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Abstract

Prompt Corrective Action (PCA) prescribes prompt and deterministic termination of banks with insufficient levels of book-value capital. This paper investigates whether reliance on book-value capital is a good policy choice and if PCA is an optimal regulatory approach. I use a variant of DeMarzo and Fishman's (2004) dynamic model of entrepreneurial finance to model interactions between a banker and a regulator. Under hidden choice of risk, private information on returns, limited commitment by the banker and costly liquidation, I first characterize the optimal incentive-feasible allocation, and then demonstrate that the optimal allocation is implementable through the combination of a risk-based deposit insurance premium and a book-value capital regulation with prompt and stochastic termination/bailout rather than deterministic termination with no bailout as in PCA. I also show that partial termnation can be used instead of stochastic termination.

Dynamic prudential regulation: Is Prompt Corrective Action optimal?

Ilhyock Shim

May 19, 2006

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1 Introduction

Over the past three decades, a number of economies across the globe have experienced banking crises which have entailed large economics costs. In the aftermath of those episodes, bank regulators have often been blamed for not having taken immediate actions or having been too generous with problem banks. As a consequence, many countries have made changes to the design of banking regulation and the deposit insurance scheme. For example, the US Congress enacted in 1991 the Federal Deposit Insurance Corporation Improvement Act which introduced Prompt Corrective Action (henceforth, PCA) and risk-based deposit insurance premiums. Japan also introduced PCA in 1998.

PCA is a commitment device designed to minimize the risk of regulatory forbearance in the face of problems with a bank. It prescribes specific actions, with little discretion for the prudential authorities, when the capitalization of a bank falls below certain thresholds.

Many economists also have pointed out possible problems with using book-value capital in banking regulation, and proposed using market-value capital instead. But in most countries, bank capital regulation is based on book-value capital, and bank regulators have adopted market-value accounting only in a limited manner.[1]

In this paper, I ask if the use of book-value capital in banking regulation is a good policy and if PCA is an optimal bank capital regulation. To answer if it is optimal to close a bank promptly or delay closure, we need a dynamic model. Also, when we design banking regulation, it is natural to consider the long-term relationship between a regulator and a bank. Thus, I build a dynamic model of prudential regulation with the following assumptions. First, in every period a banker makes hidden choice of risk, has private information on returns and chooses either to give up the bank and enjoy the outside option or to stay in business. Second, a regulator can liquidate the bank, although liquidation is socially costly. Under

[1]Recently, the Financial Accounting Standard Board has tried to introduce fair-value accounting rule in banking regulation, but practitioners seem more cautious about adopting it. For example, see Board of Governors of the Federal Reserve System (2005) and Basel Committee on Banking Supervision (2004).

these assumptions, I show that it is optimal to base bank capital regulation on book-value capital, but that it is optimal for the regulator to use stochastic termination/bailout rather than deterministic termination with no bailout.

My model is a variant of DeMarzo-Fishman's (2004) dynamic model of entrepreneurial finance. I first construct a simple dynamic economy with a risk-neutral bank owner/manager (henceforth, the banker) and a risk-neutral regulator (henceforth, the regulator). The regulator is both the provider of deposit insurance and the setter of bank capital regulation, with an objective to minimize the potential tax burden related to the closure of banks.[2] The banker is assumed to have access to a long-term risky investment opportunity, whose return distributions are known a priori to the regulator. The regulator proposes a long-term regulation to the banker including an initial level of required capital. Once the banker accepts the regulation, the regulator charters the bank, and the banker takes deposits and invests them into the project, which generates independent returns over time. The return realized at time t finances the banker's consumption and the deposit insurance premium.

There are three contracting frictions in every period. First, the banker can exert costly and hidden effort to affect the distribution of returns.[3] Second, the banker can observe the realized return, but the regulator cannot, so the regulator relies on the banker's report on the return. Third, the banker can terminate the bank in favor of an outside option. The regulator can also terminate the bank, and receive the proceeds from liquidation, which I

[2] In this paper, the regulator acts in the interest of the taxpayers, so that there is no principal-agent problem between the regulator and the taxpayers. Moreover, as modeled by Akerlof and Romer (1993), a full guarantee of the bank's deposits is equivalent to the depositors holding goverment debt and the government lending money directly to the bank. Dewatripont and Tirole (1994) propose that the goal of banking regulation should be to provide active representation for small depositors who are unwilling or unable to monitor the bank. I need to emphasize that small depositors protected by the deposit insurance scheme are also taxpayers, who are responsible for the losses in a deposit insurance fund. In this sense, the deposit insurer as a regulator is the representative of small depositors/taxpayers.

[3] DeMarzo and Fishman (2004) only considered the case where the high effort is socially optimal in the first-best sense. In this paper, I also consider the other case where the low effort is first-best optimal.

assume to be lower than the project's value under no contracting frictions.

In this setup, I first characterize the optimal allocation between the banker and the regulator. Optimality prescribes action conditional on the relationship between the banker's continuation utility and the two thresholds: a higher dividend threshold and a lower termination threshold. The optimal allocation comprises (i) positive consumption by the banker and no termination by the regulator when the banker's continuation utility is above the dividend threshold, (ii) zero consumption and positive probability of termination when the continuation utility is below the termination threshold, and (iii) zero consumption and no termination when it is between the two thresholds. When the high effort is first-best optimal, the optimal allocation under the contracting frictions prescribes the high effort whatever value the banker's continuation utility takes. This is a standard result. A more interesting result of this paper is that, when the low effort is first-best optimal, under certain circumstances, the optimal allocation prescribes the low effort when the continuation utility is high, but the high effort when it is low.

Then, I demonstrate that the optimal allocation can be implemented by the combination of a risk-based deposit insurance premium and a book-value capital regulation with stochastic termination/bailout of an undercapitalized bank.[4] This contrasts with the deterministic termination with no bailout as is currently stipulated by PCA. In this implementation, the level of book-value capital takes the role of a record-keeping device, as the banker's continuation utility does.

The intuition behind this result is simple. Under deterministic termination, a bank is terminated with certainty when its capital level falls below a threshold. Then, the banker's continuation utility is zero. In this case, it is hard for the regulator to provide the banker

[4] In this paper, the risk-based deposit insurance premium is not determined according to the fair-pricing rule, but works like a tax imposed on the bank by the regulator in order to induce the desired level of effort and truthtelling by the bank. FDIC (2001) shows that the current US risk-based deposit insurance premium is not indeed fairly priced. Isaac (2000) also points out that the FDIC in practice collects premiums from banks and thrifts, and turns them over the Treasury.

with any incentive to act in her interest. However, under stochastic termination, with some probability, a bank is bailed out. The banker has a positive continuation utility although termination is possible. In this case, there is more scope for better alignment of the banker's incentive with the regulator's.

I also show that stochastic termination and partial termination are equivalent when partial termination implies scaling down the bank's assets and liabilities and thus all the corresponding cash flows. Thus, if a regulator cannot credibly implement stochastic termination, partial termination can be a more realistic alternative. Comparative statics show that, when the liquidation value of a bank decreases or the riskiness of a bank increases in terms of mean-preserving spreads, the initial required capital increases, but the risk-based deposit insurance premium schedule does not change. These results bear on policymakers when they design risk-based capital regulation and deposit insurance premium.

This paper lies at the intersection of the literatures on banking regulation and dynamic contracts. There are few dynamic models analyzing the welfare properties of PCA. Sleet and Smith (2000) consider the appropriate design of a safety net in a two-period model when a government runs deposit insurance and a discount window. They show that, for some economies, the case for closing troubled banks "promptly" is not strong in the presence of social costs of closure. Kocherlakota and Shim (2005) construct a dynamic model economy in which entrepreneurs pledge collateral to borrow from banks. Assuming that collateral value has aggregate risk over time, that entrepreneurs can abscond with the project but lose the collateral, and that depositors can withdraw deposits in any period, they show that the optimal banking regulation exhibits forbearance if the ex-ante probability of collapse in collateral value is sufficiently low, but exhibits PCA if it is sufficiently high.

