

**An Incentive Approach to
Banking Regulation**

by

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1. Introduction.

Recent events in the savings and loan industry have drawn attention to the difficult problems facing bank regulators. Among these problems is the limited information regulators possess about the activities and capabilities of individual banks. With imperfect information and limited policy instruments, it is difficult for regulators to motivate banks to operate entirely in the social interest. The intent of this research is to analyze optimal banking regulation in a simple model that focuses on one source of the limited information available to regulators.

Employing techniques developed in the agency literature (e.g., Laffont and Tirole [1986]), we examine how a regulator should employ the policy instruments at his disposal to maximize expected welfare in the banking industry. One component of welfare is the social loss from bankruptcy. The optimal regulatory policy is structured, in part, to minimize this loss. The probability of bankruptcy is reduced by improving the quality of the bank's loan portfolio, by reducing the number of dollars loaned out by the bank, and by increasing the equity reserves the bank is required to hold. Our focus is on the optimal interplay of these policy instruments. Our findings are consistent with the policy recommendations of prominent academicians and practitioners. (See, for example, White [1989].) To illustrate, we find that banks with higher quality loan portfolios will earn higher profits, be required to hold smaller reserves, and be permitted to make more loans. We also demonstrate that the optimal probability of bankruptcy does not vary with the induced quality of the bank's loan portfolio.

These and other findings are recorded formally in section 3. First, though, the model we analyze is described in section 2. Section 4 discusses extensions of our basic model. These extensions are important because the model we analyze

departs from reality in important ways. For instance, we abstract from explicit competition among banks by focusing on the behavior of a single representative bank. Furthermore, we assume that the quality of the bank's loan portfolio is observable to the regulator.¹ What is not observable to the regulator are the costs incurred by the bank in improving the quality of its loan portfolio (e.g., the bank's diligence). This is the critical information asymmetry we analyze.

2. The Model.

There are two main actors in our model: the government regulator and the bank. The regulator's task is to structure the bank's insurance premium, required reserves, portfolio quality and loan levels so as to maximize expected welfare in the industry. The bank's objective is to maximize its profits, taking as given the mandates of the regulator. A key element of our analysis is the information asymmetry between the regulator and the bank. The bank knows how costly it is to improve the quality of its loan portfolio and how diligently it has labored to enhance this quality. Since the regulator cannot monitor the banks day-to-day operations, however, the regulator cannot directly observe either of these important pieces of information.

To model this critical information asymmetry formally, we assume the final quality of the bank's loan portfolio (q) is the sum of: (1) exogenous, or innate, quality, q_0 ; and (2) the bank's diligence or effort, e . Innate quality is beyond the bank's control; it might be determined for example, by the state of the local economy. We model q_0 as the realization of a random variable with positive support on the interval $[\underline{q}, \bar{q}]$. The density function for this random variable is $f(q_0)$. $F(q_0)$ will denote the corresponding distribution function. Following much of the incentive literature, we assume
$$\frac{d}{dq_0} \left\{ \frac{1-F(q_0)}{f(q_0)} \right\} \leq 0.$$

The bank can raise the quality of its loan portfolio above q_0 by e units if it incurs personal cost (or disutility) $D(e)$. This cost might stem from the attention devoted to carefully screening loan applications or to securing a carefully diversified loan portfolio. We assume that the marginal cost of improving quality increases at a nondecreasing rate, i.e., $D'(e) > 0$, $D''(e) > 0$ and $D'''(e) \geq 0 \quad \forall e \geq 0$. Although the regulator knows the functional form of $D(\cdot)$ and the relation between quality and the bank's efforts ($q = q_0 + e$), the regulator cannot observe the realization of q_0 or how diligently the bank has labored to improve quality. Therefore, when it observes the delivered quality of the bank's loan portfolio (q), the regulator cannot be certain of the portion of this quality that is due to the bank's diligence and the portion that is due to exogenous factors beyond the bank's control.

