How To Make Banks Reveal Their Risk: the Case of Basel II*

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Abstract

The paper studies implementation of risk based capital requirements when the bank's risk is private information and its actions are hidden. The impact of two commonly used measures, recapitalization and closure, on risk revelation is studied. Recapitalization works best as a discipline device when the cost of capital is high and the project profitability is low. The opposite is true for closure. Social costs of both regimes are compared against each other and against the risk insensitive regulation. Moreover, the optimal contract is a combination of recapitalization and a fine. Recapitalization prevents moral hazard and the fine eliminates misreporting of the risk.

Keywords: banking, risk based capital requirements, recapitalization, bank closure, Basel II, adverse selection, moral hazard.

JEL Classification: G21, G28

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1 Introduction

The New Basel Accord gives banks scope to determine their capital levels. As the capital requirements are increasing in risk, banks should adjust their capital to their risk profiles. However, banks may be tempted to understate their true risk level in order to save on capital. The reason is that the banks' risk is their private information, which supervisors are able to observe only at a cost and possibly in an imperfect manner. Recently, concerns have been raised about the effectiveness of supervision in providing prudent use of the internal risk management for computation of the risk based capital requirements (Padoa-Schioppa (2004), p. 48). Moreover, the New Accord is silent about instruments facilitating the supervisory review process making the risk based capital regulation viable (see also Kaufman (2003)). Following these concerns, the paper studies the design of supervisory schemes used to elicit information about the banks' riskiness.

In the paper I analyze implementation of risk based capital regulation a la Basel II when risk is banks' private information. Capital requirements are needed to eliminate a moral hazard problem: enough capital provides incentives for banks to monitor the loans, thus decreasing default probability.[1] The supervisor has a choice between the risk insensitive and the risk based capital requirements. The risk insensitive regulation requires a capital level corresponding to high risk. However, it imposes an excessive capital level on a low risk bank.

The alternative are the risk based capital requirements. On the one hand, they allow to reduce capital level of the low risk bank. On the other, their consequence is an adverse selection problem because only the bank knows its risk profile. This reintroduces the moral hazard issue, because the high risk bank takes too little capital in order to monitor the loans. The supervisor has to introduce a scheme making the high risk bank report its risk truthfully. This scheme consists of an inspection of the bank's risk and a penalty. The inspection is costly, imperfect, stochastic and takes place before returns are realized. When the supervisor receives a signal that the bank is undercapitalized he can choose between two kinds of penalties: recapitalization and closure. The incentive compatible scheme requires that there is an inverse relationship between the level of penalty and the inspection probability. For each of these instruments the supervisor chooses an

[1] The problem is similar to the one studied by Holmstrom and Tirole (1997).

optimal scheme minimizing welfare cost of enforcing the risk based capital regulation.

The first result states that disciplining effect of penalties depends on the levels of the cost of capital and the project profitability. High cost of capital and low project profitability make misreporting less profitable in case of recapitalization. The opposite holds for the closure. When the cost of capital is high and recapitalization is expensive for the bank, misreporting incentives are low. In case of closure this effect is not present. Hence, higher cost of capital increases willingness to cheat. When the project profitability is high, the bank looses profitable business in case of closure. This makes misreporting less attractive. In case of recapitalization this effect does not exist. Moreover, the high risk bank enjoys the increase in the project profitability to smaller extent than the low risk bank. As the capital requirements depend on loan rates, this make misreporting more desirable for the high risk bank.

The second result is that high inspection probability is necessary to provide the supervisor power to enforce the risk based capital requirements. It has to be high enough to make not only the high risk bank misreport, but also the low risk bank not to overestimate it risk in order to avoid erroneous penalty.

The third result follows from the welfare analysis. The risk based regulation with recapitalization dominates when the cost of capital is high, the one with closure, when it is intermediate, and the risk insensitive, when it is low. High cost of capital has two positive effects in case of the switch to the first type of regulation. It provides high savings on capital for the bank L and on the disciplinary measures following low incentives to misreport. This second effect is reversed in case of closure what makes it better for the intermediate cost of capital. However, when capital is cheap the low risk bank may take capital corresponding to high risk in order to avoid supervisory intervention at all. It makes the risk insensitive capital requirements less costly in welfare terms.

The fourth result states that when closure is substituted with a fine, the optimal supervisory scheme entails a combination of recapitalization and a fine. Recapitalization eliminates the moral hazard problem and the fine provides truthtelling incentives. The reason is that the fine is a tougher penalty for the bank than recapitalization.

The issue of my paper is important with regard to the question what sort of scheme should be applied to enforce the risk based capital requirements contained in the Basel II Accord. Moreover it helps to assess which factors affect the implementation cost and guarantee that the new regime fulfills its objectives. Given that the risk based capital regulation delivers lower implementation cost when the cost of capital and the inspection quality are high, the issue arises whether the switch to risk based capital requirements is a right move. The difference between the cost of capital and of deposits may be decreasing because of competition for deposits. The inspection quality can also suffer from the increased internalization of the banks making them more opaque.

The main assumptions of the model are motivated as follows. The simplified approach to modelling the underlyings of Basel II allows for easier presentation of the driving forces behind the behavior of the bank. Capital requirements eliminate the moral hazard problem, as the risk shifting has been a major justification for the capital regulation (Santos (2000) and Tirole (2001)). The inspection before the return realization is proposed in the Principle 2 of the Basel II Accord (BCBS (2004), p. 162). Assessing the bank's risk through comparison of realized returns with reported risk may not be suitable for credit risk as a loan default is a rare event (Saidenberg and Schuermann (2003)). The considered penalties for undercapitalization are the most prevalent ones in the existing supervisory intervention processes. Recapitalization is proposed in the Principle 4 of Basel II Accord (BCBS (2004), p. 165) and in the prompt corrective action (PCA) in the USA. Closure is also a penalty for undercapitalization in PCA.[2]

The paper complements existing literature on the risk based capital requirements in the following way: it is concerned with the design of optimal capital requirements and optimal supervisory schemes. Moreover, it provides the welfare analysis. There exist two papers concerned with the optimal risk based capital requirements. However, they take penalty for misreporting as given, therefore abstracting from optimal design of supervisory intervention. Prescott (2004) sets up a model analog to the costly state verification studied by Townsend (1979) and Gale and Hellwig (1985). He obtains capital requirements increasing in risk for low risk levels and flat for high ones. Blum (2007) assumes that the penalty for misreporting is not high enough to make the high risk bank report its risk truthfully. This justifies a recent proposal to increase capital levels for low risk in the Basel II Accord.

[2] See e.g. Nieto and Wall (2006) for the overview of the PCA design.

The remainder of the paper is organized as follows. In Section 2 the modelling setup is described. In Section 3 the supervisory scheme for recapitalization is derived and welfare analysis is conducted. The same is done for closure in Section 4. Social welfare comparison between these two penalties is conducted in Section 5. Section 6 summarizes and discusses the results. In Section 7 possible extensions are discussed. The Section 8 concludes the paper. Appendix consists of the proofs of the results.

2 Model

There are three agents: depositors, a bank and a supervisor.