The results of this paper are similar to those of Dewatripont and Tirole (1994), who analyze the effect of banks' governance structures on managerial moral hazard in a static setting. They first show that the optimal managerial incentive scheme threatens the manager with frequent external interference in the case of poor performance, and rewards him with a passive attitude for good performance. They then show that this policy can be implemented by both equity and debt with voluntary recapitalization. I show in this paper that, under broader informational frictions, both deposit insurance premiums and bank capital regulation can implement the dynamic optimal allocation between the regulator and a banker.

The paper proceeds as follows. Section 2 presents the model and solves for the optimal allocations. Section 3 shows how the optimal allocations can be implemented by the regulatory instruments. Section 4 shows the equivalence of stochastic and partial termination rules. Section 5 provides the results of comparative statics. Section 6 compares the current practice with the model-implied regulation, and discusses on regulatory forbearance. Finally, Section 7 concludes.

2 Model

2.1 Environment

There are two infinitely-lived agents: the banker and the regulator. Time is discrete, and time periods are indexed by $t = 0, 1, \cdots, T$. I assume infinite horizon, i.e., $T = \infty$.[5] There is a single perishable consumption good in every period. The banker is risk neutral, has limited wealth, and values a consumption stream $\{c_t\}_{t=1}^{\infty}$ as $E\left[\sum_{t=1}^{\infty} \beta^t c_t\right]$. The regulator is risk neutral, has unlimited wealth, and values a consumption stream $\{x_t\}_{t=1}^{\infty}$ as $E\left[\sum_{t=1}^{\infty} \delta^t x_t\right]$, where $\beta \leq \delta$.

At the beginning of period 0, the banker has an initial endowment of ε_0 units of the consumption good. If he transfers K_0 units of the good to the regulator, he can set up a bank, receive D units of deposits from the regulator and invest them in a long-term risky technology. I normalize D to 1, and assume $\varepsilon_0 < 1$ so that the banker needs to take deposits to invest.

[5] The main results don't change when I assume a finite horizon.

In each period $t \geq 1$, the banker receives a stochastic endowment from this investment, which is unobservable to the regulator. That is, Y_t units of the good are available at period t, where Y_t is continuous with an interval $S \equiv \left[\underline{y}, \overline{y}\right]$ as support, where $\underline{y} \leq 0$ and $\overline{y} > 0$. I assume that endowments $\{Y_t\}$ are independent over time. The number of units of the endowment good realized in period t are denoted y_t. The probability density of Y_t, f^e, is determined by the level of effort e at period t. I assume that the choice of e_t only affects the current Y_t, so that I preserve intertemporal independence of Y_t. For simplicity, I assume that the banker can either exert high effort ($e = 1$) or low effort ($e = 0$). Exerting effort implies a disutility for the banker that is equal to $\psi(e) \geq 0$ units of the good, with the normalization $\psi(e) = \psi e$, i.e., $\psi(0) = 0$ and $\psi(1) = \psi > 0$. Specifically, in every period the banker can exert costly monitoring effort ψ to the firm or the project he made loans to. I assume that the banker's utility function is separable between consumption and effort.

Costly effort is assumed to reduce risk in the sense of first-order stochastic dominance (FOSD). In particular, if $e_t = 0$, the distribution function of Y_t becomes $F(y_t \mid e_t = 0) \equiv F^0(y_t)$, and if $e_t = 1$, it becomes $F(y_t \mid e_t = 1) \equiv F^1(y_t)$. Note that, from the definition of FOSD, $F^0(y) > F^1(y)$ holds for all $y \in [\underline{y}, \overline{y}]$.[6] That is, the higher the level of effort, the lower the probability of receiving an endowment lower than a given threshold. I denote the mean of y_t corresponding to F^0 and F^1 by μ_0 and μ_1, respectively, where $\mu_0 < \mu_1$ from FOSD. I assume that $f^0(y_t)$ and $f^1(y_t)$ are known to both the banker and the regulator at the beginning of the initial period.

The bank can be terminated in any period τ. Upon termination, the banker gets utility $J_\tau \geq 0$ from an outside option such as remaining unemployed, and the regulator receives $L_\tau \geq 0$ units of the good from the liquidation of the long-term investment. Note that I need to assume $\beta \min\{\mu_1 - \psi,\, \mu_0\}/(1-\beta) > J$ to guarantee participation of the banker. I also assume $L < \max\{\mu_1 - \psi,\, \mu_0\}/(1-\beta)$, which implies socially costly liquidation. For

[6] I can generalize the choice of effort by letting the banker choose $e \in [0, \overline{e}]$, but need to assume $\partial F(x \mid e_t)/\partial e_t > 0$, $\forall x, \forall e_t$.

simplicity, I assume that $J_\tau = J = 0$ and $L_\tau = L \geq 0$, $\forall \tau$. There are no future interactions between the banker and the regulator after τ. Thus, $Y_t = 0$ for all $t > \tau$.

I denote the history of realized endowments through period t by $y^t \equiv \{y_1, ..., y_t\}$. Let λ_t indicate whether the bank was terminated in period $t-1$ ($\lambda_t = 1$) or not ($\lambda_t = 0$) for all $t \geq 1$. Thus, $\lambda_t = 0$ means that the bank is active at the beginning of period t. Then, I define the set of all possible histories of endowments and terminations up to t by $H_t \equiv S^t \times \{0,1\}^t$ and a history $h_t = (y^t, \lambda^t) \in H_t$. Also, I denote by Λ_t the set of histories of termination/survival where termination occurred at or before $t-1$.

An *allocation* of resources in this environment is a stochastic vector process specifying consumption and termination $(c, x, p) = \{c_t, x_t, p_t\}_{t=1}^{\infty}$, where $c_t : H_t \to \mathbb{R}_+$,[7] $x_t : H_t \to \mathbb{R}$, and $p_t : H_t \to [0,1]$.[8] Here, $c_t(h_t)$ is consumption by the banker after history h_t, $x_t(h_t)$ is consumption by the regulator after history h_t, and $p_t(h_t)$ is the probability of termination by the regulator after history h_t. Note that I allow stochastic termination by the regulator.

An allocation (c, x, p) is *feasible* if, $\forall (t, h_t)$,

$$\begin{aligned}
&c_t(h_t) + x_t(h_t) \leq y_t, \\
&c_t(h_t) \geq 0, \\
&c_t(h_t) = x_t(h_t) = 0 \qquad \text{if } \lambda^t \in \Lambda_t.
\end{aligned}$$

Beyond the physical restrictions, there are three additional contracting frictions in this environment. The first friction is that at the beginning of period t, the banker chooses e_t, but the regulator cannot observe it. The second is that in the middle of period t, the banker observes the realization of y_t, but the regulator does not. The third is that at the end of

[7] I assume that the banker has limited liability, so that $c_t \geq 0$, but the regulator does not. Note that allowing for no negative consumption is equivalent to setting the utility of a negative consumption to $-\infty$, as in Cole and Kocherlakota (2001).

[8] As will be shown in Proposition 1, under some circumstances, we also need to consider a randomization $\widehat{p_t}$ over inducing high effort or low effort.

period t, after the banker receives his consumption c_t, the banker can opt for termination.[9]

Given any allocation, the banker can engage in three forms of deviations from the prescription of that allocation. First, the banker can choose the effort level different from the level the regulator wants. Second, the banker can pretend to have a lower endowment realization than the actual in period t, that is, he can report $\widehat{y}_t < y_t$. I assume that the banker cannot borrow, sell assets nor issue new equity, so that the report on endowments entails physical payment by the banker. Third, the banker can choose to terminate the bank depending on the realized history. He may terminate the bank, even if the regulator does not. Also, in the initial period, the banker can choose to set up a bank or not.

