frac{r+\rho}{r-\rho}\right) \text{ and } \sqrt{c} > \frac{\rho}{r-\rho}. \tag{16}$$

Lemma 2

Condition (16) sufficiently guarantees that $\alpha - 2R + \rho D < 0$ *at all* $D \in [0,1]$ *and for all* $\theta \in \Theta$ *and, hence, yields the second-order condition (15).*

Recall the definition of the set Θ; namely, a loan contract will be made if and only if the *a priori* quality index is in the set Θ. The following lemma provides an important characterization of this set.

Lemma 3

Assume that condition (16) holds. Let $\underline{\theta}$ *be the minimum of all* $\theta \in \Theta$*; then*

$$\alpha \gtrless R(\theta, D^{\Delta}(\theta)) \text{ for } \theta \gtrless \underline{\theta}.$$

This lemma establishes two things. First, the minimum loan quality, $\underline{\theta}$, is one where α is just enough to fully pay off the loan rate charged by the bank. Second, a loan will be made if and only if $\theta \geq \underline{\theta}$, or $\Theta = \{\theta: \theta \geq \underline{\theta}\}$.

Using Lemmas 1 through 3, we can now prove the following proposition regarding the bank's optimal capital structure.

Proposition 1

Assume that $\theta^b < \underline{\theta} < 1$ *and that condition (16) also holds. The bank's optimal capital structure satisfies:* $D^{\Delta}(\underline{\theta}) = 1$ *if* $\underline{\theta} \leq \theta^a$ *and* $D^{\Delta}(\underline{\theta}) = D^m(\underline{\theta})$ *if* $\underline{\theta} \geq \theta^a$*;* $D^{\Delta}(\theta)$ *is strictly decreasing in* θ *and* $D^{\Delta}(\theta) \leq D^m(\theta)$ *for* $\underline{\theta} \leq \theta \leq 1$*, where the equality holds only for* $\theta = \underline{\theta} \geq \theta^a$ *and* $D^{\Delta}(1) > (=)\ 0$ *if*

$$a < (=) r\sqrt{2c}\left[\frac{2c(r-\rho)+\rho\sqrt{2c}}{c(r-\rho)+\rho\sqrt{2c}}\right]. \tag{17}$$

This proposition establishes two important properties for the bank's optimal capital structure under full information without capital regulations. First, the proposition demonstrates that the bank's role as a depository financial institution depends on the relationship between various parameters. If the inequality in condition (17) is satisfied, then it is optimal for the bank to use some deposits whenever it makes a loan, that is, to perform its traditional role of a depository financial intermediary.

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[14] This condition yields $\alpha < rc$, which is sufficient for $P \leq 1$.

This condition would more likely be met for a greater c, a greater $r - \rho$, or both given α. A *ceteris paribus* increase in c would mean a greater monitoring cost for the bank given a level of equity, thereby reducing its incentive to use equity financing.[15]

Perhaps more valuable for this analysis is the second property of the bank's optimal capital structure. That is, the level of the bank's optimal deposit financing tends to decrease as the loan's quality increases. For a loan of a higher quality, the bank finds that the value of the firm increases as it increases its equity financing and correspondingly revises the loan rate charged to break even. As noted earlier, the nature of the bank's monitoring technology is such that the loan quality index, θ, and the bank's monitoring effort, M, are complementary to each other. Therefore, the bank would find the same monitoring effort more productive for a higher quality loan, and thus increase its monitoring effort. As the loan quality successively increases, the marginal benefit of increased monitoring induced through greater equity financing successively increases, while the marginal cost of associated liquidity service fees foregone remains constant.

Figure 2 illustrates the bank's optimal capital structure in two alternative scenarios in terms of $\underline{\theta}$. In Panel A with $\theta^a \leq \underline{\theta}$, $D^\Delta(\theta)$ equals $D^m(\theta)$ at $\theta = \underline{\theta}$, decreases in θ, and equals a non-negative fraction at $\theta = 1$. While $D^m(\theta)$ is also decreasing in θ (from its definition in Lemma 1), it remains greater than $D^\Delta(\theta)$ for all $\theta > \underline{\theta}$.[16] In Panel B with $\theta^b < \underline{\theta} < \theta^a$, $D^\Delta(\theta)$ equals 1 at $\theta = \underline{\theta}$, decreases in θ, and equals another non-negative fraction at $\theta = 1$. $D^\Delta(\theta)$ always remains smaller than $D^m(\theta)$.

$R(\theta)$ is defined as the equilibrium market loan rate schedule which is obtained by substituting $D^\Delta(\theta)$ into equation (10). For a loan of quality θ, this market loan rate, $R(\theta)$, and the bank's optimal capital structure, $D^\Delta(\theta)$, determine the equilibrium loan contract between the bank and the borrower. This contract maximizes the firm's value and leads the bank to break even.

Figure 3 illustrates the equilibrium loan contract $\{R(\theta), D^\Delta(\theta)\}$ for $\theta = \underline{\theta}, \theta'$, and 1, where $\underline{\theta} < \theta' < 1$. Two points should be noted in Figure 3. First, given θ, the equilibrium loan contract is such that the iso-value line for the firm, $V^F(\theta)$, is tangent to the zero-value line for the bank, $V^B(\theta)$. Such a tangency occurs to the left of $D^m(\theta)$ for both θ' and 1, while it occurs exactly at $D^m(\theta)$ for $\underline{\theta}$. Second, $D^\Delta(\theta)$ gets successively lower as θ gets successively higher. The bank does not employ any equity at $\theta = \underline{\theta}$, while its equity financing is maximized at $\theta = 1$. $R(\theta)$ is taken to be decreasing in θ for an illustrative purpose.[17]

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[15] A *ceteris paribus* increase in the liquidity service fee, $r - \rho$, would also increase the bank's incentive to use deposits.

[16] Note that, when $\underline{\theta} = \theta^a$, $D^\Delta(\theta) = D^m(\theta) = 1$.

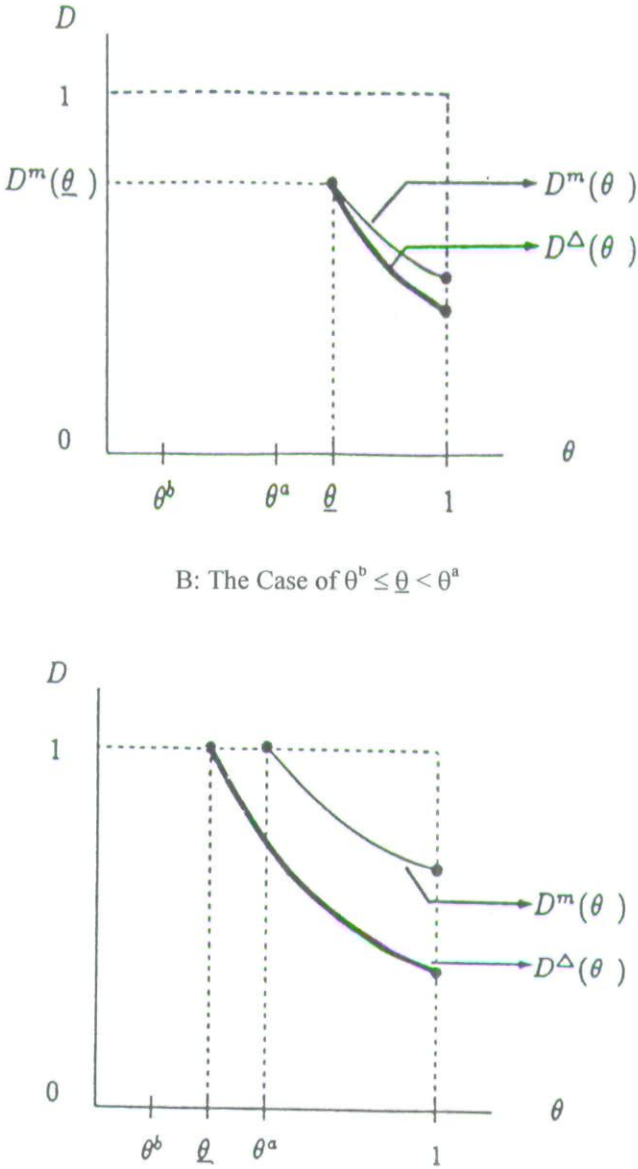
[17] Totally differentiating $R(\theta)$, we obtain

$$\frac{dR}{d\theta} = \frac{\partial R}{\partial \theta} + \frac{\partial R}{\partial D^\Delta}\frac{\partial D^\Delta}{\partial \theta}.$$