The depositors are fully insured. The net deposit rate is r_D.[3]

The bank (also referred to as "it") is owned and managed by risk neutral shareholders protected by limited liability. Instead of investing in the bank the shareholders have an outside option yielding a net return $\delta > r_D$.[4] The assumption that $\delta > r_D$ is common in the banking literature (see e.g. Hellman, Murdock and Stiglitz (2000) and Repullo (2004)). Deposits are cheaper because they provide special services to depositors (not modelled here), like liquidity, not available by holding stocks. The bank can invest in loan portfolios of size 1 financed with capital k and deposits $1-k$.

After the loan portfolio has been financed, nature determines its type $i = H, L$. L occurs with probability π. i is a bank's private information. The gross return of portfolio i is given by:

$$\begin{cases} 1+r, \text{ with } 1-p_i \\ 1-\lambda, \text{ with } p_i, \end{cases}$$

where r is a net return, λ is a loss given default and p_i is the default rate of loans in a portfolio i. It holds that $p_H > p_L$. Thus expected gross return on the portfolio i, $1+r_i$, is

$$1 + r_i = 1 + r - (r + \lambda)p_i.$$

[3] r_D can be interpreted as a total cost of issuing one unit of depostits, incorporating deposit rate, fix deposit insurance fee and operating costs.

[4] From now on, terms bank and shareholders mean the same.

The portfolio return is deterministic. The model can be easily extended to encompass stochastic nature of the default rates of a loan portfolio.[5]

The portfolio i has a positive net present value, $1 + r_i > 1$. Instead of operating the portfolio i, the bank can earn private benefits b. In such a case all loans fail in the portfolio.[6] Moreover, private benefits are socially inefficient, i.e. $1 > b$.

The timing is as follows. First, the bank finances the portfolio. Second, nature chooses i. Third, the bank decides, whether to operate the portfolio or earn private benefits. Fourth, the returns realized.

The unregulated bank finances its portfolio only with deposits because they are cheaper than the capital. This may be the source of a moral hazard problem a la Holmstrom and Tirole (1997), when the deposit rate is too high. The unregulated bank prefers private benefits, if the profits from the portfolio i are lower than b:

$$1 + r_i - (1 + r_D) = r_i - r_D < b.$$

The left hand side is the profit of the bank financed fully with deposits when it operates i. The right hand side when it earns private benefits. In what follows the last expression is assumed to hold. Otherwise the moral hazard problem would not exist. I assume that each portfolio i is profitable under 100% capital financing:

$$r_i - \delta > 0. \tag{1}$$

The supervisor (described also as "he") maximizes social welfare and has power to regulate the bank. The bankruptcy of the bank causes social cost C. C is high enough to make the supervisor want to prevent inefficient behavior of the bank. The supervisor cannot observe whether the bank operates i, but he can observe the bank's capital level.[7] He can use this ability to eliminate the

[5] The return scheme can be seen as a reduced form of a single risk factor model by Vasicek (2002) used to compute the capital requirements in the Basel II Accord. See also Repullo and Suarez (2004) for use of this model.

[6] It is without loss of generality. One could assume that the default rate is so low that the investment has negative NPV.

[7] Of course, the supervisor will observe ex post that the bank has failed but then it is too late.

moral hazard problem by introducing capital requirements. When the shareholders' stake in the bank is high enough the bank chooses to operate the efficient project.[8] The following Lemma establishes the minimum capital requirements leading to the choice of i.

Lemma 1 *When $b > r_i + \lambda$, there exist no capital level, for which the bank prefers the portfolio i. When $b \leq r_i + \lambda$, the smallest capital requirements eliminating moral hazard are given by $k_i = \frac{b-r_i+r_D}{1+r_D}$.*

The lemma states that if the private benefits are not too high there exist capital levels eliminating moral hazard. The smallest capital requirements depend on i. It holds that $k_L < k_H$, because the portfolio H yields a lower return, for which private benefits are more desirable. From that point on the analysis is conducted for the case of existence of k_i, i.e. it holds that $r_i + \lambda \geq b$. k_i increases, when b, λ, r_D and p_i increase and r decreases. Each change in the parameters making i less attractive against b requires increase in k_i.

The supervisor maximizing social welfare would like to set the lowest possible capital requirements, because capital financing is socially costly. It is so because instead of financing alternative project yielding δ the shareholders put their wealth in the bank. k_H and k_L would have the lowest social cost but they introduce an adverse selection problem as i is bank's private information. The bank L chooses k_L and behaves efficiently.[9] The bank H saves on capital by choosing k_L and appropriates b. It does not matter what capital structure is chosen before i is realized, because there is no friction in adjusting capital structure.[10]

The supervisor has two possibilities in order to solve the adverse selection problem. The first one is to introduce insensitive capital requirements of k_H. This eliminates moral hazard, but it is burdensome for the bank L. The second possibility is to implement a supervisory scheme, which would make the capital requirements based on i viable. The supervisory scheme consists of two instruments: an inspection taking place upon the report of i by the bank and a penalty. The inspection has a cost m, is stochastic and noisy. Without loss of generality, I focus on the case in which the supervisor inspects with probability q when the bank reports L and there is no inspection

[8] See Holmstrom and Tirole (1997) and Tirole (2001) for a similar problem.
[9] If nature chooses i, the bank is called "the bank i".
[10] Alternatively, I could assume that financing takes place after realisation of i.

when the bank reports H. The noisy inspection means that the supervisor detects the true i with probability $\gamma > 1/2$ and receives a false signal with probability $1 - \gamma$.[11] When the supervisor receives a signal contrary to the bank's report, he can impose a penalty on the bank. In the next two sections I study two types of penalties: recapitalization and closure. The choice of the penalties is motivated by the fact that these are the most prevalent penalties for undercapitalization. In the extension part I study a more general version of optimal penalty design.

The timing of the moves under regulation is as follows. First, the supervisor announces and commits to the supervisory scheme consisting of the probability of inspection q and a penalty. Second, the bank finances the portfolio. Third, nature chooses $i = H, L$. Fourth, after the bank has learned i it reports it to the supervisor. Fifth, inspection is conducted, when the report is L. The supervisor punishes the bank when he receives a signal contrary to the report. Sixth, the bank decides whether to earn private benefits or not. Finally, the returns are realized.

3 Recapitalization as penalty

3.1 Optimal supervisory scheme

The social welfare, i.e. the expected value of the bank minus the expected inspection cost, under the capital requirements based on i with recapitalization as penalty is:

$$W_1 = \pi \left[r_L - r_D - (\delta - r_D)k_L - q(1-\gamma)(\delta - r_D)(\Delta k + x) - qm\right] + (1-\pi)\left(r_H - r_D - (\delta - r_D)k_H\right),$$

where $\Delta k = k_H - k_L$. The term in the square brackets is the expected value of the bank L minus the expected inspection cost. The value of the bank is diminished by the penalty with recapitalization occurring by mistake with probability $q(1-\gamma)$. The supervisor forces the bank to increase its capital level to $k_H + x$ in order to eliminate moral hazard. The second term is the value of the bank H. The capital requirements are equal to k_i. This situation can be interpreted as the case

[11] In a general case the probability of mistake would differ across i. It could be interpreted as a back testing: there exists an early noisy signal of the portfolio type, like early defaults.

when the capital requirements are set and a supervisory scheme has to be designed.[12]