The regulator is concerned with the quality of the bank's loan portfolio because higher quality levels reduce the probability of bankruptcy. Bankruptcy entails social costs that the regulator seeks to avoid. Bankruptcy occurs when the net returns from the bank's loans, L , fall short of the bank's reserves, R . There are assumed to be stochastically diminishing returns to loans made by the bank. These diminishing returns are reflected in the bank's effective loan level, $E(L)$. This variable increases at a decreasing rate with the bank's nominal loan level, i.e., $E'(L) > 0$ and $E''(L) < 0 \quad \forall L \geq 0$. The bank's gross return from L dollars of loans is $rE(L)$, where r is the realized return on effective loans. At the time loans are made, the return on these loans is a random variable. The density function for this random return is denoted $g(r|q)$, with corresponding distribution function $G(r|q)$. Higher levels of quality enhance the distribution of returns in the sense of first-order stochastic dominance. Thus, $G_q(r|q) \leq 0 \quad \forall r \in [\underline{r}, \bar{r}]$, with strict inequality for some r .

The bank's net return on loans is its gross return, $rE(L)$, less the cost of its loan funds. For simplicity, we assume the bank faces a perfectly elastic supply of loan funds at a fixed (competitive) rate that is normalized to unity. The elastic supply is due in part, to the regulator's promise to guarantee (i.e., fully insure) all deposits secured by the bank. In this setting, the bank's net return from loans L is $rE(L) - L$; and bankruptcy occurs if $rE(L) - L + R \leq 0$. Therefore, when R dollars are held in reserve, the probability of bankruptcy when L dollars are loaned out in a portfolio of quality q is $G(r^B|q)$, where

$$r^B E(L) - L + R = 0. \quad (2.1)$$

The bank's reserves, R , are what it places at risk when it makes loans. These reserves are best viewed as being raised in the equity market. For simplicity, we assume the bank faces a perfectly elastic supply of equity at price $c > 1$. This cost of equity for the bank exceeds the return it must pay to depositors because depositor's funds are insured, while the bank's reserves are not guaranteed by the government.²

If the bank avoids bankruptcy, its payoff is the sum of its net returns and reserves, less the insurance premium, P , it pays to the regulator before making any loans. If bankruptcy does occur, the bank's insurance premium is not refunded, nor does it receive (or make) any additional payments. Instead, the regulator "takes over" the failed bank. In doing so, the regulator incurs a bankruptcy cost, $[1 + b]|rE(L) - L + R|$. We assume $b > 0$, to capture the idea that the losses to the regulator from bankruptcy are proportional to but exceed the bank's realized shortfall in net revenue. The additional losses to the regulator might arise, for example, when he is forced to sell the assets of the failed bank at a discount.

To limit these losses from bankruptcy, the regulator attempts to motivate the

bank to enhance the quality its loan portfolio. The policy instruments of the regulator are: (1) the insurance premium it charges the bank, P ; (2) the amount of reserves it requires the bank to raise and keep on hand, R ; and (3) the amount of loans it allows the bank to make, L . The regulator can tie the level of each of these policy variables to the quality of the bank's loan portfolio. Thus, for example, the regulator may allow the bank to issue more loans, pay a smaller insurance premium, and/or keep fewer reserves on hand the higher is the quality of the bank's loan portfolio.

We model the regulator as presenting a menu of linked options $\{q(\cdot), P(\cdot), L(\cdot), R(\cdot)\}$ to the bank. The bank is permitted to choose one of these options after observing the environment in which it is operating, i.e., after observing the realization of innate quality, q_0 . We will denote by $\{q(q_0), P(q_0), L(q_0), R(q_0)\}$ the particular option the bank will select in equilibrium when q_0 is the realized level of innate quality. After announcing the option it has selected, the bank pays the required insurance premium to the regulator, raises and sets aside the stipulated reserves, and then proceeds to make the selected number of loans, while ensuring the associated level of quality for its loan portfolio. Some time after the loans are made, the return (r) on the loan portfolio is realized, and it becomes known whether the bank has "failed", or has avoided bankruptcy. In this simple model, the interaction between the regulator and the bank is not repeated.

In designing the menu of options he offers to the bank, the regulator seeks to maximize expected total surplus in the industry. Total surplus consists of the bank's profits plus the value of the regulator's budget surplus. The budget surplus is the sum of the total value of the insurance premium paid by the bank and the monetary losses incurred by the regulator when bankruptcy occurs. These

losses include the cost of public funds that are used to compensate depositors.