The sign of this derivative is, in general, ambiguous. The first term in the right-hand side is clearly negative, that is, a higher θ would result in a lower loan rate with D^Δ being constant. However, the second term can be seen as positive for all $\theta > \underline{\theta}$ using Lemma 1 and Proposition 1, and it is zero at $\underline{\theta}$.

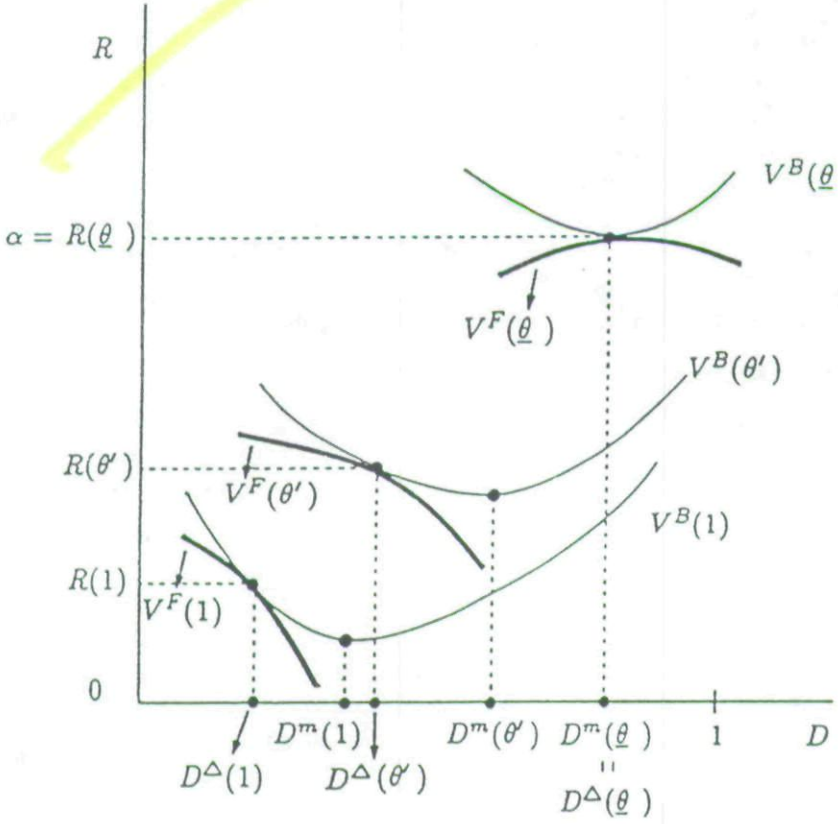
Figure 2
The Bank's Optimal Capital Structure, D^{Δ}

A: The Case of $\theta^a \leq \underline{\theta}$



As a result, while $R(\theta)$ clearly decreases at $\underline{\theta}$ and remains lower than $R(\underline{\theta})$ for all $\theta > \underline{\theta}$, it may not be monotone for some $\theta > \underline{\theta}$.

Figure 3
The Relationship Between the Market Loan Rate, R, and the Bank's Optimal Capital Structure, D^{Δ}



Note: $V^B(\theta)$ and $V^F(\theta)$ are the iso-value lines for the bank and the firm, respectively, given θ, where $\underline{\theta} < \theta' < 1$. For the firm, the direction of increase in $V^F(\theta)$ is southwest for both θ' and 1 but south for $\underline{\theta}$. For the bank, $V^B(\theta)$ indicates that its value is zero (positive, negative) on (above, below) the line given θ.

This section concludes by examining bank capital regulations that are socially optimal. The economy consists of four groups of economic agents in our model: bank shareholders, depositors, borrowing firms, and the regulator who administers the deposit insurance and imposes capital requirements on banks. Since banks operate in a competitive capital market, their (equity's net present) value is zero in equilibrium. Since the deposit market is also competitive, the depositors' cost of holding deposits, $r - \rho$, equals the value of deposit-related liquidity services provided to them per dollar deposit, that is, depositors' surplus is also zero in equilibrium.[18] Moreover, since the regulator observes θ and thus applies an actuarially fair deposit insurance premium, the deposit insurance system will always break even. Therefore, the only welfare implication of bank capital regulations concerns the surplus earned by the borrowing firms through bank loans in this economy.

To solve the social welfare maximization problem described above, we only need to note the following two points. First, a minimum capital requirement on a loan, $e(\theta)$, that is no greater than the bank's optimal equity, $E^{\Delta}(\theta)$, would be non-binding and, hence, redundant. That is, if $e(\theta) \leq E^{\Delta}(\theta)$, then the bank would indeed employ $E^{\Delta}(\theta)$. Therefore, in equilibrium, the bank would break even, and the firm value would be at the maximum level. Second, any capital requirement that is greater than the bank's optimal equity would clearly be suboptimal, since the maximized firm value would then decrease.

Summarizing these two observations, we state the following proposition without proof.

Proposition 2

If the regulator observes θ and charges the fairly-priced deposit insurance premium given by equation (6), any bank capital requirement would at best be redundant.

Proposition 2 implies that under full information the absence of bank capital regulations (*laissez-faire*) is socially optimal. This is because the bank is bound to use equity level $E^{\Delta}(\theta)$ due to loan market competition. In other words, while all rents accrue to the borrowing firms since the deposit insurer breaks even as do banks in a competitive market, banks in equilibrium would maximize their clients' values even in the absence of capital regulations. Such bank behavior would result in maximum social welfare.[19]

Bank Regulations Under Asymmetric Information

In this section, we assume that the regulator cannot observe the bank's loan quality θ. However, the regulator does know the probability distribution function governing firms in terms of the loan quality, $F(\theta)$, and the associated density, $f(\theta)$, where $f(\theta) > 0$ for all $\theta \in [0,1]$.

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[18] If the deposit market is not competitive, then the value of liquidity services depositors obtain per dollar of deposits may exceed the interest rate differential $r - \rho$. Our model could be extended to include such surplus in the measure of social welfare without qualitatively changing our results. Incorporating depositors' surplus in the welfare function would tend to further increase the maximum bank deposit financing allowed. Thus, such capital requirements would continue to be redundant.

[19] Even if the deposit insurance premium schedule is such that the regulator breaks even only on an aggregate basis, any capital requirement would remain redundant under full information. However, the equilibrium equity financing schedule would then be different from the one given in Proposition 1, reflecting cross-subsidization among borrowers of different loan qualities. In this regard, whether the regulator's objective should be to break even, and whether the regulator should break even contract-by-contract or on an aggregate basis, would depend on the equilibrium equity financing schedule and the social welfare function of the economy.