The supervisor faces the following constraints. At the reporting stage the bank has to adjust its capital structure according to the realization of i. I assume that the bank starts with $k = 0$ in order to simplify the exposition. The incentive compatibility (IC) constraints guaranteeing that both types of the bank truthfully reveal their type at the reporting stage read

$$\begin{aligned} & [1-q(1-\gamma)]\left(r_L - r_D - (\delta - r_D)k_L\right) + q(1-\gamma)\left(r_L - r_D - (\delta - r_D)(k_H + x)\right) \\ \geq\ & r_L - r_D - (\delta - r_D)k_H, \end{aligned} \tag{2}$$

and

$$r_H - r_D - (\delta - r_D)k_H \geq (1 - q\gamma)\left[b - k_L(1+\delta)\right] + q\gamma\left(r_H - r_D - (\delta - r_D)(k_H + x)\right). \tag{3}$$

The first (second) constraint is for the bank L (H). The left hand side of each constraint is the expected value of the bank under the truthful report of i. In case of the bank L there is a possibility of being punished by mistake represented by the second term on the left hand side of (2). The right hand side is the value of the bank in case of misreporting. The bank L still behaves well because k_H is higher than required k_L for this bank. Misreporting by the bank H, however, is not detected with probability $1 - q\gamma$ and it can appropriate private benefits. Both constraints can be rewritten as:

$$x \leq \left(\frac{1}{q(1-\gamma)} - 1\right)\Delta k \tag{4}$$

for the bank L and

$$x \geq \left(\frac{1}{q\gamma} - 1\right)\frac{1+\delta}{\delta - r_D}\Delta k \tag{5}$$

for the bank H.

It is worthwhile to analyze the IC constraints in more detail. First, (4) and (5) imply the standard substitution between the inspection probability and the level of penalty. Second, the

[12] In a general case there is a possibility that the supervisor could find optimal to make the capital requirement for the bank L not binding. However, it turns out that this possibility is tedious to analyze and does not provide any additional insight.

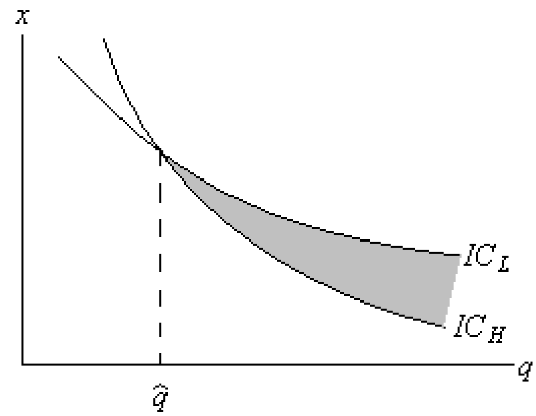

Figure 1: The incentive compatible set of $(q; x)$ is depicted with grey. IC_H and IC_L are the incentive compatibility constraints for the bank H and L.

supervisory scheme has a different effect on the truthtelling incentives of the banks. In case of the bank H the penalty has to be high enough in order to discourage misreporting. However, the bank L may be punished by mistake when it reports *truthfully*. Thus, the penalty cannot be too high in order not to destroy the truthtelling incentives. Formally, the supervisory scheme is incentive compatible for both i's, when x lies in an interval implied by (4) and (5). The bound on x from (4) has to be bigger or equal to the one from (5). This is equivalent to the following restriction on q:

$$q \geq \frac{1}{1-\gamma}\left(1 - \frac{2\gamma - 1}{\gamma}\frac{1+\delta}{1+r_D}\right) \equiv \widehat{q}. \tag{6}$$

Third, IC constraints intersect in $q = \widehat{q}$ in the $(q; x)$-diagram. The IC constraint for the bank H is steeper than for the bank L. Thus, a marginal decrease of q requires a higher increase in x to make the bank H report truthfully than for the bank L. The reason is different gain from misreporting for both types. The bank H gains more because it may obtain private benefits and save on the capital. The bank L only escapes from higher capital level imposed by mistake.

The incentive compatible set $(q; x)$ is depicted by the grey area in the figure 1.

The participation constraints can be ignored, because the IC constraints satisfy them because of (1).

The additional increase in capital requirement x is restricted from below and above. It cannot be smaller than 0 because then the capital level after penalty, $k_H + x$, would not prevent moral hazard. It cannot be higher than $1 - k_H$ either, because it is a capital structure variable and formally the financing with capital cannot be higher than 1.[13] q is naturally bounded between 0 and 1. These constraints are summarized as

$$0 \leq x \leq 1 - k_H \text{ and } 0 \leq q \leq 1. \tag{7}$$

Two conditions have to be satisfied, when the supervisor should be able to implement incentive compatible $(q; x)$: (4) and (5) have to satisfy (7) and $\widehat{q} \leq 1$[14]. This is guaranteed by the following condition:[15]

$$\gamma \geq \max \left\{ \frac{\Delta k(1+\delta) + (\delta - r_D)(1-k_H)}{(1+\delta)\Delta k}; \frac{1+\delta}{1+r_D} - \sqrt{\frac{1+\delta}{1+r_D}\left(\frac{1+\delta}{1+r_D} - 1\right)} \right\}. \tag{8}$$

(8) has an intuitive interpretation. Decreasing supervisor's ability to detect misreporting, γ, has to be compensated by increase in x or q. If γ is too low, i.e. does not satisfy (8), then the incentive compatible x and q are so high that do not satisfy either (7) or $\widehat{q} \leq 1$. It means that the supervisor lacks the power to enforce capital requirements based on i. Moreover, it can be that the supervisor is constrained by $\widehat{q} \leq 1$ in its optimal choice. In order to eliminate this possibility I assume that the first term is higher than the second. This will also make (4) redundant.

The supervisor solves the following program while choosing the optimal supervisory scheme:

$$\max_{q,x} \; W_1, \text{ s.t.: (5), (7).}$$

The solution is given by the following Lemma.

Lemma 2 *When the inspection cost is sufficiently high ($m > \overline{m}$), the optimal inspection probability is*

$$q_1^1 = \frac{1}{\gamma} \frac{\Delta k(1+\delta)}{\Delta k(1+\delta) + (\delta - r_D)(1-k_H)}$$

[13] In a more general setup the explicit upper bound on x would be ignored. This is done in the extenstion part.
[14] $\widehat{q} \leq 0$ arises only if $r_D > \delta$, what is not possible in this setup.
[15] The first term is obtained by inserting $x = 1 - k_H$ and $q = 1$ into (5) and solving them for γ. The second term is the smaller solution of the quadratic inequality implied by $\widehat{q} \leq 1$.

and $x_1^1 = 1 - k_H$*. When the inspection cost is sufficiently low* ($m \leq \overline{m} = (1-\gamma)(1+r_D)\Delta k$)*, the inspection probability is* $q_1^2 = 1$ *and*

$$x_1^i = \left(\frac{1}{\gamma} - 1\right)\frac{1+\delta}{\delta - r_D}\Delta k.$$

There arise two corner solutions as a consequence of social welfare being linear in q. While increasing q the supervisor trades off the marginal cost of inspection m against the marginal benefit of decrease in x. Hence there arises a threshold for the inspection cost $\overline{m}$ separating the two solutions. When m is higher than $\overline{m}$, the supervisor prefers to inspect as rarely as possible and set capital level to 1. When m is below $\overline{m}$, it is optimal to inspect always saving on x.