The social cost of a dollar of public funds is assumed to be $1 + \lambda (> 1)$ dollars, reflecting the social losses that occur when distortionary taxes are imposed in one sector to finance deficits in other sectors of the economy.³ Thus, the regulator's objective is to maximize the expected value of $[1 + \lambda]S + \pi$, where S represents the regulator's budget surplus and π represents the bank's profits.

To represent the regulator's problem formally, it is helpful to define these two variables more precisely. First, consider the bank's profits. Let

$$\begin{aligned} \pi(\hat{q}_0 | q_0) = & \int_{r^B}^{\bar{r}} [rE(L(\hat{q}_0)) - L(\hat{q}_0) + R(\hat{q}_0)] dG(r | q(\hat{q}_0)) \\ & - D(q(\hat{q}_0) - q_0) - c[P(\hat{q}_0) + R(\hat{q}_0)]. \end{aligned} \quad (2.2)$$

$\pi(\hat{q} | q_0)$ is the expected profit of the bank when innate quality is actually q_0 , but the bank chooses from the menu offered by the regulator the option that, in equilibrium, will be chosen by the bank when \hat{q}_0 is the realized level of innate quality. This expected profit consists of any positive monetary returns from loans less the disutility incurred in securing quality $q(\hat{q}_0)$ for the loan portfolio less the costs of the required insurance premium and reserves. We assume that funds for the insurance premium, like reserves, are obtained by the bank at marginal cost $c > 1$.

It is also helpful to define the expected equilibrium budget surplus for the regulator when q_0 is the realized level of innate quality for the bank's loan portfolio:

$$S(q_0) = cP(q_0) + [1 + b] \int_{r^B}^{r^B} [r E(L(q_0)) - L(q_0) + R(q_0)] dG(r | q(q_0)). \quad (2.3)$$

Thus, the regulator's expected surplus is the difference between the total return from the insurance premium he charges the bank⁴ and the expected social costs of bankruptcy.

This notation allows a formal statement of the regulator's problem, [RP]:

$$\text{Maximize}_{q, P, L, R} \int_{\underline{q}}^{\bar{q}} \left\{ [1 + \lambda] S(q_0) + \pi(q_0) \right\} dF(q_0)$$

subject to, $\forall q_0, \hat{q}_0, \in [\underline{q}, \bar{q}]$:

$$\pi(q_0) = \pi(q_0|q_0) \geq 0; \quad \text{and} \quad (2.4)$$

$$\pi(q_0) \geq \pi(\hat{q}_0|q_0). \quad (2.5)$$

The individual rationality constraints (2.4) ensure that for all realizations of innate quality, the bank expects to earn nonnegative (extranormal) profits. The incentive compatibility constraints (2.5) identify $\{q(q_0), P(q_0), L(q_0), R(q_0)\}$ as the option the bank will select when its innate quality level is q_0 .

3. Findings.

Before characterizing the actual solution to [RP], consider the *first-best* solution to the regulator's problem. This is the policy the regulator would implement if he shared the bank's private knowledge of its innate quality level (so that the incentive compatibility constraints (2.5) were not relevant), and if the cost of each dollar of public funds were simply one dollar.

Definition. At the first-best solution to the regulator's problem, $\forall q_0 \in [\underline{q}, \bar{q}]$

$$(i) \quad \int_{\underline{q}}^{\bar{q}} \delta (rE(L^*(q_0)) - L^*(q_0) + R^*(q_0)) dG_q(r|q^*(q_0)) - D'(q^*(q_0) - q_0) = 0; \quad (3.1)$$

$$(ii) \int_{\underline{r}}^{\bar{r}} \delta'(rE(L^*(q_0)) - L^*(q_0) + R^*(q_0)) [rE'(L^*(q_0)) - 1] dG(r|q^*(q_0)) = 0; \text{ and } (3.2)$$

$$(iii) [1 + b]G(r^{B*}|q^*(q_0)) + [1 - G(r^{B*}|q^*(q_0))] - c = 0; \quad (3.3)$$