Banks now have an incentive to abuse the deposit insurance system. However, by appealing to Myerson's (1979) revelation principle, the regulator can restrict itself to incentive-compatible regulatory schedules.[20] From a potential array of such schedules, which also ensure that the deposit insurance system breaks even, the regulator must next choose one that maximizes social welfare.

As assumed in the first section, the regulator costlessly observes the loan rate, R, and the deposit financing, D, that the bank uses to finance a loan. Such observation is the first component of regulatory supervision and requires the bank to be consistent between its choice of the loan contract variables, R and D, and its loan quality report, $\hat{\theta}$. However, to satisfy such a consistency requirement, but nevertheless to possibly misrepresent its loan quality, the bank might engage in a side-payment with the borrower. Therefore, the second component of regulatory supervision is to observe and penalize such side-payments in order to prevent them. Although the regulator may generally find it relatively costly to observe such side-payments, this article examines only two polar cases: when side-payments observation is costless and when such observation is prohibitively costly.

When side-payments are costlessly observed and can be eliminated through some contingent penalty, the regulator may presume that no side-payments will be made while designing incentive-compatible regulations. However, when such observation is prohibitively costly, the regulator must explicitly consider potential side-payments in designing incentive-compatible regulations.

Let $V^B(\theta,\hat{\theta})$, $V^F(\theta,\hat{\theta})$, $R(\theta,\hat{\theta})$, and $D(\theta,\hat{\theta})$ be the bank and firm values without a side-payment, the loan rate, and bank deposit financing, respectively, when the bank receives a loan application from the firm of quality θ and reports $\hat{\theta}$ to the regulator, where $\hat{\theta} \neq \theta$. If the bank reports a loan quality $\hat{\theta}$ to the regulator, then for consistency it must also employ

$$R(\theta,\hat{\theta}) = R(\hat{\theta}) \text{ and } D(\theta,\hat{\theta}) = D(\hat{\theta}). \tag{18}$$

The regulator can observe these loan contract variables. Since the regulator also knows that, to break even in a competitive loan market, a truthful bank must employ $\{R(\hat{\theta}), D(\hat{\theta})\}$, the regulator would immediately infer that the bank had misrepresented its loan quality if condition (18) is not satisfied.

For notational convenience, we henceforth use R, D, $\hat{R}$, and $\hat{D}$ to denote $R(\theta)$, $D(\theta)$, $R(\hat{\theta})$, and $D(\hat{\theta})$, respectively. Using equations (9) and (13), we write

$$V^B(\theta,\hat{\theta}) = \frac{\theta(\hat{R}-\rho\hat{D})^2}{2r^2c} - (1-\hat{D}) - \left(1 - \frac{\hat{\theta}(\hat{R}-\rho\hat{D})}{rc}\right)\frac{\rho}{r}\hat{D} \tag{19}$$

and

[20] Also see Baron and Myerson (1982), Lewis and Sappington (1988a), and Lewis and Sappington (1988b) for applications of the revelation principle to the design of optimal regulatory policy for monopolistic firms with private information. Kanatas (1986) applies the principle to the risk-sensitive pricing of deposit insurance and the discount window.

$$V^F(\theta,\hat{\theta})=\frac{\theta(\hat{R}-\rho\hat{D})(\alpha-\hat{R})}{r^2c}. \tag{20}$$

Let us define $S(\theta,\hat{\theta})$ to be the side-payment that occurs between the bank and the borrowing firm when the true loan quality is θ but the bank reports $\hat{\theta}$ to the regulator. On one hand, if side-payments observation is costless, then we have $S(\theta,\hat{\theta}) \equiv 0$ since side-payments would be severely penalized. On the other hand, if side-payments observation is prohibitively costly, then we let $S(\theta,\hat{\theta})$ be positive if the bank makes a side-payment to the firm and negative if the bank receives a side-payment from the firm. Using this definition, the firm earns $V^F(\theta,\hat{\theta})$ + $S(\theta,\hat{\theta})$ and the bank earns $V^B(\theta,\hat{\theta}) - S(\theta,\hat{\theta})$.

When the bank reports $\hat{\theta}$, condition (18) forces it to employ $\{\hat{R},\hat{D}\}$ for the loan. Therefore, to remain competitive, the bank will report falsely if and only if

$$V^F(\theta,\hat{\theta})+S(\theta,\hat{\theta})>V^F(\theta) \text{ and } V^B(\theta,\hat{\theta})-S(\theta,\hat{\theta})>V^B(\theta). \tag{21}$$

The regulator's problem now may be viewed in two stages as follows. In the first stage, the regulator chooses the capital requirement schedule that maximizes social welfare. Given the bank's report of $\hat{\theta}$, the second stage of the regulator's problem is to observe both R and D actually employed and check the consistency requirements stated in condition (18). The regulator also observes and penalizes any side-payment if such observation is costless.

Consider the regulator's capital requirement schedule, e, which specifies the bank's minimum equity contribution for a loan, that is,

$$E(\theta) \geq e(\theta) \text{ for all } \theta \in [0,1]. \tag{22}$$

Such a capital requirement schedule, if binding, would govern the bank's capital structure. It would then influence the bank's monitoring effort associated with a loan as well as its average cost of capital. As a result, it would influence the market loan rate schedule and the value of the borrower's surplus.

To determine the social welfare function, W(e), first note that in equilibrium given e, $R(\theta)$ and $D(\theta)$ would be such that $V^F(\theta)$ is maximized and $V^B(\theta)$ equals zero. Depositors' surplus is then zero and the deposit insurance system breaks even. Denoting the minimum acceptable loan quality satisfying condition (22) by $\underline{\theta}^e$, we then define the borrower's surplus or the maximum firm value given e as

$$V^F(\theta,e(\theta))=\frac{\theta((R(\theta)-\rho D(\theta))[\alpha-R(\theta)]}{r^2c}\geq 0 \text{ for all } \theta\geq\underline{\theta}^e. \tag{23}$$

Viewing the density $f(\theta)$ as the relative social weight assigned to a loan of quality θ yields the following social welfare function:

$$W(e)=\int_{\underline{\theta}^e}^{1} V^F(\theta,e(\theta))f(\theta)d\theta. \tag{24}$$

The regulator must choose a capital requirement schedule e to maximize this social welfare function subject to the following:

$$E(\theta) \geq e(\theta) \geq E^{\Delta}(\theta), \tag{25a}$$

$$V^{F}(\theta) > (=)\ 0 \text{ for all } \theta > (\leq)\ \underline{\theta}^{e}, \tag{25b}$$

$$V^{F}(\theta, \hat{\theta}) + S(\theta, \hat{\theta}) \leq V^{F}(\theta),\ V^{B}(\theta, \hat{\theta}) - S(\theta, \hat{\theta}) \leq V^{B}(\theta), \text{ or both,} \tag{25c}$$

$$\text{for all } \theta \geq \underline{\theta}^{e} \text{ and all } \hat{\theta} \geq \underline{\theta}^{e}.$$

It should be noted that, in equations (24) and (25a) through (25c), both V^F and V^B have already incorporated $\pi(\theta)$ and $R(\theta)$ as expressed in equations (6) and (10), respectively. Condition (25a) is the bank's minimum capital requirement, which must be no less than the bank's optimal equity financing under full information in order to be effective.[21] Condition (25b) is the firm's participation constraint in the loan market and determines the minimum acceptable loan quality given e, $\underline{\theta}^{e}$. Finally, condition (25c) states the incentive-compatibility condition that would induce the bank to truthfully reveal its loan quality to the regulator.