A *strategy* $(e, \widehat{y}, q) = \{e_t, \widehat{y}_t, q_t\}_{t=1}^{\infty}$ is a stochastic vector process specifying the banker's effort, report and termination decisions, where $e_t : H_t \to \{0, 1\}$, $\widehat{y}_t : H_t \to S'(y_t) \equiv [\underline{y}, y_t]$, and $q_t : H_t \to \{0, 1\}$. Here, $e_t(h_t)$ is the banker's decision to exert high effort ($e_t = 1$) or low effort ($e_t = 0$) after history h_t, $\widehat{y}_t(h_t)$ is the banker's report on the realized value of Y_t after history h_t, and $q_t(h_t)$ is the banker's decision to terminate or quit the bank ($q_t = 1$) or not ($q_t = 0$) after history h_t. Note that $q_t(h_t) = 1$ if $q_{t-1}(h_{t-1}) = 1$. Let Σ be the set of all possible strategies.

I define $W(c, x, p; e, \widehat{y}, q)$ as the ex-ante continuation utility of the banker at the end of period 0, given an allocation (c, x, p) and a strategy $(e, \widehat{y}, q)$, that is,

$$W(c, x, p; e, \widehat{y}, q) = E_0^e \left[\sum_{t=1}^{\infty} \beta^t (Y_t - \widehat{y}_t + c_t - \psi e_t) \right].$$

The above expectation E_0^e is associated with the distribution of $\{Y_t\}_{t=1}^{\infty}$ determined by e, and the termination time τ of the bank depends on p and q. Note that once the bank is terminated, the banker has no reason to exert high effort and the regulator will not induce high effort from then on.

[9] Since the banker can terminate the bank anytime during the period t and $c_t \geq 0$, he can wait until the regulator decides to terminate or not. Thus, I can without loss of generality assume that the banker terminates the bank right after the regulator's termination decision.

Let $(e^*, \widehat{y}^*, q^*) = \{e^*_t, \widehat{y}^*_t, q^*_t\}_{t=1}^{\infty}$ be the optimal-effort/truth-telling/no-quitting strategy, in which $\widehat{y}^*_t(h_t) = y_t$ and $q^*_t(h_t) = 0$ for all $(t,\, h_t)$, and $e^*_t(h_t) = 0$ if $\lambda^t \in \Lambda_t$, and $e^*_t(h_t) = 0$ or 1 otherwise.[10] An allocation (c, x, p) is *incentive-compatible* if

$$W(c, x, p; e^*, \widehat{y}^*, q^*) = \max_{(e,\widehat{y},q)\in\Sigma} W(c, x, p; e, \widehat{y}, q).$$

An allocation that is both incentive-compatible and feasible is *incentive-feasible*. Incentive-feasible allocations should induce optimal effort, truthtelling and no quitting by the banker in every period. The intuition for constructing incentive feasible allocations is as follows. First, in order to induce the optimal level of effort, a feasible allocation should possess a strong incentive, i.e., reward a good outcome and punish a bad outcome sufficiently. Second, using the revelation principle, I show that it is weakly optimal for the banker to tell the truth, given a feasible allocation. Finally, the banker terminates the bank in period t, if the the banker's continuation utility derived from the allocation at the end of period t is less than the value of the outside option J_t. Thus, in order to induce no quitting, p_t should be determined such that the regulator terminates the bank with probability one if the banker is supposed to terminate the bank.

Given an incentive-feasible allocation (c, x, p), the ex-ante continuation utility of the regulator at the end of period 0 is given by

$$V(c, x, p) = E_0^{e^*}\left[\sum_{t=1}^{\infty}\delta^t x_t + \delta^\tau L\right],$$

and the ex-ante continuation utility of the banker at the end of period 0 is given by

$$W(c, x, p) = E_0^{e^*}\left[\sum_{t=1}^{\infty}\beta^t (c_t - \psi e^*_t)\right],$$

[10] Note that depending on the parameter values and history, the regulator wants to induce either high effort or low effort. Proposition 1 shows exactly how e^*_t is determined.

where τ is the time the bank is terminated, which is determined by p, and the expectation $E_0^{e^*}$ is associated with $f^{e^*}(y_t)$ for all t.

The above environment is different from that of DeMarzo and Fishman (2004, henceforth, D-F) in the following aspect. D-F modeled two sources of contracting frictions: private information and limited commitment by the agent. I model explicitly the banker's hidden choice of costly effort and the corresponding risk in addition to the two frictions. Thus, the banker's continuation utility in my model is net of costs related to the optimal level of effort every period before termination, while the agent's continuation payoff in D-F is not associated with costs of effort. Moreover, as will be clear at the end of the next subsection, D-F considered both the case with a monopolistic agent and competing investors, and the case with a monopolistic investor and competing agents. This paper focuses on the situation where the regulator has the exclusive right to charter a banker from a competitive pool, which is natural in the banking regulation setting. In particular, I emphasize the role of initial capital requirement derived from the maximization problem of the regulator.

2.2 Optimal allocations

The goal of this subsection is to characterize the optimal incentive-feasible allocations in the above environment. Let (c, x, p) be an incentive-feasible allocation, and Γ^* be the set of all incentive-feasible allocations. From this set, I set up the following ex-ante pseudo planner's problem and derive the continuation function at the end of period 0:

$$V(w) = \max_{(c,x,p)\in\Gamma^*} V(c, x, p) \qquad s.t.\ W(c, x, p) = w \tag{1}$$

An *optimal* allocation (c^*, x^*, p^*) is a solution of (1). The continuation function $V(\cdot)$ derived from (1) gives the highest possible continuation utility attainable by the regulator, given a continuation utility w for the banker. If I choose any optimal allocation, I fix a value of w, which specifies a point on the continuation function. Note that V may have an increasing region.

From feasibility, I get $x_t = y_t - c_t$. Thus, I redefine a feasible allocation as a pair (c, p). Now I rewrite the ex-ante pseudo planner's problem as the following sequence problem, $PP(w)$.

$PP(w)$: Ex-ante pseudo planner's problem

$$
\begin{aligned}
V(w) = \quad & \max_{\{c_t, p_t\}_{t=1}^{\infty}} E_0^{e^*} \left[\sum_{t=1}^{\infty} \delta^t (Y_t - c_t) + \delta^\tau L \right] \\
& s.t. \;\; E_0^{e^*} \left[\sum_{t=1}^{\infty} \beta^t (c_t - \psi e_t^*) \right] = w, \\
& \quad (e^*, \widehat{y}^*, q^*) \in \arg\max_{(e, \widehat{y}, q)} E_0^{e} \left[\sum_{t=1}^{\infty} \beta^t (Y_t - \widehat{y}_t + c_t - \psi e_t) \right], \\
& \quad c_t \geq 0, \quad \forall t, h_t, \\
& \quad 0 \leq p_t \leq 1, \quad \forall t, h_t, \\
& \quad Y_t = 0, \quad \forall t > \tau, \\
& \quad \widehat{y}_t \leq y_t, \quad \forall t, h_t.
\end{aligned}
$$

Next, I define a recursive formulation for the pseudo planner's problem in the following functional equation, FE.

FE: Static pseudo planner's problem

$$
\begin{aligned}
v(w_0) = \quad & \max_{(c(\cdot), p(\cdot), w(\cdot))} \delta E^{e^*} \left[y - c(y) + [1 - p(y)] \, v\left(w(y)\right) + p(y) L \right] \\
& s.t. \;\; \beta E^{e^*} \left[c(y) - \psi e^* + [1 - p(y)] \, w(y) \right] = w_0, \\
& \quad E^{e^*} [c(y) - \psi e^* + [1 - p(y)] \, w(y)] \geq E^{-e^*} [c(y) - \psi(1 - e^*) + [1 - p(y)] \, w(y)], \\
& \quad c(y) + [1 - p(y)] \, w(y) \geq y - y' + c(y') + \left[1 - p(y')\right] \left[1 - q'\right] w(y'), \\
& \qquad \qquad \forall y' \leq y, \; \forall q', \\
& \quad c(y) \geq 0, \quad \forall y, \\
& \quad 0 \leq p(y) \leq 1, \quad \forall y, \\
& \quad w_{glb} \leq w(y) \leq w_{lub},
\end{aligned}
$$

where E^{e^*} is the expectation with respect to f^{e^*}, E^{-e^*} is the expectation with respect to the complement of f^{e^*} (i.e., if $e^* = 1$, $-e^* = 0$, and vice versa), w_{glb} is the greatest lower bound and w_{lub} is the least upper bound for the value of $w(y)$. In this problem, $w_{glb} = J = 0$, and $w_{lub} = \beta \max(\mu_1 - \psi, \mu_0)/(1 - \beta)$.