Comparative statics of the optimal solution is intuitive as every change undermining the bank H's truthtelling incentives requires increase in q and x. q_1^1 and x_1^2 increase when r_D, p_H and λ increase, as well as when γ, δ and p_L decrease. Observe that for the case $m > \overline{m}$ there are two effects influencing the comparative statics in equilibrium: (i) changes in the incentives (shift of the curve implied by (5)) and (ii) change in the upper bound of x. x_1^1 does not change when γ, δ and p_L change. It decreases, when r_D, p_H and λ increases, and increases with r. That is why the change in r has no clear cut effect on q_1^1. Accordingly, x_1^2 increases with r.

Two of these results deserve more attention. First, increase in the cost of capital lowers q_1^1 and x_1^2. It may seem counterintuitive as δ is actually the reason for misreporting and its increase would demand rather the increase in q and x. However, high δ magnifies also the impact of the penalty with higher capital requirements. This allows to lower the level of discipline measures.

Second, increase in r undermined the truthtelling incentives. It seems counterintuitive as higher r makes portfolios i more attractive against b. However, increase in r makes misreporting more profitable for the bank H. It is so because the difference between k_H and k_L increases as the bank H enjoys r less often then the bank L. This result is due to binding capital requirements.

3.2 Comparison with the risk insensitive regulation

Now I compare social welfare for the capital requirements based on i with social welfare for the insensitive capital regulation. Social welfare from the latter type of regulation is

$$W_0 = \pi \left(r_L - r_D - (\delta - r_D)k_H\right) + (1-\pi)\left(r_H - r_D - (\delta - r_D)k_H\right).$$

The difference in social welfare between these two types is

$$\Delta W_1 = W_1 - W_0 = \pi \left[(\delta - r_D)\Delta k - q(1-\gamma)(\delta - r_D)\left(\Delta k + x\right) - qm\right].$$

The first term of ΔW_1 represents savings from financing the bank L with less capital after shifting to the regulation based on i. The second term is expected social cost of punishing the bank L by mistake. The last term is the expected cost of inspection. The following Proposition establishes a dominance region for the capital requirements based on i as a constellation of γ and δ.

Proposition 1 *The capital requirements based on i dominate the insensitive regulation in welfare terms, when the inspection quality γ and the cost of capital δ are sufficiently high. The function $\gamma_1(\delta)$ separating the dominance regions is decreasing in δ.*

Higher γ increases social welfare of regulation based on i for two reasons. First, the bank L is punished less frequently. Second, the supervisor detects misreporting by the bank H with higher probability. This allows to lower q and x.

Higher δ is beneficial for the capital requirements based on i also for two reasons. First, savings for the bank L are higher. Second, higher δ magnifies the disciplining effect of penalty with higher capital requirements allowing to decrease q and x.

The function $\gamma_1(\delta)$ is defined by the equality $\Delta W_1 = 0$ and it separates dominance regions for both types of regulation. It is decreasing in the $(\delta; \gamma)$-diagram, because increases of γ and δ have a positive effect on ΔW_1.

The result from Proposition 1 is depicted in the figure 2. The line $\gamma(\overline{m})$ separates the two cases arising in Lemma 1: $(q_1^1; x_1^1)$ is relevant above this line and $(q_1^2; x_1^2)$ below. The region above of

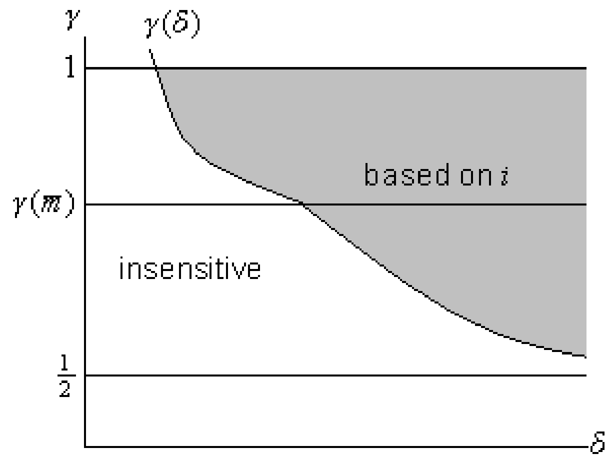

Figure 2: The dominance region of the capital requirements based on i with recapitalization is depicted in grey.

$\gamma_1(\delta)$ represents constellations of δ and γ, for which the capital requirements based on i deliver higher social welfare than the insensitive ones. Below $\gamma_1(\delta)$ the opposite holds.

The dominance region of the capital requirements based on i shrinks when m, b, λ, r_D and p_L increase, and when p_H decrease. The result is ambiguous for the change in r. Increase in m raises the expected inspection cost. Increase in b leads to lower discipline making the capital requirements based on i more expensive. Described changes in λ, p and p_H have two opposite effects on ΔW_1. On the one hand, saving on capital for the bank L is lower as Δk decreases. On the other hand, the supervisor may decrease the levels of x and q saving on implementation cost. It turns out that the first effect prevails. Decrease in r has the same qualitative effects but quantitatively their combination delivers ambiguous result. Change in r_D lower the savings and increase the levels of disciplining measure.

4 Closure as penalty

An alternative way of punishing the bank for misreporting is to close and transfer it to new shareholders. The new shareholders run the bank with the capital level of k_H preventing reoccurrence of the moral hazard problem. I assume the closure and the transfer have social cost of S. The supervisor maximizes

$$W_2 = \pi \left[r_L - r_D - (\delta - r_D)k_L - q(1-\gamma)(S + (\delta - r_D)\Delta k) - qm\right] + (1-\pi)\left(r_H - r_D - (\delta - r_D)k_H\right).$$

Again, the bank L suffers from a penalty with probability $q(1-\gamma)$. Social cost of this penalty amounts to S and the increase in the capital requirements. Because the penalty is fixed the supervisor is interested only in the optimal probability of inspection. As social welfare decreases with q the supervisor chooses the smallest incentive compatible q.

The incentive compatibility (IC) constraints read

$$\left[1 - q(1-\gamma)\right]\left(r_L - r_D - (\delta - r_D)k_L\right) \geq r_L - r_D - (\delta - r_D)k_H$$

for the bank L and

$$r_H - r_D - (\delta - r_D)k_H \geq (1 - q\gamma)\left[b - k_L(1+\delta)\right]$$

for the bank H. These constraints differ from (2) and (3) only in one detail. The bank L (H) receives nothing with probability $q(1-\gamma)$ when it reports truthfully ($q\gamma$ when it misreports).

Because the IC constraint for the bank H binds in equilibrium, the optimal probability of inspection is

$$q_2 = \frac{1}{\gamma}\frac{\Delta k(1+\delta)}{r_L - r_D - (\delta - r_D)k_L}.$$

q_2 has to be not bigger than 1 and fulfill the incentive compatibility constraint for the bank L. Both conditions are fulfilled if

$$\gamma \geq \max\left\{\frac{\Delta k(1+\delta)}{r_L - r_D - (\delta - r_D)k_L}; \frac{1+\delta}{1+2\delta - r_D}\right\}.$$ [16]

In what follows I assume that this condition is satisfied.