Unobservable Side-Payments

Suppose that it is prohibitively costly for the regulator to observe side-payments. The regulator must then take into account the possibility of such side-payments in designing the incentive-compatible regulations. The incentive-compatibility conditions in this scenario are given by the following lemma.

Lemma 4

If side-payments are unobservable, then the two regulatory requirement schedules {e, π} would be incentive-compatible and fairly priced if and only if, for all $\theta \geq \underline{\theta}^{e}$,

$$V^{F'}(\theta) = \frac{(R-\rho D)(2a-R-\rho D)}{2r^2 c}, \text{ and} \tag{26}$$

$$V^{F''}(\theta) \geq 0. \tag{27}$$

Since side-payments are allowed, an incentive-compatible capital requirement schedule must be such that the combined value of the firm and the bank would be maximized if and only if the bank is truthful, that is, the bank truthfully reports θ and employs {R(θ), D(θ)}. However, since the truthful bank would only earn zero profits in the loan market in equilibrium, maximizing the combined value would be identical to maximizing only the firm value using R in equation (10). In this situation, Lemma 4 identifies the necessary and sufficient conditions under which the firm value is maximized if and only if the bank is truthful.

Clearly, it is important to examine whether the two conditions in (26) and (27) can be jointly satisfied. This analysis yields the following proposition.

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[21] If $e(\theta) < E^{\Delta}(\theta)$, then the bank would clearly increase E (θ) up to $E^{\Delta}(\theta)$ in order to remain competitive with other truthful banks.

Proposition 3

When the regulator cannot prevent side-payments, incentive-compatible capital regulations together with fairly-priced deposit insurance are not possible.

This proposition indicates that, under asymmetric information, the role of regulations is severely restricted if side-payments between the bank and the borrower are unobservable. The intuition behind this result is as follows. Unobservable side-payments enable the bank to *consistently* misrepresent its loan quality to the regulator. In this case, since the loan rate actually charged is not the net payment from the borrower to the bank, it cannot serve as a true signal of loan quality to the regulator. Through such misrepresentation, the bank and the borrower can jointly increase their combined value at the regulator's cost, resulting in under-priced deposit insurance.

This result thus extends the negative conclusions of Chan, Greenbaum, and Thakor (1992) concerning the design of incentive-compatible and fairly-priced deposit insurance schemes to more general settings. Specifically, in our model the bank's capital structure choice affects its monitoring effort. This, in turn, affects the project's success probability and, hence, the payoffs to the firm and the bank. In contrast, Chan, Greenbaum, and Thakor (1992) assume that the project's success probability is exogenously determined.

Costless Observation of Side-Payments

Suppose now that the regulator can costlessly observe side-payments. The regulator will then prevent such side-payments through severe contingent penalties.[22] Therefore, $S(\theta, \hat{\theta}) \equiv 0$ for all θ and $\hat{\theta}$ in this subsection. The incentive-compatibility conditions in this scenario are given by the following lemma.

Lemma 5

If side-payments are costlessly observable, then the two regulatory schedules $\{e, \pi\}$ *would be incentive-compatible and fairly priced if and only if, for all* $\theta \geq \underline{\theta}^e$ *and all* $\hat{\theta} \geq \underline{\theta}^e$ *such that* $\theta > \hat{\theta}$,

$$\frac{V^F(\theta) - V^F(\hat{\theta})}{\theta - \hat{\theta}} \geq \frac{(\hat{R} - \rho\hat{D})(a - \hat{R})}{r^2 c}. \tag{28}$$

When the regulator can costlessly observe and thereby prevent side-payments between the bank and the borrower, the loan contract between the two parties will be made solely in terms of the loan rate and the bank's equity contribution. A false report by the bank would be less likely in this scenario than in the previous scenario when side-payments were possible because such a report would have to

[22] Although our analysis is restricted to this polar case for simplicity, the results presented in this subsection would continue to hold in the case when side-payments observation is only moderately costly. That is, as long as the regulator's cost of such observation is lower than the loss to the bank insurance fund possibly resulting from banks' false reports, it would prevent such side-payments. We discuss this regulatory tradeoff below in greater detail.

make both parties better off independent of each other. As a result, the incentive-compatible equity requirement necessary to induce the bank to report truthfully becomes less stringent.

To understand the intuition behind Lemma 5, first note that a bank, with a loan application of quality θ, would never falsely report a higher loan quality regardless of the firm's preference, since the bank's cost would exceed the benefit from such a false report and its value would thus be negative. However, the bank may falsely report a lower loan quality $\hat{\theta}$, since its gain from such a false report would exceed its cost. That is, while the bank's cost would be the same as that of another bank that truthfully reports $\hat{\theta}$, its benefit would be greater since $\theta > \hat{\theta}$, yielding a positive bank value. Therefore, this bank would report $\hat{\theta}$ only if such a report would also benefit the borrowing firm. Condition (28) ensures that the firm does *not* benefit from such a false report. Thus, when condition (28) is satisfied, the bank would report its true quality to remain competitive in the lending market.

In this situation, Lemma 5 establishes condition (28) as being necessary and sufficient for the two regulatory schedules, $\{e, \pi\}$, to be incentive-compatible. On one hand, condition (28) is sufficient because, given that the bank will not falsely report a higher loan quality, it will lead the firm to require the bank not to falsely report a lower loan quality. In other words, an untruthful bank would either suffer a loss or lose the customer to a truthful bank. On the other hand, condition (28) is also necessary because incentive-compatible regulations need to ensure only that the firm value would not be maximized if the bank falsely reported a lower loan quality.

By examining the feasibility of condition (28) in our model, the existence of incentive-compatible and fairly-priced regulations is established in the following proposition.

Proposition 4

When the regulator costlessly observes and prevents side-payments, incentive-compatible capital requirements together with fairly-priced deposit insurance exist and satisfy the following condition: $(R-\rho D)(\alpha-R)$ is nondecreasing in θ for all $\theta \geq \underline{\theta}^{e}$.

Contrasting Propositions 3 and 4 highlights the crucial role that side-payments observation plays in our analysis. In contrast to Chan, Greenbaum, and Thakor's (1992) impossibility result concerning the design of incentive-compatible regulations, and the similar conclusion drawn here in Proposition 3, Proposition 4 reveals that, if the regulator observes and prevents side-payments, incentive-compatible and fairly-priced regulations can in fact be jointly implemented. Proposition 4 thus extends the positive results claimed by Yoon and Mazumdar (forthcoming) to the case when bank monitoring effort influences the success probability of borrowing firms. This result highlights an important policy implication. The regulator can establish incentive-compatible and fairly-priced deposit insurance only if it can also observe loan rates and side-payments between the borrower and the bank. In general, these observations would require close bank supervision and involve substantial costs. Thus, the design of incentive-compatible regulatory policy involves a tradeoff between such regulatory supervision costs and the mispriced deposit insurance subsidy. Only if the former cost is smaller than the latter would the regulator find it optimal to design fairly-priced deposit insurance schemes in an asymmetric information scenario.

The regulator's remaining problem is to find one among these incentive-compatible capital requirement schedules that maximizes social welfare. The solution to this problem immediately follows from Proposition 4.

Corollary 1

When the regulator costlessly observes and prevents side-payments and charges the fairly-priced deposit insurance premium, any bank capital requirement would at best be redundant.