$$\text{where } \delta(x) = \begin{cases} [1 + b]x & \text{for } x \leq 0 \\ x & \text{for } x > 0, \end{cases}$$

$$\text{and } r^{B*}E(L^*) - L^* + R^* = 0.$$

Equation (3.1) identifies the first-best quality level. Quality is increased to the point where the marginal benefits due to reduced losses in bankruptcy and increased profits in solvency equal the marginal cost to the bank of supplying additional quality. The first-best level of loans, identified in (3.2), equates the value of the marginal social losses in bankruptcy to the marginal profit gains in solvency. Similarly, the first-best level of reserves, identified by (3.3), balances the marginal expected gains from additional reserves against the marginal cost of holding additional reserves.

Proposition 1 characterizes the departures from the first-best solution that the regulator implements when he does not share the bank's private knowledge of innate quality, q_0 , and when public funds are costly to raise, i.e., when $\lambda > 0$. The departures from the first-best solution are designed to limit any gains the bank might anticipate from "understating" its innate quality level by choosing from the menu of options one that, in equilibrium, will be selected by the bank when a smaller value of q_0 is realized. The regulator is concerned with limiting the bank's "information rents" because a dollar of profit is less valuable than a dollar of budget surplus when public funds are costly to raise.

The primary deviation from the first-best solution that the regulator implements is a reduction in the final quality of the bank's loan portfolio for

all but the highest realization of innate quality. (See equation (3.4) below.) The reduced quality limits the gains to the bank from understating the actual realization of q_0 and then substituting (costless) innate quality for the (costly) effort, e , that enhances quality.⁵ Given these quality distortions, however, loan levels and reserve levels are chosen efficiently. (Compare equations (3.5) and (3.6) with equations (3.2) and (3.3), respectively.) Given the quality of the loan portfolio, the expected profits of the bank are not affected differentially according to its true innate quality level by changes in reserve and loan levels. Therefore, since distortions in reserve and loan levels (unlike quality levels) play no role in limiting the rents that the bank commands from its private knowledge of q_0 , reserve and loan levels will be determined as in the first-best calculations described above.⁶ Of course, the rents of the bank cannot be eliminated when it has private knowledge of q_0 , as reflected in (3.7).

Proposition 1. At the solution to [RP]⁷, $\forall q_0 \in [\underline{q}, \bar{q}]$.

$$(i) \quad \int_{\underline{r}}^{\bar{r}} \delta (rE(L(q_0)) - L(q_0) + R(q_0)) dG_q(r|q(q_0)) - D'(q(q_0) - q_0) = \frac{\lambda}{1+\lambda} D''(q(q_0) - q_0) \frac{1 - F(q_0)}{f(q_0)}; \quad (3.4)$$

$$(ii) \quad \int_{\underline{r}}^{\bar{r}} \delta' (rE(L(q_0)) - L(q_0) + R(q_0)) [rE'(L(q_0)) - 1] dG(r|q(q_0)) = 0; \quad (3.5)$$

$$(iii) \quad [1 + b]G(r^B|q(q_0)) + [1 - G(r^B|q(q_0))] - c = 0; \text{ and} \quad (3.6)$$

$$(iv) \quad \pi(q_0) = \int_{\underline{q}}^{q_0} D'(q(\tilde{q}) - \tilde{q}) d\tilde{q}. \quad (3.7)$$

The proof of Proposition 1 (and Proposition 2) is in the Appendix. The following corollary follows directly from equation (3.6).

Corollary 1. At the solution to [RP], the probability of bankruptcy is the same for all realizations of innate quality, i.e.,

$$G(r^B|q(q_0)) = \frac{c-1}{b} \quad \forall q_0 \in [\underline{q}, \bar{q}]. \quad (3.8)$$

The following observation is also apparent from (3.8).

Corollary 2. The equilibrium probability of bankruptcy increases with the cost of equity, c , and decreases with the social cost of bankruptcy, b , i.e.,

$$\frac{d}{dc} \left\{ G(r^B|q(q_0)) \right\} > 0 \text{ and } \frac{d}{db} \left\{ G(r^B|q(q_0)) \right\} < 0 \quad \forall q_0 \in [\underline{q}, \bar{q}] \text{ at the solution to [RP].}$$

When the cost of equity rises, it becomes more costly to avoid bankruptcy. Consequently, bankruptcy is permitted to occur with greater frequency in equilibrium. On the other hand, when the social losses from bankruptcy increase, the regulator will optimally ensure a reduced incidence of bankruptcy.