There are two differences in the comparative statics results for q_2 with respect to the case of

[16] The first term comes from the condition $q_2 \leq 1$. The second arises after inserting q_2 into the incentive compatibility constraint of the bank L.

recapitalization. First, higher δ makes the bank H more prone to misreport. The reason is that the bank's shareholders do not have to provide capital in case of being punished. Hence, the bank H expects lower capital expenditure when it misreports. This effect requires increase in the optimal inspection probability. Second, a similar argument holds in case of increase in r. Because the bank's shareholders lose bank's value coming from r when closed, then the increase in r makes truthtelling more desirable. Thus, the supervisor can decrease q_2.

The difference in social welfare of the capital requirements based on i with closure and insensitive capital requirements is

$$\Delta W_2 = W_2 - W_0 = \pi \left[(\delta - r_D) \Delta k \left[1 - q_2 \left(1 - \gamma \right) \right] - q_2 \left(m + S(1-\gamma) \right) \right].$$

The following Proposition summarizes the results.

Proposition 2 *The capital requirements based on i dominate the insensitive regulation in welfare terms, when the inspection quality γ is sufficiently high and the cost of capital δ is intermediate. The function $\gamma_2(\delta)$ separating the dominance regions is first decreasing and then increasing in δ.*

The increasing cost of capital has two countervailing effects on ΔW_2. The first effect is the same as for ΔW_1: higher savings on capital for the bank L. The second effect is increase in q_2 due to higher incentives to misreport. The result is a non monotonic frontier separating the dominance regions as depicted in the figure 3.

The dominance region of the capital requirements based on i shrinks when m, b, r_D, p_H and λ increase, and r decrease. The result is ambiguous for the change in p_L. For the changes in r, p_H and p_L the results are different than in the previous section. The effects of p_H and p_L are qualitatively the same, however their magnitude is different. In case of increase in r there are two effects working in the same direction. First, higher r leads to higher Δk and to higher savings from switching. Second, higher r leads to lower q_2 thereby diminishing the implementation cost.

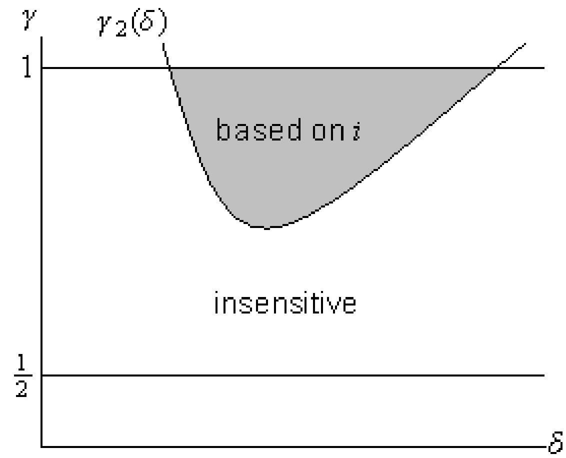

Figure 3: The dominance region of the capital requirements based on i with closure is depicted in grey.

5 Comparison of closure and recapitalization

It is worthwhile to compare social welfare for these two kinds of penalty for at least tow reasons. First, the practical question is which of the supervisory schemes is less socially costly. Second, their disciplining effect differs for two important parameters: the cost of capital and the portfolio's profitability. The difference in social welfare between them is

$$\Delta W_{21} = W_2 - W_1 = \pi \left[(q_1 - q_2) \left[m + (1-\gamma)(\delta - r_D)\Delta k \right] + (1-\gamma) \left(q_1(\delta - r_D)x - q_2 S \right) \right].$$

The inspection of the expression for ΔW_{21} delivers that closure is less socially costly when S is smaller than

$$\overline{S} \equiv \left(\frac{q_1}{q_2} - 1 \right) \frac{m}{1-\gamma} + (\delta - r_D) \left[\left(\frac{q_1}{q_2} - 1 \right) \Delta k + \frac{q_1}{q_2} x \right].$$

$\overline{S}$ consists of two relative differences between social welfare for these two penalty forms: the difference in the expected inspection cost (the first term) and in social cost of increase in capital requirements (the second term).

Increase in $\overline{S}$ means that closure becomes more favorable in welfare terms than recapitalization. Higher m increases $\overline{S}$ because closure as a harder punishment helps to save on the inspection probability. When r increases $\overline{S}$ rises too. Increasing r has negative effects on discipline in case of recapitalization and positive in case of closure. Increase in p_L and γ, as well as decrease in b, λ and p_H diminish the willingness of the bank H to misreport. However, the savings on disciplinary measures are higher in case of closure because the punishment in this case is the strongest possible, what makes $\overline{S}$ increase.

The change in the cost of capital has no such clear cut impact. δ has three effects. First, increase in δ lowers difference on expected inspection cost in $\overline{S}$. This is due to different impact on the truthtelling incentives in both cases: q_2 increases, while q_1 does not (for $m \leq \overline{m}$) or decreases (for $m > \overline{m}$). Second, increase in δ has two countervailing effects on the second term of $\overline{S}$. On the one hand, this terms increases with social cost of capital. On the other hand, it decreases as the disciplining effect works in favor of recapitalization. It turns out that increase in δ has an inverse U shape effect on this term.[17] Now the combination of the effect of δ on both terms of $\overline{S}$ gives the following. For $m > \overline{m}$ the effect on the first term is the stronger than the inverse U-shape, making $\overline{S}$ decrease with δ. However for very low m it may not be the case and the inverse U shape prevails as the overall effect, and $\overline{S}$ first increases and then decreases with δ.

6 Discussion of the results

So far I studied two penalty forms commonly used in case of undercapitalized banks. Although they can be used to make the bank reveal its risk type, their power to do so depends on the environment in which the bank operates currently. Recapitalization is less costly, when the cost of capital is high and the profitability of the bank's portfolio is low. The first result follows from the fact that high δ makes recapitalization very harmful for the bank's shareholders. By inserting their wealth into the bank they lose return on alternative valuable investment. The second result obtains because low r diminishes the difference between both capital requirements. Hence misreporting gain from saving on capital is smaller.

In case of closure both effects making recapitalization favorable for high δ and low r do not exist. When the bank is closed, it provides less capital in expectation when it misreports. Hence

[17] The formal proof can be found in the Appendix. The comparative statics are left without proof as they are simple derivatives.

higher cost of capital increases the gain from misreporting. High r in case of closure is a tough penalty for the bank, because it looses a profitable banking business.

Hence there exists trade off between the penalties. When the alternative investments deliver high and the banking business low returns the recapitalization is a better penalty. Already small levels of increase in capital levels may discipline the bank and save on social cost of implementation of the supervisory scheme. When the opposite holds, closure can be a better penalty.

Although I do not model the competition explicitly here, I can interpret the magnitude of r as a measure of competitive pressure.[18] Hence in the environments when competition is very intensive (low r) recapitalization is better. When the competition is not intense (high r) closure is better. This interpretation has an intuitive appeal. When the bank operates in a monopoly environment and enjoys high profits from its banking business, the most harmful penalty for non-compliance with regulation for it is too close it.

These results also hold when the interpretation of the cost of capital is slightly modified. δ could be interpreted as a cost of issuing equity, resulting from e.g. informational frictions.[19] It does not enter the social welfare directly, because it is only a wealth transfer. The supervisor is interested in minimizing social cost of the risk based capital requirements, amounting to the expected inspection cost in case of recapitalization augmented by the closure cost S in case of closure. This allows to extend the interpretation of the results for the informational frictions in markets.