This corollary establishes that capital requirements continue to be redundant even when there exists informational asymmetry between the bank and the regulator in terms of loan quality. However, it is important to emphasize that such redundancy of capital regulation under informational asymmetry holds only if the government can observe side-payments between the bank and the firm and prevent them, and bank loan rates and capital structures are observable by the regulator.[23] Under asymmetric information without side-payments, a false report by the bank would result in either a negative bank value or a decrease in the firm value from that obtained from a truthful bank report, which equals the firm value under full information. Thus, to remain competitive in the loan market, the bank would be truthful and voluntarily employ the full information level of equity, $E^{\Delta}(\theta)$. Therefore, in this situation, any capital requirements would either be redundant or suboptimal. Since aggregate social welfare includes only aggregate firm value in this competitive loan market, social welfare would also be maximized as all banks would voluntarily contribute E^{Δ} to remain competitive. This result corroborates recent empirical evidence that the tier one capital-asset ratios currently held by U.S. banks considerably exceed the level required by the Federal Reserve Board.[24] The regulator must, however, observe and prevent side-payments to ensure that banks truthfully reveal their loan qualities and pay actuarially fair prices for their deposit insurance protection. Our analysis thus highlights the complementary

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[23] Thus, even if side-payments can be observed and prevented, the capital requirement schedule may not be incentive-compatible if condition (28) is not satisfied. Thus, the use of observable market information such as bank loan rates and capital structure is also critically important to the design of a fairly priced deposit insurance scheme under asymmetric information. This issue is addressed in greater detail in Yoon and Mazumdar (forthcoming).

[24] Although international regulatory standards established through the Basle Accord require banks to hold at least 4 percent of their assets in tier one capital, and the Federal Reserve Board mandates a 6 percent requirement, at present the U. S. banking sector's ratio is 7.7 percent. Moreover, according to some estimates, the 30 largest U.S. banks could reduce their capital by another $32 billion without violating the capital adequacy standard (see American Banking: Loan Arrangers Ride Again, *The Economist,* February 25, 1995, p. 81).

nature of bank supervision and capital requirements that must be considered in the design of effective regulatory schemes.[25]

The socially optimal capital requirement under asymmetric information would again be increasing in loan quality since it would be the same as the full information solution established above in the second section. This follows from the fact that banks' monitoring technology is such that better quality loans are more sensitive to monitoring effort. Since monitoring effort is an increasing function of the bank's equity contribution, it follows that greater equity requirements for higher quality loans would maximize the borrowing firms' value and hence social welfare.

Our result is consistent with earlier studies by Besanko and Kanatas (1990) and Flannery (1989), which demonstrate in different settings that the bank's equity contribution must be an increasing function of loan quality for regulatory policy to be incentive-compatible. Chan, Greenbaum, and Thakor (1992) also provide a similar characterization of incentive-compatible regulations when the deposit insurance subsidy is positive. In contrast, Giammarino, Lewis, and Sappington (1993) suggest that in a socially optimal incentive-compatible regulatory system, higher-quality banks face lower capital adequacy requirements. However, the social welfare function envisaged by these authors differs substantially from ours.

Thus, our framework offers an empirically testable proposition regarding bank capital structure. Cross-sectionally, safer banks should maintain higher equity capital. This prediction is also consistent with recent bank regulatory measures introduced through FDICIA. This Act classifies banks according to their *risk-adjusted* capital levels. Banks with greater risk-adjusted capital are assumed to be safer and subject to less stringent supervision compared to those banks that have inadequate risk-adjusted capital.

Social Welfare Implications

Now consider the social welfare implications of an alternative deposit insurance scheme that is not fairly priced contract-by-contract. Because the loan market is competitive with all banks having an identical monitoring technology in our model, all impacts of deposit insurance pricing are ultimately borne by the borrowing firms. Therefore, cross-subsidization among *banks* will not occur regardless of deposit insurance pricing. Furthermore, because deposit insurance is fairly priced contract-by-contract, cross-subsidization among *firms* will also not occur. Thus, the deposit insurance system assumed in our model may be justified on the following two grounds. First, the scheme is socially fair, as it leads every borrow-

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[25] FDICIA has recognized the need for close bank supervision and introduced several new measures to facilitate this (see Hempel, Simonson, and Coleman, 1994, pp. 26–28, for details). For instance, the Act imposes new accounting as well as operational and managerial standards on all insured banks (see FDICIA, Sections 121 and 39, respectively). It prohibits any management fee payments to persons with a controlling interest in the bank if that would lead to the bank's undercapitalization. In addition, it imposes more stringent measures on undercapitalized banks, including closer monitoring of the bank's capital position as well as several measures to improve bank management (see FDICIA, Section 131).

ing firm to pay a loan rate that duly compensates the bank for its cost of funds and the associated monitoring service. Second, because the regulator breaks even and does not enforce a binding capital requirement, its role in the credit market remains neutral, except for observing and penalizing side-payments. These reasons notwithstanding, the government may still wish to adopt an alternative deposit insurance system if such a system would increase social welfare. The next scenario examines a case in which the deposit insurance system is not fairly priced contract-by-contract.

Consider a deposit insurance system that involves cross-subsidization among firms but leads the regulator to break even on an aggregate basis. Whether such a mispriced deposit insurance system provides greater social welfare than the fairly-priced system analyzed in our model is, in general, ambiguous and depends on the firm value function and the distribution function governing the firms. To focus attention on the firm value function, assume that the firm's project quality is uniformly distributed in the economy. Now consider a deposit insurance system that overprices a lower-quality loan by charging an additional insurance premium and underprices a higher-quality loan by discounting the same amount so that the regulator continues to break even. When the regulator costlessly observes and prevents side-payments, such a deposit insurance system together with no capital requirements would continue to be incentive-compatible if condition (28) was satisfied. Furthermore, such a system would increase social welfare from the level attained under the fairly-priced deposit insurance system if the increase in the higher-quality firm's value more than offsets the decrease in the lower-quality firm's value. Within the basic framework of our model, but under such a mispriced deposit insurance system, the incentive-compatibility condition is generally satisfied, when side-payments are observed and prevented. Furthermore, the welfare-improving condition may also be satisfied with further parametric restrictions.[26] This implies that the fairly-priced deposit insurance system might be suboptimal under alternative settings.[27]

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[26] For example, consider the alternative deposit insurance premium, $H(\theta) = \pi(\theta)D(\theta) + h(\bar{\theta} - \theta)$, where $\pi(\theta)$ is as defined in equation (6), h is a non-negative constant, and $\bar{\theta}$ is a threshold loan quality such that the regulator breaks even on an aggregate basis while all loans with $\theta < \bar{\theta}$ are overpriced and all loans with $\theta > \bar{\theta}$ are underpriced. Under such a premium scheme, one can show that the regulator breaks even, and $V^F(\theta)$ satisfies condition (28) and it is possible that $V^{F\prime\prime}(\theta) > 0$.

[27] Another setting in which fairly pricing deposit insurance on a contract-by-contract basis may not be socially optimal is if the social welfare function was constructed as a weighted average of government and corporate profits, where the associated weights are determined by some voting rule. By increasing insurance premiums across all loan qualities over and above the fair price, the government could then indirectly tax the corporate sector. The social welfare could then increase if society attached a greater weight to government spending than to private spending. In this case, the fairly-priced deposit insurance system might again be suboptimal.

CONCLUSION

Our analysis of the problem of designing bank deposit insurance and capital requirement schedules that maximize social welfare in an economy where competitive banks monitor their loans and also provide liquidity services to their depositors yields several new insights regarding the role of bank capital regulations.