Although the equilibrium probability of bankruptcy does not vary with the induced quality level of the bank's portfolio of loans, loan and reserve levels do vary systematically with quality.

Corollary 3. The higher the quality of the bank's portfolio, the more loans the bank is permitted to make and the fewer reserves it is required to hold i.e., $\frac{dL}{dq} > 0$ and $\frac{dR}{dq} < 0$ at the solution to [RP].

Proof. From equations (2.1) and (3.8), $G\left(\frac{L-R}{E(L)}|q\right) = \frac{c-1}{b}$. Therefore, $\frac{dR}{dq} = \frac{E(L)G_q(\cdot)}{g(\cdot)} < 0$. Furthermore, $\frac{dL}{dq} = -\frac{[E(L)]^2 G_q(\cdot)}{g(\cdot)[E(L) - [L-R] E'(L)]} \stackrel{s}{=} E(L) - [L-R] E'(L) > E(L) - L E'(L) > E(L) - L \frac{E(L)}{L} = 0$. The last inequality follows the concavity of $E(\cdot)$. ■

To obtain additional insight into the optimal regulatory policy, a comparative static analysis is useful. The results of this analysis are recorded in Proposition 2. The statement of the Proposition includes a sufficient condition for the second-order conditions for [RP] to be satisfied. This condition requires a change in the quality of the bank's loan portfolio to have a small impact on the equilibrium probability of bankruptcy. This will be the case, for example, if $g(\cdot)$ is continuously differentiable everywhere and the equilibrium probability of bankruptcy is sufficiently small.⁸

Proposition 2. Suppose $G_q(r^B|q(q_0))$ is sufficiently small $\forall q_0 \in [q, \bar{q}]$. Then at the solution to [RP]:

- (i) higher levels of innate quality are associated with loan portfolios of higher quality, more loans, and greater reserves, i.e., $\frac{dq}{dq_0} > 0$, $\frac{dL}{dq_0} > 0$, and $\frac{dR}{dq_0} > 0$;
- (ii) as the cost of public funds increases, delivered quality, loan levels, and reserve levels all decline, i.e., $\frac{dq(q_0)}{d\lambda} < 0$, $\frac{dL(q_0)}{d\lambda} < 0$, and $\frac{dR(q_0)}{d\lambda} < 0$ $\forall q_0 \in [q, \bar{q}]$; and
- (iii) as the cost of equity increases, the quality of the bank's loan portfolio, loans levels, and reserve levels all decline, i.e., $\frac{dq(q_0)}{dc} < 0$, $\frac{dL(q_0)}{dc} < 0$,

$$\text{and } \frac{dR(q_0)}{dc} < 0 \quad \forall q_0 \in [q, \bar{q}).$$

Because any level of quality is less costly for the bank to provide the larger is the realization of q_0 , loan portfolios of higher quality are induced from the bank the higher is its innate quality level. A higher quality portfolio increases the expected returns from additional loans, so more loans are induced. To maintain the optimal probability of bankruptcy (recall Corollary 1), reserves are increased to counteract the larger outstanding loan balance, as reported in property (i) of Proposition 2.

The more costly it is to raise public funds for use in the banking industry, the more severely will the regulator limit the rents that accrue to the bank. The bank's profits are restricted by reducing the induced quality of the bank's loan portfolio. (Recall property (iv) of Proposition 1, which states that the bank's profits increase with q_0 more rapidly the higher the induced quality of its loan portfolio.) With a loan portfolio of lower quality in place, fewer loans will be permitted, thereby allowing a reduction in the bank's reserves, as recorded in property (ii) of Proposition 2.