Let (c^*, p^*) be an optimal allocation that satisfies the ex-ante pseudo planner's problem, $PP(w)$. Define $w_t(h_t, \lambda_{t+1})$ as the banker's continuation utility at the end of period t after history $h_t = (y^t, \lambda^t)$ and λ_{t+1}, where

$$w_t(h_t, \lambda_{t+1}) \equiv W_t(c^*, p^*; h_t, \lambda_{t+1}) = E_t^{e^*}\left[\sum_{s=t+1}^{\infty} \beta^{s-t}(c_s^*(h_s \mid h_t, \lambda_{t+1}) - \psi e_s^*)\right].$$

Appendix I shows that I can solve the ex-ante pseudo planner's problem in a recursive manner. Instead of having the regulator choose (c_t, p_t) as a function of the history $h_t = (y^t, \lambda^t)$, I let the regulator choose the allocation (c_t, p_t) as a function of w_{t-1} and y_t, and choose the law of motion for w_t which specifies the continuation utility of the banker from period $t + 1$ on as a function of $(w_{t-1}, y_t, \lambda_{t+1})$.

Before I fully characterize the continuation function $v_t(\cdot)$ at the end of period t recursively, it is useful to consider the first-best continuation function. In the first-best setting, there is no informational asymmetry, no hidden effort, and no termination by the banker. Now, it is optimal for the regulator to maximize the expected value of the sum of the discounted endowment flows and the discounted liquidation value, and then provide the banker's continuation utility with a transfer payment. The first-best total continuation utility at the end of period t is calculated as $V_t^{fb} \equiv \max\limits_{\tau^{fb} > t} E_t^e \left[\sum_{s=t+1}^{\infty} \delta^{s-t}(Y_s - \psi e_t) + \delta^{\tau^{fb}-t} L\right]$, where τ^{fb} is the time the bank is terminated by the regulator in the first-best sense. Then the first-best continuation function at the end of period t is given by $v_t^{fb}(w) = V_t^{fb} - w$. In period τ^{fb} when the bank is terminated, $V_{\tau^{fb}}^{fb} = 0$, so $v_{\tau^{fb}}^{fb}(w) = -w$. Note that once the bank is to be terminated, the agency problem disappears and the continuation function becomes linear.

From the assumption that liquidation is socially costly, $V_t^{fb} > L$ holds, so that the first-best termination never happens and I can set $\tau^{fb} = \infty$. Thus, if $(\mu_1 - \mu_0) > \psi$,

$V_t^{fb} = \delta(\mu_1 - \psi)/(1-\delta)$, and if $(\mu_1 - \mu_0) < \psi$, $V_t^{fb} = \delta\mu_0/(1-\delta)$. In general, the level of effort in each period in the first-best case is set to maximize $E[y_t \mid e_t] - \psi(e_t)$.

However, once I consider incentive compatibility and the possibility of stochastic termination by the regulator, the continuation function $v_t(\cdot)$ is generally concave as shown below. The intuition is that, as the banker's continuation utility becomes small, it is hard for the regulator to punish the banker by lowering the banker's continuation utility. Thus, as the banker's continuation utility decreases, the regulator's continuation utility increases at a slower rate or even decreases. If the continuation function is not fully concave, I can use randomization or a convex hull to concavify the continuation function.[11]

Suppose there is a concave continuation function $v_t(\cdot)$, which gives the maximum value of the regulator's continuation utility, given a value of the banker's continuation utility. Now I introduce consumption by the banker and termination by the regulator. I know that if this can expand the continuation function, that is, increase the regulator's continuation utility further given the same value of the banker's continuation utility, then the regulator will use these tools. In particular, if providing one unit of consumption right now to the banker is cheaper than promising one unit of continuation utility, then the regulator will use consumption instead of continuation utility to reward the banker. Also, if termination of a bank gives a higher continuation utility to the regulator given a value of the banker's continuation utility, the regulator will terminate the bank.

Given $v_t(\cdot)$, let $\overline{w}_t = \inf\{w \mid v_t'(w) \leq -1\}$ be the minimum value of the banker's continuation utility above which the regulator has to sacrifice one or more units of the consumption to provide one more unit of the continuation utility to the banker. Denote by $\underline{w}_t$ the banker's continuation utility at the point of tangency of the line constituting the convex hull of the continuation function $v_t(\cdot)$ and the utility from termination $(0, L)$. Let l_t be the slope of this tangent line. Also, denote by $\overline{w}_t^1$ the threshold of the banker's continuation utility, below

[11] Note that since the continuation function is a Pareto frontier, given the possibility of randomization, it has to be concave. Also, as is shown in the next paragraph, the optimal allocation is well defined, once the continuation function is concave and thus its first-order derivative is weakly decreasing.

which the regulator wants to induce high effort with probability one, and by $\underline{w}_t^0$ the threshold, above which the regulator wants to induce low effort with probability one. When f^{e^*} and L are given, $\{\overline{w}_t,\ \underline{w}_t,\ \overline{w}_t^1,\ \underline{w}_t^0\}$ is determined endogenously. Proposition 1 shows that $v_t(\cdot)$ is generally concave, and that the optimal allocation (c_t^*, p_t^*) is a function of the state variable w_{t-1} and y_t. The proofs of the propositions and the corollary are in Appendix II.

Proposition 1 *(1) If $v_t(\cdot)$ is concave, $v_{t-1}(\cdot)$ is also concave for all t.*

(2) When $\mu_1 - \mu_0 \geq \psi$, the regulator always induces high effort, and thus the optimal allocation and the law of motion for w_t are as follows:

$$c_t^*(w_{t-1}, y_t) = \max\ \{y_t - [\mu_1 - (\beta^{-1}w_{t-1} + \psi - \overline{w}_t)],\ 0\},$$
$$p_t^*(w_{t-1}, y_t) = \max\ \{0,\ \min\ \{1,\ [\underline{w}_t - (\beta^{-1}w_{t-1} + \psi + y_t - \mu_1)]/\underline{w}_t\}\},$$
$$w_t = \min\ \{\overline{w}_t,\ \max\ \{\underline{w}_t,\ \beta^{-1}w_{t-1} + \psi + y_t - \mu_1\}\}.$$

(3) When $\mu_1 - \mu_0 < \psi$, the optimal allocation and the law of motion for w_t are as follows depending on the value of w_{t-1}:

(i) When $w_{t-1} \leq \overline{w}_{t-1}^1$, the regulator induces high effort. Thus,

$$c_t^*(w_{t-1}, y_t) = \tfrac{\psi}{\mu_1-\mu_0} \max\ \{y_t - [\mu_1 - \tfrac{\mu_1-\mu_0}{\psi}(\beta^{-1}w_{t-1} + \psi - \overline{w}_t')],\ 0\},$$
$$p_t^*(w_{t-1}, y_t) = \max\ \{0,\ \min\ \{1,\ [\underline{w}_t' - (\beta^{-1}w_{t-1} + \psi + \tfrac{\psi}{\mu_1-\mu_0}(y_t - \mu_1))]/\underline{w}_t'\}\},$$
$$w_t = \min\ \{\overline{w}_t',\ \max\ \{\underline{w}_t',\ \beta^{-1}w_{t-1} + \psi + \tfrac{\psi}{\mu_1-\mu_0}(y_t - \mu_1)\}\}.$$

(ii) When $w_{t-1} \geq \underline{w}_{t-1}^0$, the regulator induces low effort. Thus,

$$c_t^*(w_{t-1}, y_t) = \max\ \{y_t - [\mu_0 - (\beta^{-1}w_{t-1} - \overline{w}_t')],\ 0\},$$
$$p_t^*(w_{t-1}, y_t) = \max\ \{0,\ \min\ \{1,\ [\underline{w}_t' - (\beta^{-1}w_{t-1} + y_t - \mu_0)]/\underline{w}_t'\}\},$$
$$w_t = \min\ \{\overline{w}_t',\ \max\ \{\underline{w}_t',\ \beta^{-1}w_{t-1} + y_t - \mu_0\}\}.$$