7 Extensions

7.1 Fine as a punishment

Formally, closure equals to taking away the profits from the shareholders. This can be achieved with a fine.[20] The fine has a different disciplining effect than the capital requirements. In the

[18] Analogous interpretation is given by Morrison and White (2005).

[19] This interpretation a la Myers and Majluf (1984) is used in Repullo (2004), Repullo and Suarez (2004), and Freixas, Loranth and Morrison (2007).

[20] Other possibility is to downsize the bank. However, it is always worse than a fine, because downsizing means that the supervisor resigns on financing socially efficient project by the bank.

latter case the bank looses only the difference between the cost of capital and deposits, $\delta - r_D$. In the former case the bank looses the fine and its opportunity cost δ. However, the fine cannot substitute fully recapitalization as a penalty. The reason is that fine does not eliminate the moral hazard problem. After having being punished the bank has to pay the fine anyhow, independently of the choice whether it operates the portfolio i or takes b.[21] Hence the supervisor has to increase the capital level to at least k_H from the reported k_L, when he obtains the signal contrary to the report.

The supervisor solves the following program:

$$\max_{(q,x,f)} \pi \left[r_L - r_D - (\delta - r_D)k_L - q(1-\gamma)((\delta - r_D)x + \delta f)) - qm \right] + (1-\pi)\left(r_H - r_D - (\delta - r_D)k_H \right)$$

s.t.:

$$r_H - r_D - (k_H + x)(\delta - r_D) - f(1+\delta) \geq b - (k_L + x)(1+\delta) - f(1+\delta)$$

$$r_H - r_D - (\delta - r_D)k_H \geq (1 - q\gamma)\left[b - k_L(1+\delta) \right] + q\gamma \left[r_H - r_D - (k_L + x)(\delta - r_D) - f(1+\delta) \right].$$

$$r_H - r_D - (k_L + x)(\delta - r_D) - f(1+\delta) \geq 0$$

$$0 \leq q \leq 1.$$

The first constraint is the incentive constraint eliminating the moral hazard. The second constraint is the truthtelling constraint of the bank H.[22] The third constraint is the participation constraint of the bank H. And the last set bounds x and q due to their nature. The program delivers the following optimal solution:

Lemma *If $m \geq (1-\gamma)r_D\Delta k$, then $q = \frac{1}{\gamma}\frac{\Delta k(1+\delta)}{r_L - r_D - (\delta - r_D)k_L}$, $x = \Delta k$ and f comes from the binding participation constraint. If $m < (1-\gamma)r_D\Delta k$, then $q = 1$, $x = \Delta k$ and f comes the from the binding truthtelling constraint.*

As the fine is a tougher penalty for the bank, the supervisor orders recapitalization only to the level preventing the moral hazard. The truthtelling incentives will be brought about with the fine.

[21] Imposing the fine after the returns are realized does not change anything.

[22] For simplicity I neglect the same constraint for the bank L and assume that it is satisfied.

7.2 Constrained supervisor

There exists a possibility that the supervisor is free to choose q, but not the level of punishment. In reality the level of punishment can be set exogenously and the supervisor may only then choose q. If this is the case and in addition the institution setting the level of punishment is not sharing the supervisor's point of view, the punishment may be too small to be incentive compatible for the bank H, even for $q = 1$.

Blum (2007) suggests as a solution an increase in the capital requirement for the bank L. It decreases gains from misreporting and may restore the incentive compatibility. However in my setup this measure decreases social gains of the capital requirements based on i undermining their objective of lowering burden of the bank L.

7.3 No commitment case

Assumption that the supervisor is able to commit ex ante to a certain probability of inspection may seem sometimes unrealistic. Moreover, ex ante commitment scheme is ex post inefficient the bank H behaves well in equilibrium.

Lack of commitment to q requires that the supervisor chooses it after the bank's report. Hence this requires to find an equilibrium in mixed strategies in inspection and misreporting of the bank H. The no commitment case is tedious to analyze as there are cases in which mixed strategies do not arise.[23] However the qualitative results on the impact of δ and r on truthtelling incentives remain unchanged. Observe also that in my setup no commitment always delivers lower social welfare than commitment. The reason is that, in addition to the punishment of the bank L, the bank H goes sometimes bankrupt as it cheats with a positive probability.

7.4 Risk shifting

Consider the following change in the model. At stage 1 the bank finances the project with k of capital and $1-k$ of uninsured deposits. At stage 2 the bank faces the following decision: it chooses between two levels of risk. After the risk has been chosen the bank decides whether to monitor

[23] The note with the full analysis of this case can be obtained on request.

the chosen project or not (stage 3). Monitoring is costly and involves the cost of b.[24] Each project $i = H, L$ when monitored has the following return scheme

$$\begin{cases} R_i, \text{ with } p_i \\ 0, \text{ with } 1 - p_i, \end{cases}$$

where $p_H < p_L$, $R_H > R_L$ and $p_H < p_L$, $p_H R_H - b > p_L R_L - b > 1$. When the project i is not monitored, its returns are

$$\begin{cases} R_i, \text{ with } p_i - \Delta_i \\ 0, \text{ with } 1 - p_i + \Delta_i, \end{cases}$$

and it satisfies $p_i R_i - b > 1 > (p_i - \Delta_i) R_i$ and assume that $(p_H - \Delta_H) R_H > (p_L - \Delta_L) R_L$.[25]

Observe that unregulated bank (financed only with deposits) paying R_D to its depositors prefers always the project H, because it yields higher returns and lower expected repayment to depositors. In order to guarantee the existence of moral hazard problem the unregulated bank has to have incentives not to monitor H, i.e. it has to hold that

$$b > \Delta_H (R_H - R_D).$$

Then the minimal capital level eliminating the moral hazard is

$$k_H = 1 - \frac{\Delta_H R_H - b}{\Delta_H R_D}.$$

k_H is between 0 and 1. Risk insensitive capital requirement k_H makes the bank choose H and monitor it.

Such capital requirement may not be a desirable situation. First, it can be that the bank is financially constrained and cannot provide k_H. Second, as in the Basel I Accord, when too high risk insensitive capital requirement may encourage the banks to disregard the less risky projects. In both situations there could be a scope for the risk based capital requirements.

[24] Instead of monitoring one could consider an inefficient risk shifting. But I stick to the basic model to keep it comparable.

[25] The modelling of the situation is similar to the setup of Freixas and Parigi (2007).

While considering taking the project L the bank would have to provide at least

$$k_L = 1 - \frac{\Delta_L R_L - b}{\Delta_L R_D}$$

of capital in order to monitor it. Now observe two things. Firstly, $k_L < k_H$ holds only if:

$$R_L - \frac{b}{\Delta_L} > R_H - \frac{b}{\Delta_H},$$

i.e. the monitoring in the case of L is relatively more profitable than in case of H. Secondly, when the bank takes k_L it is not yet guaranteed that it will take L! Due to taken assumptions it holds that

$$(p_H - \Delta_H)(R_H - (1-k_L)R_D) > p_H(R_H - (1-k_L)R_D) - e > p_L(R_L - (1-k_L)R_D) - b.$$[26]

It means that if the bank takes k_L it chooses H and behaves inefficiently without a supervisory scheme.