First, under full information, the bank has an interior optimum capital structure in the absence of any capital regulations. This result reflects the tradeoff between liquidity service fees foregone and monitoring benefits earned through increased equity financing. Banks are shown to optimally use increased equity financing for higher-quality loans, which are more sensitive to bank monitoring. Second, social welfare, which is defined as borrowers' surplus in our competitive market framework, is maximized under full information if the regulator does not impose any capital requirements, that is, follows a *laissez-faire* policy. Third, the regulator's problem is more complex when it cannot observe the bank's loan quality. The regulator must then design incentive-compatible regulations to force banks to reveal their true loan qualities and pay a fair deposit insurance premium. This is possible only if the regulator can observe the capital structure and loan rate that the bank actually employs in the competitive loan market, and can also prevent side-payments between the bank and the borrower. Finally, we examine which one of the many alternative incentive-compatible capital requirement schedules should be chosen by the regulator to maximize social welfare. Once again, even under asymmetric information, the *laissez-faire* policy turns out to be incentive-compatible and socially optimal.

Our analysis highlights some important policy implications. It demonstrates that ultimately bank supervision and prevention of bank-borrower collusive side-payments may be of greater importance than capital regulations in establishing incentive-compatible and fairly-priced deposit insurance schemes. This provides theoretical support for recent bank supervisory measures introduced in the United States through FDICIA. However, bank supervision may entail substantial costs. Thus, the regulator faces a tradeoff between such supervisory costs and the mispriced deposit insurance subsidy saved.

APPENDIX

Proof of Lemma 1

Consider the following three cases.

Case 1: $\theta^a \le \theta$. The signs of the first derivative given in the lemma follow from the right-hand side of equation (11) by the definition of $D^m(\theta)$, where $D^m(\theta) \le 1$ in this case (the equality holds at $\theta = \theta^a$). The sign of the second derivative is positive because the bracket term in the right-hand side of equation (12) is positive in this case since $\theta^a > \theta^b$.

Case 2: $\theta^b \le \theta < \theta^a$. The sign of the first derivative is negative because at all $D \in [0,1]$ the right-hand side of equation (11) is negative in this case. The sign of the second derivative is non-negative from equation (12) by using the definition of θ^b. Note also that $D^m(\theta) > 1$ for $\theta^b < \theta < \theta^a$.

Case 3: $0 < \theta < \theta^b$. The sign of the first derivative is negative for the same reason as in Case 2 given that $\theta^b < \theta^a$. The sign of the second derivative is now negative from equation (12).■

Proof of Lemma 2

First, the two conditions in (16) together yield that $\alpha < -\rho + 2r\sqrt{c}$. Now, $\alpha - 2R + \rho D < 0$ if and only if $\alpha < \alpha^*(\theta, D) = 2R(\theta, D) - \rho D$, where $R(\theta, D)$ is from equation (10). Consider the following two cases.

Case 1: $\theta^a \le \theta$. From Lemma 1, we know that $R(\theta, D)$ is minimized at $D = D^m(\theta)$ in this case. Thus, for all such θ and all $D \in [0, 1]$,

$$\alpha^*(\theta, D) \ge -\rho + 2R(\theta, D^m(\theta))$$

with the equality holding only if $D^m(\theta) = 1$. Using the definition of $D^m(\theta)$, we re-write the right-hand side as

$$-\rho + 2\sqrt{\frac{r^2 c}{\theta}\left(2 - \frac{c(r-\rho)^2}{\theta\rho^2}\right)} \ge -\rho + 2\sqrt{\frac{r^2 c}{\theta}} \ge -\rho + 2r\sqrt{c}.$$

The first relationship holds because $2 - \frac{c(r-\rho)^2}{\theta\rho^2} > 2 - \frac{rc(r-\rho)}{\theta\rho^2} \ge 1$, and the second one holds because $\theta \le 1$. Thus, condition (16) is sufficient for the negative sign.

Case 2: $\theta < \theta^a$. From Lemma 1, we know that $R(\theta, D)$ is minimized at $D = 1$ in this case. Thus, for all such θ and all $D \in [0, 1]$,

$$\alpha^*(\theta, D) \ge -\rho + 2R(\theta, 1) = -\rho + 2\sqrt{\rho^2 + \frac{2rc\rho}{\theta}}.$$

Now $R(\theta, 1)$ is decreasing in θ for $\theta < \theta^a$, and recall from Case 1 that $R(\theta, D^m(\theta))$ is nonincreasing in θ for $\theta \ge \theta^a$. Thus, for any θ' and θ'' such that $\theta' < \theta^a < \theta''$,

$$R(\theta', 1) > R(\theta^a, 1) = R(\theta^a, D^m(\theta^a)) \ge R(\theta'', D^m(\theta''))$$

since $D^m(\theta^a) = 1$. Thus, condition (16) is again sufficient for the negative sign.■

Proof of Lemma 3

Let us write $R(\theta) = R(\theta, D^{\Delta}(\theta))$, $V^B(\theta) = V^B(\theta, D^{\Delta}(\theta))$, and $V^F(\theta) = V^F(\theta, D^{\Delta}(\theta))$ for notational ease.

We first prove that $\alpha = R(\underline{\theta})$. From the definitions of the set Θ and the schedule $R(\theta)$, it follows that $V^B(\underline{\theta}) = 0$ and $V^F(\underline{\theta}) \geq 0$. However, we shall prove that $V^F(\underline{\theta}) = 0$ always. To this end, suppose that $V^F(\underline{\theta}) > 0$. It then follows from equation (13) that $\alpha > R(\underline{\theta})$. Consider the following two cases.

Case 1: R is nondecreasing. In this case, there must exist some $\theta' < \underline{\theta}$ such that $R(\theta') \leq R(\underline{\theta})$. This indicates that $V^B(\theta') = 0$ and $V^F(\theta') \geq 0$, and thus that $\theta' \in \Theta$. So, $\underline{\theta}$ is not the minimum.

Case 2: R is decreasing. In this case, one can find $\theta'' < \underline{\theta}$ such that $R(\theta'') = \alpha$. Since $V^B(\theta'') = 0$ and $V^F(\theta'') = 0$, it again follows that $\theta'' \in \Theta$. So again, $\underline{\theta}$ is not the minimum. In both Cases 1 and 2, it therefore follows that the supposition is false. Thus, $V^F(\underline{\theta}) = 0$ or $\alpha = R(\underline{\theta})$.

To prove that $\alpha > R(\theta)$ for $\theta > \underline{\theta}$, we show that $V^F(\theta)$ is strictly increasing in θ for $\theta > \underline{\theta}$. This will then yield the desired result since, from equation (13), we have $V^F(\theta) > 0$ if and only if $\alpha > R(\theta)$. Totally differentiating $V^F(\theta)$ in equation (13) and rearranging terms, we get

$$\frac{dV^F}{d\theta} = \left(\frac{\partial V^F}{\partial R}\frac{\partial R}{\partial D^{\Delta}} + \frac{\partial V^F}{\partial D^{\Delta}}\right)\frac{\partial D^{\Delta}}{\partial \theta} + \frac{\partial V^F}{\partial R}\frac{\partial R}{\partial \theta} + \frac{\partial V^F}{\partial \theta}.$$

The sign of this derivative is positive because, by the definition of D^{Δ}, the first term in the right-hand side is zero. The parenthesized term is zero at $D^{\Delta} < 1$, whereas it is either zero or positive at $D^{\Delta} = 1$, where $\frac{\partial D^{\Delta}}{\partial \theta} = 0$. The second term is positive due to Lemma 2, and the last term is non-negative because the bank can break even only if $\alpha \geq R$.