(iii) when $\overline{w}_{t-1}^1 < w_{t-1} < \underline{w}_{t-1}^0$,

with probability $\widehat{p}_t^* = (\underline{w}_{t-1}^0 - w_{t-1})/(\underline{w}_{t-1}^0 - \overline{w}_{t-1}^1)$, the regulator induces high effort, and

$$c_t^*(w_{t-1}, y_t) = \tfrac{\psi}{\mu_1-\mu_0} \max\ \{y_t - [\mu_1 - \tfrac{\mu_1-\mu_0}{\psi}(\beta^{-1}\overline{w}_{t-1}^1 - \overline{w}_t')],\ 0\},$$
$$p_t^*(w_{t-1}, y_t) = \max\ \{0,\ \min\ \{1,\ [\underline{w}_t' - (\beta^{-1}\overline{w}_{t-1}^1 + \psi + \tfrac{\psi}{\mu_1-\mu_0}(y_t - \mu_1))]/\underline{w}_t'\}\},$$
$$w_t = \min\ \{\overline{w}_t',\ \max\ \{\underline{w}_t',\ \beta^{-1}\overline{w}_{t-1}^1 + \psi + \tfrac{\psi}{\mu_1-\mu_0}(y_t - \mu_1)\}\};$$

with probability $1-\widehat{p}_t^*$*, the regulator induces low effort, and*

$$c_t^*(w_{t-1}, y_t) = \max\ \{y_t - [\mu_0 - (\beta^{-1}\underline{w}_{t-1}^0 - \overline{w}_t')],\ 0\},$$

$$p_t^*(w_{t-1}, y_t) = \max\ \{0,\ \min\ \{1,\ [\underline{w}_t' - (\beta^{-1}\underline{w}_{t-1}^0 + y_t - \mu_0)]/\underline{w}_t'\}\},$$

$$w_t = \min\ \{\overline{w}_t',\ \max\ \{\underline{w}_t',\ \beta^{-1}\underline{w}_{t-1}^0 + y_t - \mu_0\}\}.$$

The proof of Proposition 1 basically follows the structure of D-F. The difference is that the hidden choice of risk by the banker is explicitly added in the agency stage. The first result of Proposition 1 comes from the multi-stage structure of D-F. D-F also show that, in models with binary (high/low) hidden effort choice, if the first-best level of effort is the high effort, then the optimal contract takes the same form as that without hidden effort, which corresponds to the second result of Proposition 1. Thus, the additional incentive compatibility constraint associated with hidden effort does not bind. By contrast, the third result shows that, when $\mu_1 - \mu_0 < \psi$, the optimal allocation may differ depending on the level of the banker's continuation utility: when the continuation utility is relatively high, the regulator wants to induce low effort; when the continuation utility is relatively low, the regulator wants to induce high effort.

The intuition is as follows. Note that when the continuation utility is relatively high, the continuation function is almost linear. Thus, the benefit from reducing the variance of endowments by inducing high effort is small, and saving the cost of high effort $\mu_0 - (\mu_1 - \psi)$ is more important. However, when the continuation utility is relatively low, the continuation function is highly concave. Now the benefit from reducing the variance by inducing high effort is larger than that from saving the cost of high effort. Appendix III provides an example for this case.

To understand how the optimal allocation is determined, I define the intermediate state variable w_t^c as follows: $w_t^c \equiv (\beta^{-1}w_{t-1} + \psi + y_t - \mu_1)$ when $\mu_1 - \mu_0 \geq \psi$; $w_t^c \equiv (\beta^{-1}w_{t-1} + \psi + \frac{\psi}{\mu_1-\mu_0}(y_t - \mu_1))$ when $\mu_1 - \mu_0 < \psi$ and $w_{t-1} \leq \overline{w}_t^1$; $w_t^c \equiv (\beta^{-1}w_{t-1} + y_t - \mu_0)$ when $\mu_1 - \mu_0 < \psi$ and $w_{t-1} \geq \underline{w}_t^0$. Note that w_t^c is important in determining the optimal allocation: $c_t(w_t^c) = \max(w_t^c - \overline{w}_t,\ 0)$ and $p_t(w_t^c) = \frac{\underline{w}_t - w_t^c}{\underline{w}_t}$. If w_t^c is high enough, the banker can enjoy positive consumption, while if w_t^c is low, the regulator terminates the bank stochastically. Figures 1 and 2 show how the optimal allocation is determined as a function of w_t^c given $v_t^c(\cdot)$.

Finally, I consider the optimal choice of the initial condition w_0 and the initial capital requirement K_0. The initial period has two stages. In the first stage, as a monopolistic regulator, the regulator proposes a dynamic allocation to a potential banker from a competitive pool.[12] The regulator offers the required level of the initial transfer from the banker to the regulator, K_0. If the initial wealth of a potential banker ε_0 is less than K_0, he cannot accept the offer. If ε_0 is equal to or greater than the required initial transfer K_0, he will accept the offer, as long as he breaks even, i.e. $K_0 \leq w_0^c$, where w_0^c is the continuation utility of the banker right before consumption by the banker in period 0, and $w_0^c = c_0 + w_0$. Using backwards induction, I can derive the continuation function right before consumption in period 0, $v_0^c(\cdot)$.

In the second stage of period 0, the banker consumes c_0 and the regulator exercises stochastic termination p_0, as she does in period $t \geq 1$. As is clear in the proof of Corollary 1, consumption c_0 by the banker in period 0 is essentially a partial refund of initial transfer K_0, and thus I can ignore the second stage of the initial period. Corollary 1 shows that in the above setup, the optimal initial choice of K_0 and w_0 coincides with $\overline{w}_0$.

Corollary 1 $K_0^* = w_0^* = \overline{w}_0$.

[12] I can instead assume that the regulator is fully "captured" by the potential banker. Then, the potential banker will not pay any initial transfer and will choose w_0^c at a high level, so the regualtor just breaks even. I don't use this assumption here, since I assume that the regulator tries to minimize the tax burden in the initial period. I revisit this issue in the discussion section.

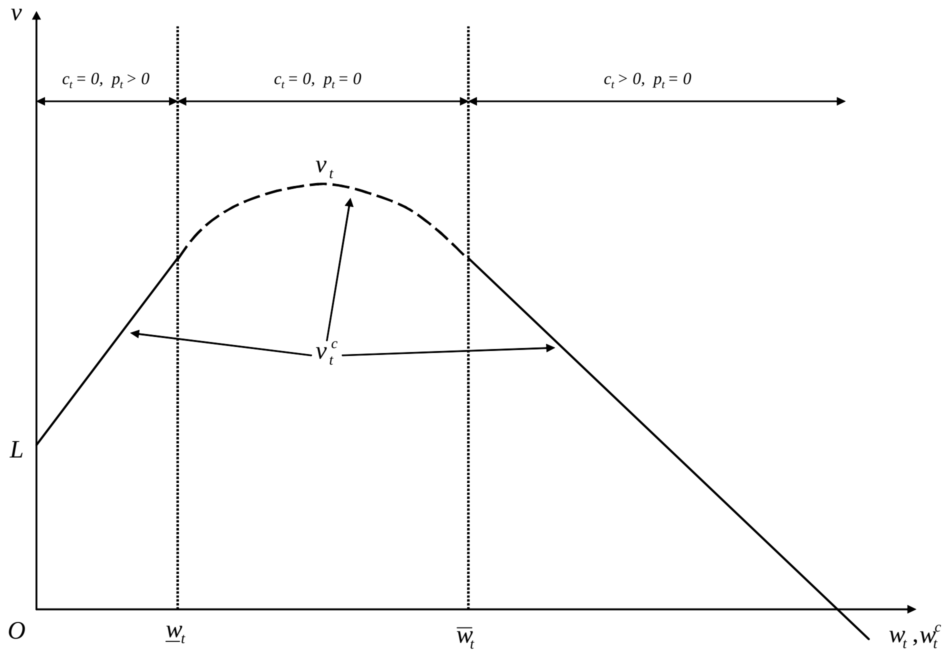

Figure 1: Determination of the Optimal Allocation when $\mu_1 - \mu_0 > \psi$.