Hence there is a need for a supervisory scheme guaranteeing that the bank with k_L takes L. After the bank chosen the risk and before it has decided whether to monitor or not the supervisor makes the bank report the risk (or simply observes the capital level) and conducts an inspection like in the basic setup. The incentive compatibility constraint making the bank with k_L choose L looks as follows:

$$\begin{aligned} & [1-q(1-\gamma)]\, p_L(R - R_D(1-k_L)) + q(1-\gamma)\left[p_L(R - R_D(1-k_H-x)) - (k_H + x - k_L)E - fE\right] - b \\ \geq \;& (1-q\gamma)(p_H - \Delta_H)(R_H - R_D(1-k_L)) + q\gamma\left[p_H(R - R_D(1-k_H-x)) - (k_H + x - k_L)E - fE - b\right]. \end{aligned}$$

The LHS is the payoff of the bank when it reports and takes L. With probability $q(1-\gamma)$ the supervisor makes mistake in its risk assessment. The bank L is punished by recapitalization from k_L to $k_H + x$ and a fine f. The RHS is the payoff of the bank when it takes H and reports L. With probability $q\gamma$ the supervisor gets the true signal. Increase in the capital requirements provides the incentives to monitor once H has been taken. In this setup there is only one incentive compatibility constraint. Its purpose is to eliminate risk shifting incentives when k_L is taken. However, it is nature similar to the truthtelling constraints in the previous setup.

8 Conclusions

The paper has been concerned with the design of the supervisory schemes under the risk based capital requirements a la Basel II. The supervisor punishes the bank with recapitalization or closure, when the signal received during inspection is different from the bank's risk report. Changes in two important policy variables, the cost of capital and the project profitability, impact the incentives to misreport differently depending on the penalty type. This leads to different conclusions about the effectiveness of supervisory schemes.

High cost of capital and low project profitability increase incentives for truthful risk reporting under recapitalization. This may surprising as they may be reasons for which the bank understates its riskiness to save on capital. Higher cost of capital magnifies the impact of recapitalization as penalty. Lower project profitability decreases the difference between the capital requirements. In case of closure the effects are reversed. Closure makes the bank loose its profits but it does not require providing costly capital. These assertions imply the welfare analysis results.

After studying the existing mechanisms I turn to an optimal contract design. This yields the result that the optimal supervisory scheme entails recapitalization and closure. Recapitalization is used only to prevent the moral hazard. The fine provides the truthtelling incentives.

The results of my paper highlight the importance of the supervisory scheme design in the discussion about the cost of implementation of the Basel II Accord. The implementation cost amounts not only to the cost of compliance with the regulation rules borne by banks. It is also about the cost of supervisory schemes making the risk based capital requirements viable. Conditions under which this latter cost can be diminished seem to be demanding. First, it requires high inspection quality, which cannot be taken for granted as the banks' opaqueness increases (Furfine (2001)). Moreover, each scheme is optimal under different conditions, hence the supervisor has to be aware under what circumstances the banks operate in order to chooses the right scheme. The results about the impact of the cost of capital are robust to changes in the modelling scheme.

When it comes to the project profitability the results hinge on the fact that the chosen capital requirements are binding. However, one important feature has been left out for the further research: separation of ownership and control. The introduction of managerial incentives is left for the further research.

Appendix

Proof of Lemma 1. The bank monitors if the following holds

$$1 + r_i - (1 - k_i)(1 + r_D) \geq \max\{b; b + 1 - \lambda - (1 - k_i)(1 + r_D)\}. \tag{9}$$

The term on the left (right) hand side is the value from efficient (inefficient) investment in the bank. The right hand side contains two possible expressions for the bank's value because it is possible that the capital requirements are high enough to cover the losses from the loan default. (9) can be rewritten as

$$\min\left\{k_i; \frac{\lambda + r_D}{1 + r_D}\right\} \geq \frac{b - r_i + r_D}{1 + r_D}.$$

Observe that if $r_i + \lambda < b$, then the last expression cannot be satisfied. Thus, the first statement of the Lemma is obtained. Then it is easy to see that if $r_i + \lambda \geq b$, then the minimum capital level that eliminates the moral hazard problem is given by $\frac{b - r_i + r_D}{1 + r_D}$. ■

Proof of Lemma 2. The supervisor maximizes social welfare what is equivalent to minimization of implementation cost. Thus maximization of W_1 boils down to the following

$$\min_{x,q} q\left[(1 - \gamma)(\delta - r_D)(\Delta k + x) + m\right],$$

subject to (5) and (7). Observe that the objective function is increasing in q and x hence (5) binds at the optimum. After plugging (5) into the objective function it becomes

$$\frac{1 - \gamma}{\gamma}\Delta k(1 + \delta) + q\left[m - (1 - \gamma)(1 + r_D)\Delta k\right].$$

Then if $m > (1-\gamma)(1+r_D)\Delta k = \overline{m}$ the last equation is increasing in q. Hence the supervisor wants to set the smallest possible q, i.e. q_1^1. If $m \leq \overline{m}$, the supervisor wants to have the highest probability of inspection, i.e. $q = 1$, and the smallest level of x. ■

Proof of Proposition 1. When $m > \overline{m}$ plugging q_1^1 into ΔW_1 and rearranging $\Delta W_1 \geq 0$ is equivalent to

$$\gamma \geq \frac{(1+\delta)\left((\delta - r_D)(1-k_L) + m\right)}{(\delta - r_D)[\Delta k + (1+2\delta)(1-k_L) - r_D(1-k_H)]}.$$

The term on the right hand side builds the upper part of the function separating the dominance regions, $\gamma_1(\delta)$. Deriving this term with respect to δ delivers

$$-\frac{\left[\begin{array}{c} m\left[(1+r_D)(\Delta k + (1-k_L)(1+2\delta) - r_D(1-k_H) + 2(1+\delta)(\delta - r_D)(1-k_L)\right] + \\ (\delta - r_D)^2(1+r_D)(1-k_H)(1-k_L) \end{array}\right]}{\left[(\delta - r_D)[\Delta k + (1+2\delta)(1-k_L) - r_D(1-k_H)]\right]^2} < 0.$$

This proofs that the first part of $\gamma_1(\delta)$ is decreasing in the $(\gamma;\delta)$-diagram.

If $m \leq \overline{m}$, the condition for $\Delta W_1 \geq 0$ is

$$\delta \geq \frac{(1-\gamma)^2}{2\gamma - 1} + \frac{\gamma}{2\gamma - 1}\frac{m}{\Delta k} + \frac{\gamma^2}{2\gamma - 1} r_D.$$

The last expression defines implicitly the lower part of $\gamma_1(\delta)$. The derivative of the right hand side term of the last expression with respect to γ is negative:

$$\frac{\partial \delta}{\partial \gamma} = -\frac{6\,(1-\gamma)\,\gamma}{(2\gamma - 1)^2} - \frac{m}{\Delta k}\frac{2}{(2\gamma - 1)^2} - \frac{2\gamma(1-\gamma)}{(2\gamma - 1)^2} r_D < 0.$$

Because the right hand side term is invertible for positive δ and $\gamma \in [0.5; 1]$, the lower part of $\gamma_1(\delta)$ is also decreasing. Rearranging the expressions for both parts of the function $\gamma(\delta)$ shows that they both intersect exactly at the line $\gamma(\overline{m})$. ■