Finally, we know that $\alpha < R(\theta)$ for $\theta < \underline{\theta}$ since such θ would otherwise belong to the set Θ.■

Proof of Proposition 1

Using equation (11), we rewrite the term in the square bracket in equation (14) as

$$\frac{1}{R}\left[\left(\rho^2 D - \frac{rc(r-\rho)}{\theta}\right)(\alpha - 2R + \rho D) - \rho(\alpha - R)R\right], \tag{A1}$$

where R is given by equation (10). The sign of the first derivative in equation (14) is the same as that of the term in equation (A1) for all $\theta > 0$. First, evaluating this term at $D = 1$ for $\theta = \underline{\theta} \leq \theta^a$ yields a non-negative value, because $\rho^2 \leq \frac{rc(r-\rho)}{\underline{\theta}}$, $\alpha - 2R + \rho < 0$, and $\alpha = R$. The second derivative in equation (15) is negative because Lemma 1 indicates that $\frac{\partial R}{\partial D} < 0$ and $\frac{\partial^2 R}{\partial D^2} \geq 0$ in this case. Thus, $D^{\Delta}(\underline{\theta}) =$

1. Next, the term equals zero when evaluated at $D = D^m(\theta)$ for $\theta = \underline{\theta} \geq \theta^a$. Again, the second derivative in equation (15) is negative. Thus, $D^\Delta(\underline{\theta}) = D^m(\underline{\theta})$. We rewrite the first-order condition in equation (14) as $J(\theta, D^\Delta)$. Applying the implicit function theorem, we get

$$\frac{dD^\Delta}{d\theta} = -\frac{\frac{\partial J}{\partial \theta}}{\frac{\partial J}{\partial D^\Delta}}. \tag{A2}$$

In equation (A2), the denominator is the second derivative in equation (15). Its sign is negative for $\theta > \theta^b$ because we have $\frac{\partial^2 R}{\partial D^2} > 0$ and $\alpha - 2R + \rho D < 0$, and $\frac{\partial R}{\partial D}$ must be nonpositive if the derivative in equation (14) equals zero. Using equation (A1), we rewrite the numerator in the right-hand side of equation (A2) as

$$\frac{rc(r-\rho)(\alpha-2R+\rho D)}{\theta^2 R} + \frac{rc(r-D(r-\rho))}{\theta^2 R}\left[(D - \frac{rc(r-\rho)}{\theta\rho^2})(\alpha+\rho D)-\rho\right] < 0.$$

The sign is determined as follows: the first term is negative from Lemma 2. For the second term, it is clear that $r - D(r-\rho) > 0$. Now note from equation (A1) that if the first-order condition holds, then the term, $D - \frac{rc(r-\rho)}{\theta\rho^2}$, must be nonpositive. Thus, we get a negative sign for the term in equation (A2), which yields the first result. To see the next result, note the definitions of $D^\Delta(\theta)$ and $D^m(\theta)$. The derivative in equation (14) must be non-negative when evaluated at $D^\Delta(\theta)$, whereas it becomes nonpositive when evaluated at $D^m(\theta)$. The second derivative in equation (15) can be shown to be negative for $\theta \geq \underline{\theta} > \theta^b$ in a manner similar to one used for equation (12). Thus, $D^\Delta(\theta) \leq D^m(\theta)$. We know that $D^\Delta(\theta) = D^m(\theta)$ only for $\theta = \underline{\theta} \geq \theta^a$ because we have $\frac{\partial V^F}{\partial D} = \frac{\partial R}{\partial D} = 0$ only if $\alpha = R$ (or $\theta = \underline{\theta}$) and $\theta \geq \theta^a$. We evaluate the term in equation (A1) at $D = 0$ for $\theta = 1$ to get

$$-\frac{rc(r-\rho)(\alpha - 2\sqrt{2r^2c})}{\sqrt{2r^2c}} - \rho(\alpha - \sqrt{2r^2c}). \tag{A3}$$

Condition (17) gives a non-negative sign for equation (A3). One can show that the second derivative in equation (15) is negative for $\theta = 1$ in a manner similar to one used for equation (A2). Thus, it follows that $D^\Delta(1) \geq 0$, where the equality holds only if condition (17) holds as an equality.■

Proof of Lemma 4

Since $S(\theta, \hat{\theta}) = V^B(\theta, \hat{\theta})$ in equilibrium, the three conditions in equation (25c) reduce to the single condition that $V^F(\theta) \geq V^F(\theta, \hat{\theta}) + V^B(\theta, \hat{\theta})$. Using equations (19) and (20) and noting that $V^B(\theta) = V^B(\hat{\theta}) = 0$ in equilibrium, we obtain

$$V^F(\theta) \geq V^F(\hat{\theta}) + \frac{(\theta-\hat{\theta})(\hat{R}-\rho\hat{D})(2\alpha-\hat{R}-\rho\hat{D})}{2r^2c}, \tag{A4}$$

where $V^F(\hat{\theta}) = V^F(\hat{\theta}, \hat{\theta})$. Reversing the roles of θ and $\hat{\theta}$, we have

$$V^F(\hat{\theta}) \geq V^F(\theta) + \frac{(\hat{\theta}-\theta)(R-\rho D)(2\alpha-R-\rho D)}{2r^2c}. \tag{A5}$$

Combining equations (A4) and (A5) yields

$$\frac{(\hat{R}-\rho\hat{D})(2\alpha-\hat{R}-\rho\hat{D})}{2r^2c} \leq \frac{V^F(\theta)-V^F(\hat{\theta})}{\theta-\hat{\theta}} \leq \frac{(R-\rho D)(2\alpha-R-\rho D)}{2r^2c}. \tag{A6}$$

For $\theta \geq \hat{\theta}$, we see that the term, $(R - \rho D)(2\alpha - R - \rho D)$, is nondecreasing in θ, and, hence, the term in the middle of equation (A6) must be continuous almost everywhere for $\theta \geq \underline{\theta}^e$. Thus, if we take its limit as $\hat{\theta} \to \theta$, we get the derivative as expressed in equation (26) almost everywhere. Since this derivative is nondecreasing in θ, we get equation (27).

Conversely, condition (25c) is implied by the two conditions in the lemma as follows: for $\theta \geq \hat{\theta}$,

$$\begin{aligned}
&V^F(\theta)+V^B(\theta)-V^F(\theta,\hat{\theta})-V^B(\theta,\hat{\theta})\\
&=V^F(\theta)-V^F(\theta,\hat{\theta})-\frac{(\theta-\hat{\theta})(\hat{R}-\rho\hat{D})^2}{2r^2c}\\
&=V^F(\theta)-V^F(\hat{\theta})-\frac{(\theta-\hat{\theta})(\hat{R}-\rho\hat{D})(2\alpha-\hat{R}-\rho\hat{D})}{2r^2c}\\
&=\int_{\hat{\theta}}^{\theta} V^{F'}(\tilde{\theta})d\tilde{\theta}-(\theta-\hat{\theta})V^{F'}(\hat{\theta})\\
&\geq 0.
\end{aligned}$$

The first equality above follows from equation (19) and the condition that $V^B(\theta) = V^B(\hat{\theta}) = 0$ in equilibrium. The second and third equalities follow from equations (20) and (26), respectively. The above sign follows because $V^{F''}(\theta) \geq 0$. This result is equivalent to the conditions in (25c) since $S(\theta, \hat{\theta}) = V^B(\theta, \hat{\theta})$ in equilibrium.■

Proof of Proposition 3

To prove the proposition, it is sufficient to show that the two conditions (26) and (27) cannot hold simultaneously in our model.