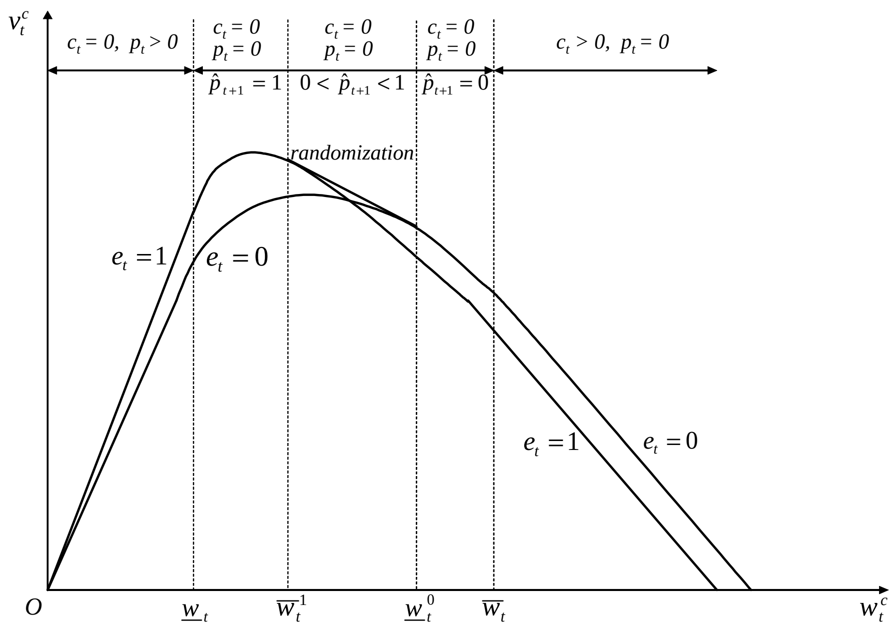

Figure 2: Determination of the Optimal Allocation when $\mu_1 - \mu_0 < \psi$.

3 Implementation

In section 3, I considered the optimal allocation in a dynamic setting. Now I describe a corresponding dynamic game between the banker and the regulator, and show that the dynamic game's outcome coincides with the ex-ante optimal allocation, when I choose an appropriate combination of a book-value capital regulation and a risk-based deposit insurance premium.

$\{Y_t\}_{t=1}^{\infty}$ represents independent cash flows or profit streams from the assets the banker holds. The regulator and the banker have the same risk-neutral preferences as before. The banker can exert a hidden effort, which affects the distribution of Y_t as before. The banker can observe the realization of Y_t, but the regulator cannot, so that the regulator should rely on the banker's report of y_t, which I again denote as $\widehat{y}_t$. Also, the banker can quit any time in period t. Denote λ^t as the termination history up to $t-1$.

The timing of the game is as follows. At the beginning of the initial period, both the regulator and a potential banker know the distributions of Y_t, f^0 and f^1. The regulator makes the banker a take-it-or-leave-it offer, which consists of the initial required capital K_0, deposit insurance premium $\widetilde{x}_t$, dividend payments d_t, and termination probability p_t at every period, where $(\widetilde{x}_t, d_t, p_t)$ are functions of the level of a book-value capital. If the banker accepts the offer, he pays K_0 and opens the bank. Otherwise, he rejects the offer and enjoys the outside option 0. Once a bank is set up, the banker receives 1 unit of deposits which is invested in the project. At the end of period 0, the level of book-value capital is K_0. I assume that only deposits are invested; the initial capital is kept as cash to meet possible future liquidity needs, such as paying deposit insurance premium. Alternatively, I can assume that the capital grows at a risk-free rate r_f. But as long as $r_f < 1/\beta - 1$, the qualitative results don't change.

The banker starts period 1 with capital K_0. First, the banker chooses e_1, and y_1 is realized, and then the banker reports $\widehat{y}_1$ to the regulator or equivalently adds $\widehat{y}_1$ to K_0. Based on K_0 and $\widehat{y}_1$, the regulator charges $\widetilde{x}_1$. The new level of capital becomes $K_1^d = K_0 + \widehat{y}_1 - \widetilde{x}_1$. Then, the regulator allows dividend d_1 and the banker consumes $y_1 - \widehat{y}_1 + d_1$. The dividend is publicly observable consumption, while $(y_t - \widehat{y}_t)$ is private consumption. If $K_1^d < \underline{K}_1$, the regulator either terminates the bank with probability p_1, or bailout the bank by recapitalizing it, so that $K_1 = \underline{K}_1$ with probability $1-p_1$. If the bank is not terminated by the regulator, the banker can choose either to terminate the bank ($q_1 = 1$) or continue into period 2 ($q_1 = 0$). If the bank is not terminated by the end of period 1, the same game repeats in period 2. Figure 3 summarizes the timing of events of the game.

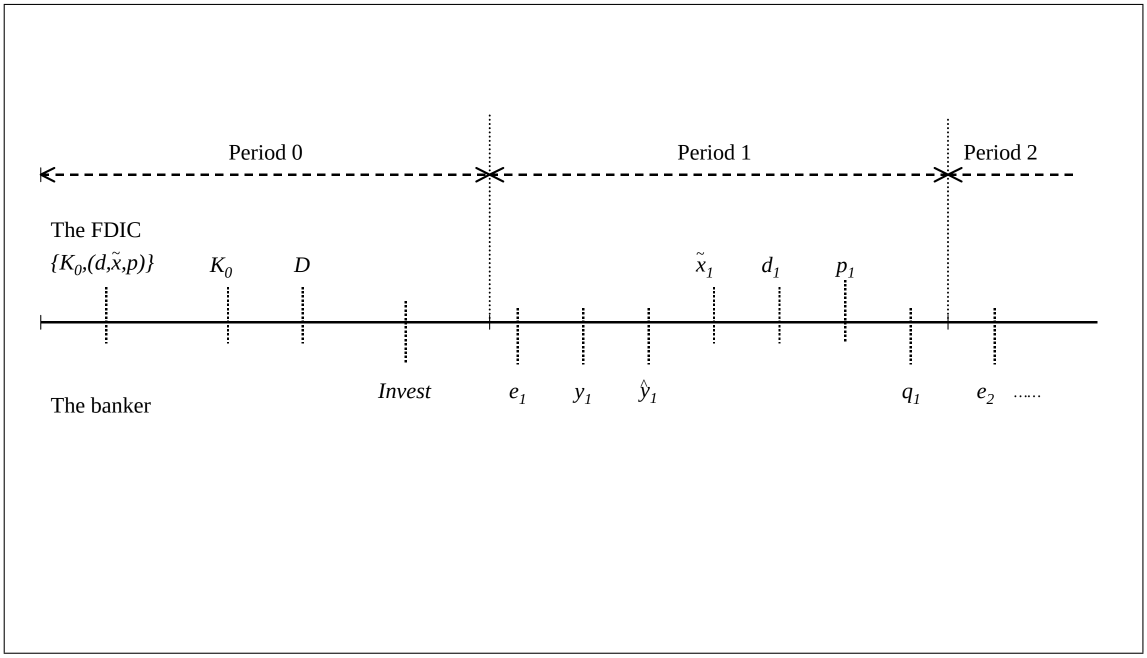

Figure 3: Timing of the Game

In the context of banking regulation, the game works as follows. In the initial period, the regulator commits to the following standard regulation:

Deposit Insurance Premium: A deposit insurance premium is characterized by a sequence of payments $\{\widetilde{x}_t\}$ from the banker to the regulator. If a premium is not paid to the regulator, the bank is *undercapitalized*.

Book-Value Capital Regulation: A book-value capital regulation is characterized by (i) the initial capital infusion K_0, (ii) the dividend payment if the current level of capital K_t^d is above an upper bound $\overline{K}_t$, and (iii) being undercapitalized if K_t^d is below a lower bound $\underline{K}_t$.