An increase in the cost of equity makes it more costly to hold reserves as a means of limiting bankruptcy. Consequently, the bank is required to hold fewer reserves, and the probability of bankruptcy rises. To reduce the losses associated with bankruptcy, the bank is restricted to make fewer loans. With fewer loans being made, quality is less valuable on the margin, so a lower quality portfolio is induced from the bank, as indicated in property (iii) of Proposition 2. Notice that if an increase in portfolio quality would reduce the probability of bankruptcy by a sufficient amount (contrary to the hypothesis of Proposition 2), the optimal regulatory policy could involve an increase in

quality (and loans) when reserves are reduced due to an increase in c .

Even with the strong restriction imposed in Proposition 2, it is not possible to sign unambiguously the comparative static derivatives associated with changes in the cost of bankruptcy, b . Increases in b cause the regulator to reduce the equilibrium probability of bankruptcy. (Recall Corollary 2.) But this reduced probability can result either from fewer loans (and an associated reduction in the quality of the bank's loan portfolio) or from a higher quality loan portfolio (an associated increase in loans).

4. Future Directions.

We have developed a simple model to examine one aspect of the intricate task of designing optimal banking regulations. Our focus was on an information asymmetry between the regulator and the bank. No asymmetry was presumed concerning the realized quality of the bank's loan portfolio.

This is just one of the many features of our model that should be reexamined in future research. In practice, the quality of a bank's loan portfolio is generally multidimensional and difficult to assess with complete accuracy. It seems important to explore the changes that will arise in the optimal regulatory policy when it is costly for the regulator to monitor the quality of the bank's loan portfolio.⁹

Alternative formulations of loan quality also seem important to explore, particularly in a dynamic setting. In our model, the risk of bankruptcy is an "aggregate" risk, represented as a multiplicative shock to the effective (aggregate) loan supply of the bank. More generally, the bank might be able to select individual loans on the basis of their inherent risk (which is one plausible measure of quality). It is possible that a bank which perceives

bankruptcy to be likely based upon its current stock of loans would have increased incentive to undertake additional loans that are unduly risky. Thus, in this dynamic extension of the model, the regulator may optimally base his policy on measures of the bank's current profitability.

A complete analysis of optimal banking regulations should also account for competition among banks. When banks compete with each other for funds, a bank's success at attracting equity can often provide valuable information to the regulator about the bank's capabilities and performance.¹⁰

Finally, it would be interesting to consider other objectives for the regulator. For instance, the government might experience losses from bankruptcy that increase nonlinearly with the magnitude of the bank's revenue shortfall. Furthermore, it is conceivable that bank regulators may need to be motivated to act in the social interest, just as banks do.¹¹

FOOTNOTES

1. Giammarino, Schwartz and Zechner [1987] explain how market data can be employed to assess the quality or value of a bank's assets. For alternative approaches, in which the quality of a bank's loan portfolio is not publicly observable, see, for example, Lucas and McDonald [1987].
2. Conceivably, the regulator's policy and the bank's actions could influence the bank's cost of equity. We abstract from this possibility in our analysis.
3. Alternatively, one could view λ as a Lagrange multiplier associated with a constraint which limits the deficit the government can accrue in the banking industry.
4. For simplicity, we assume the highest return the regulator can secure on the funds it invests is precisely the return the bank forgoes.
5. Such quality distortions are common in incentive problems of this type. See, for example, Laffont and Tirole [1986].
6. Similar qualitative conclusions arise in Laffont and Tirole's [1989] model.
7. Throughout, we assume the second-order conditions for a maximum are satisfied and the solution to [RP] is interior. Using standard techniques, it is straightforward to show that the second order conditions will be satisfied if $q(\cdot)$ is an increasing function of q_0 at the identified solution. This will be the case, for example, if $G_q(r^B|q(q_0))$ is sufficiently small $\forall q_0 \in [q, \bar{q}]$, as indicated in Proposition 2.
8. In fact, the incidence of bankruptcy has been extremely rare in the U. S.

banking industry this century (see White [1990]).

9. For related models along these lines in different areas of application, see Baron and Besanko [1984], Laffont and Tirole [1989], and Lewis and Sappington [1990]. As noted in the introduction, other authors (e.g., Lucas and McDonald [1987]) have examined models of the banking industry where the quality of a bank's loan portfolio is not publicly observable.
10. A complete model that incorporated competition among banks could make endogenous the cost of equity to individual banks.
11. See Kane [1989a,b] for some interesting thoughts on this issue. Formal models of related issues include those of Demski and Sappington [1987] and Laffont and Tirole [1988].