Using equation (23), we get

$$\frac{dV^F(\theta)}{d\theta}=\frac{(R-\rho D)(\alpha-R)}{r^2c}+\frac{\theta}{r^2c}\left[\frac{\partial R}{\partial \theta}(\alpha-2R+\rho D)+D'(\theta)J(\theta)\right], \qquad \text{(A7)}$$

where prime denotes the derivative and $J(\theta) \equiv \frac{\partial R}{\partial D}(\alpha - 2R + \rho D) - \rho(\alpha - R)$. Note that $J(\theta) \geq 0$ from equation (14) due to equation (25a). Equating the definitional derivative in equation (A7) to the derivative in equation (26) yields

$$D'(\theta)J(\theta) - K(\theta) = 0, \qquad \text{(A8)}$$

where $K(\theta) = \frac{(R-\rho D)^2}{2\theta} - \frac{\partial R}{\partial D}(\alpha - 2R + \rho D)$.

To determine the sign of $K(\theta)$, we use both R and $\frac{\partial R}{\partial \theta}$ (from equation [10]) and rearrange terms to rewrite

$$K(\theta)=\frac{1}{2\theta R}(R-\rho D)[-R^2+(\alpha-2\rho D)R+\rho D(\alpha+\rho D)]. \qquad \text{(A9)}$$

The sign of the term in the square bracket is negative as follows: Given D, we view the term as a quadratic function in R. The value of this function is negative for $R > R^0$, where

$$R^0=\frac{1}{2}(\alpha-2\rho D+\sqrt{\alpha^2+8\rho^2D^2}).$$

However,

$$R^0 < R(1, D) \leq R(\theta, D) \text{ for } \underline{\theta}^e \leq \theta \leq 1. \qquad \text{(A10)}$$

In equation (A10), the first relationship follows by using equation (10) and condition (16). The second relationship follows because $\frac{\partial R(\theta,D)}{\partial\theta}<0$ with the equality holding only for $\theta = 1$. Since $R - \rho D > 0$, we get $K(\theta) < 0$.

We now use equation (26) to get

$$V^{F''}(\theta)=\frac{1}{r^2c}\left[\frac{\partial R}{\partial \theta}(\alpha-R)+D'(\theta)\left(\frac{\partial R}{\partial D}(\alpha-R)-\rho(\alpha-\rho D)\right)\right], \qquad \text{(A11)}$$

where one and two primes denote the first and second derivatives, respectively. Note that, in equation (A8), $J(\theta)$ must be positive since $K(\theta) < 0$. Thus, $D'(\theta) = K(\theta)/J(\theta)$. Substituting this and $\frac{\partial R}{\partial \theta}$ into equation (A11) and rearranging terms yield

$$V^{F''}(\theta)=\frac{\theta(R-\rho D)^2}{2}[(\alpha-R)R(\frac{\partial R}{\partial D}-\rho)-\rho^3 D^2]\leq 0.$$

$V^{F''}(\theta)$ is negative for $D < D^{\Delta}$ for $\theta > \underline{\theta}^e$ because $\frac{\partial R}{\partial D} < 0$, while the equality holds only for $\theta = \underline{\theta}^e$ and $D(\underline{\theta}^e) = 0$. Thus, condition (27) is violated for all $\theta > \underline{\theta}^e$.■

Proof of Lemma 5

Since $S(\theta, \hat{\theta}) \equiv 0$ in this scenario, the conditions in (25c) become

$V^B(\theta, \hat{\theta}) \leq V^B(\theta)$, $V^F(\theta, \hat{\theta}) \leq V^F(\theta)$, or both, for all $\theta \geq \underline{\theta}^e$, and all $\hat{\theta} \geq \underline{\theta}^e$. (A12)

Consider $\theta > \hat{\theta}$. Using equation (19), we rewrite

$$V^B(\theta,\hat{\theta})=V^B(\hat{\theta})+\frac{(\theta-\hat{\theta})(\hat{R}-\rho\hat{D})^2}{2r^2c}>V^B(\hat{\theta})=V^B(\theta)=0, \tag{A13}$$

where the last two equalities hold in equilibrium. Thus, the conditions in (A12) become equivalent to requiring that $V^F(\theta, \hat{\theta}) \leq V^F(\theta)$ for $\theta > \hat{\theta}$. Using equation (20), we rewrite this condition as

$$V^F(\hat{\theta})+\frac{(\theta-\hat{\theta})(\hat{R}-\rho\hat{D})(\alpha-\hat{R})}{r^2c}\leq V^F(\theta) \text{ for } \theta>\hat{\theta}. \tag{A14}$$

Next, consider $\theta < \hat{\theta}$. Again using equation (19), we get

$$V^B(\theta,\hat{\theta})=V^B(\hat{\theta})+\frac{(\theta-\hat{\theta})(\hat{R}-\rho\hat{D})^2}{2r^2c}<V^B(\hat{\theta})=V^B(\theta)=0.$$

That is, the condition in (A12) is unconditionally satisfied.

Thus, we know that condition (A12) holds if and only if (A14) holds. Now, it is easy to see that condition (28) gives rise to (A14), and vice versa.■

Proof of Proposition 4

We prove the existence part by showing that $V^F(\theta)$ in equation (23) satisfies condition (28).

Substituting equation (23) into $V^F(\theta)$ and $V^F(\hat{\theta})$ in condition (28) and rearranging terms, we get, for $\theta > \hat{\theta}$,

$$(R-\rho D)(\alpha-R)\geq(\hat{R}-\rho\hat{D})(\alpha-\hat{R}). \tag{A15}$$

That is, $(R - \rho D)(\alpha - R)$ is nondecreasing in θ.

To see that the relationship (A15) is feasible in our model, we differentiate $V^F(\theta)$ in condition (28) to get

$$\frac{dV^F(\theta)}{d\theta}=\frac{1}{r^2c}[(R-\rho D)(\alpha-R)+\theta\{J(\theta)D'(\theta)+L(\theta)\}], \tag{A16}$$

where

$$J(\theta)=\frac{\partial R}{\partial D}(\alpha-2R+\rho D)-\rho(\alpha-R), \text{ and}$$

$$L(\theta)=\frac{\partial R}{\partial D}(\alpha-2R+\rho D).$$

The sign of the derivative in equation (A16) can be non-negative because of the following: (1) $(R-\rho D)(\alpha-R)$ is clearly non-negative; (2) $L(\theta)$ is positive because $\frac{\partial R}{\partial \theta}$ is negative from equation (10), and $(\alpha - 2R + \rho D)$ is also negative from Lemma 2; and (3) $J(\theta)$ is either positive or zero because, while it has the same sign as that of the derivative in equation (14), it is clear that $D(\theta) \leq D^{\Delta}(\theta)$ or $E(\theta) \geq E^{\Delta}(\theta)$.

While the derivative in equation (A16) can in general be non-negative, we prove the existence part by noting that it becomes clearly positive with $D'(\theta)=0$. It is straightforward to see that incentive-compatible regulations imply equation (A15).■

Proof of Corollary 1

Consider $e(\theta) = E^{\Delta}(\theta)$, where $E^{\Delta}(\theta)$ is as defined in the second section. Such $e(\theta)$ gives rise to $J(\theta) = 0$ in equation (A16). Thus, equation (A15) is satisfied, and so is the incentive-compatible condition (28).

Now note that, if $e(\theta)$ is not explicitly required, the bank would still choose $E(\theta) = E^{\Delta}(\theta)$ because, by definition, $E^{\Delta}(\theta)$ maximizes the value of the firm of quality θ.■

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