Undercapitalization and Stochastic Termination/Bailout: If $z > 0$ is the amount of undercapitalization in period t, the regulator liquidates the bank and keeps L_t with probability $p_t(z) = z/\underline{K}_t$, or bails out the bank by increasing the level of capital by z, so that the level of capital becomes $\underline{K}_t$ with probability $1 - p_t(z)$.

Given this regulation, the banker optimally chooses strategy $\{e_t, \widehat{y}_t, q_t\}_{t=1}^{\infty}$. That is, the banker chooses every period whether to exert the optimal level of effort or not, whether to report truthfully ($\widehat{y}_t = y_t$) or consume privately ($\widehat{y}_t < y_t$), and whether to terminate the bank ($q_t = 1$) or not ($q_t = 0$).

The main result is that the above capital regulation and deposit insurance premium can implement the optimal allocation in two steps. First, I show that a combination of the above regulatory instruments generates the outcome equivalent to the ex-ante optimal allocation, assuming that the banker exerts the optimal effort, never quits and the banker chooses to use all of the realized return to increase book-value capital every period, i.e., the banker chooses to enjoy no private consumption. Second, I show that the banker who wants to maximize $E_t^e\left[\sum_{s=t}^{\infty}\beta^{s-t}(Y_s - \widehat{y}_s + d_s - \psi e_t)\right]$ finds the optimal-effort/truth-telling/no-quitting strategy optimal, for all t and after any history $(\widehat{y}^{t-1}, \lambda^t)$ summarized by K_t. Proposition 2 shows the exact form of the deposit insurance premium and the capital regulation.

Proposition 2 *The ex-ante optimal allocation is equivalent to the outcome of the following combination of a book-value capital regulation and a risk-based deposit insurance premium:*

(1) Suppose $\mu_1 - \mu_0 \geq \psi$. Then, the deposit insurance premium is $\widetilde{x}_t = \mu_1 - \psi - K_{t-1}(\beta^{-1} - 1)$, which is decreasing in the level of book-value capital at the beginning of period t, K_{t-1}. The book-value capital regulation consists of initial capital $K_0 = \overline{K}_0$, dividend $d_t = \max\left(K_t^d - \overline{K}_t, 0\right)$ and termination probability $p_t = \max[\left(\underline{K}_t - K_t^d\right)/\underline{K}_t, 0]$, where $\overline{K}_t = \overline{w}_t$ and $\underline{K}_t = \underline{w}_t$.

(2) Suppose $\mu_1 - \mu_0 < \psi$. Then, when $K_{t-1} < \overline{K}_t^1$, the deposit insurance premium is $\widetilde{x}_t' = \frac{\psi}{\mu_1 - \mu_0}\mu_0 - K_{t-1}(\beta^{-1} - 1) - y_t(\frac{\psi}{\mu_1 - \mu_0} - 1)$, which is decreasing in both the level of book-value capital at the beginning of period t, K_{t-1}, and the realized return, y_t; when $K_{t-1} > \underline{K}_t^0$,

the deposit insurance premium is $\widetilde{x}_t' = \mu_0 - K_{t-1}(\beta^{-1} - 1)$, which is decreasing in K_{t-1}; when $\overline{K}_t^1 \leq K_{t-1} \leq \underline{K}_t^0$, with probability $\widehat{p}_t = (\underline{K}_t^0 - K_{t-1})/(\underline{K}_t^0 - \overline{K}_t^1)$, the regulator charges $\left[\beta^{-1}(K_{t-1} - \overline{K}_t^1)\right]$ to the banker and then the banker pays the deposit insurance premium $\widetilde{x}_t' = \left[\frac{\psi}{\mu_1 - \mu_0}\mu_0 - K_{t-1}(\beta^{-1} - 1) - y_t(\frac{\psi}{\mu_1 - \mu_0} - 1)\right]$, or with probability $1 - \widehat{p}_t$, the regulator pays $\left[\beta^{-1}(\underline{K}_t^0 - K_{t-1})\right]$ to the banker, and then the banker pays the deposit insurance premium $\widetilde{x}_t' = \left[\mu_0 - K_{t-1}(\beta^{-1} - 1)\right]$. The book-value capital regulation consists of initial capital $K_0 = \overline{K}_0$, dividend $d_t = \max\left(K_t^d - \overline{K}_t, 0\right)$, termination probability $p_t = \max[\left(\underline{K}_t - K_t^d\right)/\underline{K}_t, 0]$, and randomization $\widehat{p}_t$ of induced effort, where $\overline{K}_t = \overline{w}_t'$, $\underline{K}_t = \underline{w}_t'$, $\underline{K}_t^0 = \underline{w}_{t-1}^0$, and $\overline{K}_t^1 = \overline{w}_{t-1}^1$.

The dividend and termination rules from this game are the same as the consumption and termination rules in the ex-ante optimal allocation. Note that the level of capital K replicates the law of motion of w, so now K works as a record-keeping device. Also note that stochastic termination is coupled with stochastic bailout. If $\underline{K}_t > K_t^d$, the bank is either terminated with probability p_t or bailed out with probability $1 - p_t$.[13]

Depending on the parameter values, I have obtained three different risk-based deposit insurance premiums from Proposition 2. First, when $\mu_1 - \mu_0 \geq \psi$, the deposit insurance premium in period t is decreasing only in the capital level at the beginning of period t. Next, when $\mu_1 - \mu_0 < \psi$ and $K_{t-1} < \overline{K}_t^1$, the deposit insurance premium in period t is decreasing in both the capital level at the beginning of period t and the return of the current period. The intuition for this difference is as follows. When $\mu_1 - \mu_0 < \psi$ and $K_{t-1} < \underline{K}_t^0$, the optimal allocation prescribes that the banker be rewarded with the increase in the continuation payoff by more than one dollar, given an increase in profit by one dollar. To implement this allocation, the banker is rewarded with more than one dollar, through the increase in the dividend by one dollar, as well as through the decrease in the deposit insurance premium,

[13] Note that when the regulator terminates the bank with capital $K_t = w_t^c$, this amount belongs to the regulator. On the other hand, when the regulator bails out the bank, she should pay $\underline{K}_t - K_t = \underline{w}_t - w_t^c$ to the bank to replenish capital. Thus, in expectation, $\frac{\underline{w}_t - w_t^c}{\underline{w}_t} \cdot w_t^c - \frac{w_t^c}{\underline{w}_t} \cdot (\underline{w}_t - w_t^c) = 0$ and the regulator breaks even.

given an increase in the profit by one dollar. Thus, when inducing the positive effort is more costly, the deposit insurance premium should be more strongly risk-based, while the book-value capital regulation maintains a similar structure. Finally, when $\mu_1 - \mu_0 < \psi$ and $K_{t-1} > \underline{K}_t^0$, the deposit insurance premium in period t is decreasing only in the capital level at the beginning of period t. The intuition is that since the capital level is high enough, the regulator wants to induce less costly effort, i.e., low effort, and thus the deposit insurance premium need not be strongly risk-based.

It should be noted that under a set of parameters, the regulator wants to randomize over inducing high or low effort. This requires the regulator to adjust the level of capital up or down depending on the result of randomization $\widehat{p}_t$. Instead of incorporating the adjustments in the deposit insurance premium, I separated the adjustments from the normal deposit insurance premium because the adjustments are paid before the effort is chosen while the deposit insurance premium is paid after it is chosen.

Note that D-F show that a set of simple financial contracts can implement an optimal long-term financial contract, while I show that the well-designed combination of a risk-based deposit insurance premium and a bank capital regulation can implement the ex-ante optimal dynamic allocation. In particular, D-F use credit line balance as a record-keeping device: the amount of credit line balance determines every period if the investor allows dividends or terminates the project. On the other hand, I use the level of book-value capital as the record keeping device. Also, D-F use a long-term debt as a tool to coordinate the level of credit line with the agent's continuation utility, while I use risk-adjusted deposit insurance premium to coordinate the level of book-value capital with the banker's continuation utility, which is a proxy for a bank's market-value capital. Both the long-term debt in D-F and the deposit insurance premium in this paper work as a transfer from the agent to the principal, but they differ in that in a stationary setting the coupons of the long-term debt is constant over time while the deposit insurance premium depends on the level of capital as long as the bank capital grows at a risk-free rate $r_f < 1/\beta - 1$ or as long as $\mu_1 - \mu_0 < \psi$ and $K_{t-1} < \overline{K}_t^1$.