APPENDIX

Proof of Proposition 1.

Using standard techniques (e.g., Laffont and Tirole [1986]), it is straightforward to verify that the incentive compatibility constraints (2.5) require

$$\pi'(q_0) = D'(q(q_0) - q_0) \quad \text{a.e.} \quad (\text{A1.1})$$

(A1.1), together with $q'(q_0) \geq 0 \quad \forall q_0 \in [\underline{q}, \bar{q}]$ and $\pi(\underline{q}) = 0$, are sufficient for (2.4) and (2.5) to hold.

Using (A1.1), integration by parts reveals

$$\int_{\underline{q}}^{\bar{q}} \pi(q_0) dF(q_0) = \int_{\underline{q}}^{\bar{q}} D'(q(q_0) - q_0) [1 - F(q_0)] dq_0. \quad (\text{A1.2})$$

Substituting from (2.2) and (2.3), and using (A1.2), the regulator's problem can be rewritten as

$$\begin{aligned} \text{Maximize } \int_{\underline{q}}^{\bar{q}} \left\{ \int_{\underline{r}}^{\bar{r}} \delta(rE(L(q_0)) - L(q_0) + R(q_0)) dG(r|q(q_0)) \right. \\ \left. - cR(q_0) - D(q(q_0) - q_0) - \frac{\lambda}{1+\lambda} D'(q(q_0) - q_0) \frac{1 - F(q_0)}{f(q_0)} \right\} dF(q_0) \quad (\text{A1.3}) \end{aligned}$$

Pointwise maximization of (A1.3) with respect to q , L , and R yields equations (3.4), (3.5) and (3.6), respectively. Equation (3.7) follows directly from (A1.1).

Proof of Propostion 2.

From (A1.3), define

$$\begin{aligned} Z(L, q) \equiv \int_{\underline{r}}^{\bar{r}} \delta(rE(L) - L + R) dG(r|q) \\ - cR - D(q - q_0) - \frac{\lambda}{1+\lambda} D'(q - q_0) \frac{1 - F(q_0)}{f(q_0)}. \quad (\text{A2.1}) \end{aligned}$$

R and r^B are now treated as functions of L and q, where from equation (1) and Corollary 2,

$$r^B = \frac{L - R}{E(L)}, \text{ and} \quad (\text{A2.2})$$

$$G(r^B|q) = \frac{c - 1}{b}. \quad (\text{A2.3})$$

(A2.2) and (A2.3) then provide

$$\frac{dr^B}{dL} = [E'(L)]^{-2} [E(L) - [L - R]E'(L)] > 0; \quad (\text{A2.4})$$

$$\frac{dr^B}{dq} = \frac{\partial r^B}{\partial E} \frac{dE}{dq} = - \frac{G_q(r^B|q)}{G_r(r^B|q)} > 0; \quad (\text{A2.5})$$

$$\frac{dR}{dL} = [1 - r^B E(L)] > 0; \text{ and} \quad (\text{A2.6})$$

$$\frac{dR}{dq} = E(L) \frac{G_q(r^B|q)}{G_r(r^B|q)} < 0. \quad (\text{A2.7})$$

Total differentiation of the necessary conditions for an interior maximum of (A2.1) provides

$$\begin{bmatrix} Z_{qq} & Z_{qL} \\ Z_{Lq} & Z_{LL} \end{bmatrix} \begin{bmatrix} dq \\ dL \end{bmatrix} = - \begin{bmatrix} Z_{qq_0} & Z_{qc} & Z_{q\lambda} & Z_{qb} \\ Z_{Lq_0} & Z_{Lc} & Z_{L\lambda} & Z_{Lb} \end{bmatrix} \begin{bmatrix} dq_0 \\ dc \\ d\lambda \\ db \end{bmatrix} \quad (\text{A2.8})$$

It is straightforward although tedious to verify that application of Cramer's Rule to (A2.8), using (3.4) - (3.6) and (A2.2) - (A2.7), provides the reported comparative static results.

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