Comparative statics results from Section 3.2. The derivatives are only for the case of the upper part of $\gamma_1(\delta)$ as the lower case can be dealt by inspection. The derivatives are as follows:

$$\frac{\partial\gamma_1(\delta)}{\partial b} = \frac{(1+\delta)\,(1+r_D)\,((1+2\delta-r_D)m-(\delta-r_D)(p_H-p_L)(r+\lambda))}{(\delta-r_D)\,[[\Delta k+(1+2\delta)(1-k_L)-r_D(1-k_H)]]^2} > 0.$$

The sign obtains because

$$\begin{aligned} (1+2\delta-r_D)m-(\delta-r_D)(p_H-p_L)(r+\lambda) &> \\ (p_H-p_L)(r+\lambda)\,[(1+2\delta-r_D)(1-\gamma)(1+r_D)-(\delta-r_D)] &> 0. \end{aligned}$$

The first part of this inequality holds due to $m > \overline{m}$ and the second from the fact that $1-\gamma > \frac{\delta-r_D}{1+2\delta-r_D}$ which is due to $\widehat{q} > 0$. The other derivatives read

$$\frac{\partial\gamma_1(\delta)}{\partial p_L} = \frac{(1+d)(r+\blacksquare)(2m(1+\delta)+\delta(1-k_H))}{\delta[\Delta k+(1+2\delta)(1-k_h)]^2} > 0,$$

$$\frac{\partial\gamma_1(\delta)}{\partial p_H} = -\frac{(1+d)(r+\blacksquare)(m+d(1-k_L))}{\delta[\Delta k+(1+2\delta)(1-k_h)]^2} < 0,$$

$$\frac{\partial\gamma_1(\delta)}{\partial r} = \frac{(1+d)(-m(1+p_H+2\delta(1-p_L)-2p_L)-\delta(p_H-p_L)(1-b-c-\blacksquare))}{\delta[\Delta k+(1+2\delta)(1-k_L)]^2},$$

$$\frac{\partial\gamma_1(\delta)}{\partial\lambda} = \frac{(1+\delta)(-m(p_H-p_L)+mp_L(1+2\delta)-\delta\,(p_H-p_L)\,(1-b-c+r))}{\delta[\Delta k+(1+2\delta)(1-k_L)]^2}.$$

$\blacksquare$

Proof of Proposition 2. After inserting q_2 in ΔW_2 the condition for $\Delta W_2 \geq 0$ is as follows:

$$\gamma \geq \frac{[m+S+\Delta k(\delta-r_D)]\,(1+\delta)}{(r_L-r_D-(\delta-r_D)k_L)(\delta-r_D)+[S+\Delta k(\delta-r_D)]\,(1+\delta)} \equiv \gamma_2(\delta).$$

The derivative of $\gamma_2(\delta)$ has ambiguous sign and reads

$$\frac{\partial \gamma_2(\delta)}{\partial \delta} = \left[(r_L - r_D - (\delta - r_D)k_L)(\delta - r_D) + \left[S + \Delta k(\delta - r_D)\right](1+\delta)\right]^{-2} \left[\begin{array}{c} \delta^2 \left[\Delta k(r_L - r_D + k_L(1+r_D)) + k_L(m+S) - m\Delta k\right] \\ -\delta \left[r_D \Delta k(r_L - r_D + k_L(1+r_D)) - k_L(m+S) + m\Delta k\right] \\ \Delta k(m - r_D^2(r_L - r_D + k_L(1+r_D))) + \\ (m+S)\left[-r_D^2(1-k_L) + r_L - r_D(1-2k_L - r_L)\right] \end{array}\right].$$

The nominator of this derivative defines a second order polynom of δ. Observe that for reasonably small m the term at δ^2 is positive, meaning that the defined parabola has its arms turned upside. Moreover, after some algebra for $\delta = r_D$ the nominator is equal to $-(1+r_D)\left[(m+S)(r_L - r_D) + m\Delta k(1+r_D)\right]$, which is always negative within the model. This means that for $\delta > r_D$ $\frac{\partial \gamma_2(\delta)}{\partial \delta}$ has at first negative sign and then positive. This is gives the U-shape of $\gamma_2(\delta)$. ■

Comparative statics results from Section 4. For $m > \overline{m}$ the derivative of $\overline{S}(\delta)$ with respect to δ is quite a complicated object. However it can be shown that the derivative has the following properties. Its nominator is a quadratic function of δ with negative term at δ^2. Its maximum is a linear and decreasing function in parameter m and evaluated at $m = \overline{m}$ it is 0. Then because for any $m > \overline{m}$ the maximum is negative the sign of the nominator is always negative, hence $\overline{S}(\delta)$ is decreasing in δ. For $m \in (0; \overline{m}]$ the matters are more complicated. Again one can study the sign of the nominator of the derivative. It turns out that its maximum (-1) is lower than $\delta = r_D$. Hence one can look at the sing of the derivative at this point. It turns out that for m close to $\overline{m}$ it is negative, so $\overline{S}(\delta)$ is decreasing in δ. However, at $m = 0$ the nominator has the value of

$$\begin{aligned} & -\Delta k(1+r_D)\left[k_H(1+r_D) - \gamma(r_L - r_D + k_L(1+r_D))\right] \\ = \; & -\Delta k(1+r_D)\left[k_H(1+r_D) - \gamma b\right] \\ = \; & -\Delta k(1+r_D)\left[b(1-\gamma) - (r_H - r_D)\right] \end{aligned}$$

which sign is not clear cut. This means that $\overline{S}(\delta)$ may have an inverted U-shape. ■

Proof of Lemma 3. The program can be rewritten

$$\min_{(q,x,f)} qm + q(1-\gamma)((\delta - r_D)x + \delta f)$$

s.t.:

$$IC_{MH}\text{: } x \geq \Delta k$$

$$IC_{TT}\text{: } q\gamma\left[(\delta - r_D)x + (1+\delta)f + (1+r_D)\Delta k\right] \geq \Delta k(1+\delta)$$

$$IR\text{: } (\delta - r_D)x + (1+\delta)f \leq r_H - r_D - (\delta - r_D)k_L$$

$$0 \leq q \leq 1$$

The truthtelling constraint is binding. Then I can solve it for f and plug it into objective function and the participation constraint. Then the program gets:

$$\min_{(q,x)} q\left[m + (1-\gamma)\left(\frac{\delta - r_D}{1+\delta}x - \frac{\delta(1+r_D)}{1+\delta}\Delta k\right)\right] + \frac{\delta \Delta k(1-\gamma)}{\gamma}$$

s.t.:

$$x \geq \Delta k$$

$$\frac{1}{\gamma}\frac{\Delta k(1+\delta)}{r_L - r_D - (\delta - r_D)k_L} \leq q \leq 1$$

The solution must be such that q and the term in the square brackets are the smallest. There are two solutions, because the term in the square brackets can be negative or positive for $x = \Delta k$. If it positive then q has to be the smallest and the solution is $x = \Delta k$, $q = \frac{1}{\gamma}\frac{\Delta k(1+\delta)}{r_L - r_D - (\delta - r_D)k_L}$ and f such that IC for truthtelling holds with equality for these x and q. If it negative then $q = 1$, $x = \Delta k$ and f such that IC for truthtelling holds with equality for these x and q. The first one occurs when $m \geq (1-\gamma)r_D\Delta k$. Both solution have the property that x is hold at its minimum (just to eliminate moral hazard) and the whole punishment goes through the fine. ■

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