4 Stochastic termination and partial termination

This section shows that stochastic termination and partial termination are equivalent under the assumption that partial termination of the bank's assets scales down all the cash flows including the costs associated with effort.[14] I denote the continuation function at t by $v_t^c(w_t^c)$, for all $w_t^c \geq J = 0$. This assumption implies that termination of $(1-\alpha)$ of the assets causes the original continuation function to shrink proportionately by the factor α, so that the new continuation function after termination becomes $\widetilde{v}_t^c(w_t^c) = \alpha v_t^c(\frac{1}{\alpha} w_t^c)$, for all $w_t^c \geq J$.[15]

Now suppose that $0 < w_t^c < \underline{w}_t$, where $\underline{w}_t$ is the termination threshold associated with $v_t^c(\cdot)$. First, under stochastic termination we derived as part of the optimal allocation in the previous sections, the regulator terminates the bank with probability $p_t = \frac{\underline{w}_t - w_t^c}{\underline{w}_t}$, which gives the banker 0 and the regulator L, or bail out the bank with probability $1 - p_t$, which gives the banker $\underline{w}_t$ and the regulator $v_t^c(\underline{w}_t)$. Thus, when the banker gets w_t^c and is subject to stochastic termination, the regulator gets ex-ante $L \cdot \frac{\underline{w}_t - w_t^c}{\underline{w}_t} + v_t^c(\underline{w}_t) \cdot \frac{w_t^c}{\underline{w}_t}$.

Alternatively, under partial termination, the regulator terminates the fraction p_t of the bank, while providing the banker with the same continuation utility w_t^c for sure. Now the new size of the bank's assets is $(1 - p_t)$ of the original size, and the banker is subject to no termination since $w_t^c = (1 - p_t) \cdot \underline{w}_t$. Note that the partial termination provides the regulator with $L \cdot \frac{\underline{w}_t - w_t^c}{\underline{w}_t}$ from termination of the fraction p_t of the bank and with $(1 - p_t) v_t^c(\frac{1}{1-p_t} w_t^c)$ from the remaining bank. Thus, from the fact that $w_t^c = (1 - p_t) \cdot \underline{w}_t$, the regulator gets in total $L \cdot \frac{\underline{w}_t - w_t^c}{\underline{w}_t} + v_t^c(\underline{w}_t) \cdot \frac{w_t^c}{\underline{w}_t}$ from the partial termination, which is equivalent to what the regulator gets from the stochastic termination.

Therefore, I showed that, under the above rescaling assumption, the regulator can use partial termination instead of stochastic termination as part of the optimal allocation. Figure 4 illustrates the equivalence between stochastic termination and partial termination.

[14] DeMarzo and Fishman (2003) used this assumption in modeling investment to alter the project scale.

[15] Note that, if $J > 0$, we need to assume either that J also scales down with partial termination or that the continuation function shrinks down with $(J, 0)$ as the origin.

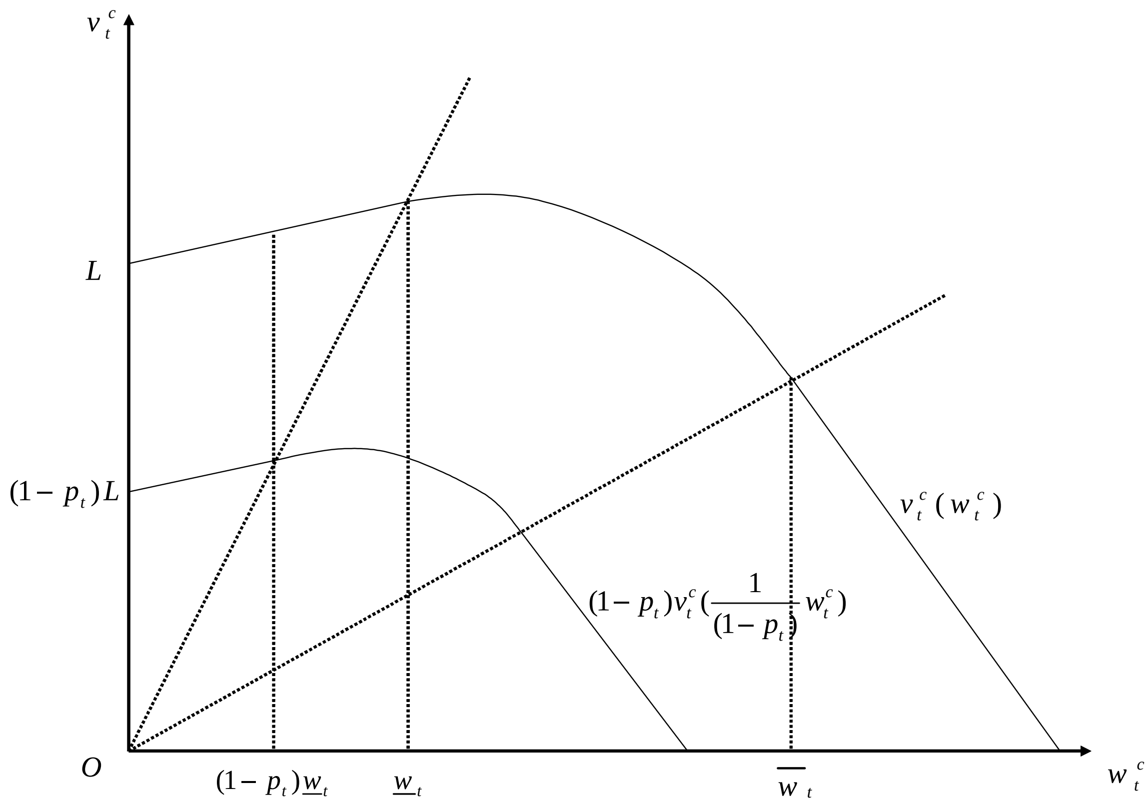

Figure 4: Stochastic Termination and Partial Termination

Let s_t be the size of the risky assets of the bank at the end of period t. Then, starting from $s_0 = 1$, $s_t = \prod_{l=1}^{t} s_0(1-p_l)$. Given the optimal allocation with stochastic termination $\{c_t, p_t\}_{t=1}^{\infty}$, the optimal allocation with partial termination is $\{c_t', p_t\}_{t=1}^{\infty}$, where $c_t' = s_{t-1}c_t$ and p_t now represents the fraction of the risky assets terminated in period t by the regulator. The law of motions for the state variable w_t and for the size s_t of the risky assets are as follows:

$$w_{t-1} \;\Rightarrow\; w_t^c = \beta^{-1}w_{t-1} + s_{t-1}(y_t - \mu_1 + \psi) \;\Rightarrow\; w_t = w_t^c$$

$$s_{t-1} \Rightarrow \quad s_t = (1-p_t)s_{t-1}$$

Also, note that, under partial termination, $\overline{w}_t = s_{t-1}\overline{w}_0$ and $\underline{w}_t = s_{t-1}\underline{w}_0$.

Now, I need to consider how to implement the optimal allocation through the combination of a bank capital regulation with partial termination and a risk-based deposit insurance premium. Before formally considering the implementation scheme, we should note the following implications of partial termination on bank capital regulations. First, under partial termination, $\underline{K}_t$ works more like the minimum capital requirement as in the current bank capital regulation, because if a bank's capital K_t goes below this threshold $\underline{K}_t$, the bank is sure to be subject to (partial) termination. Second, after the partial termination, the bank's asset size decreases, so that the capital ratio increases and the new capital ratio is exactly $\underline{K}_t$, which is the minimum level of the capital ratio to avoid termination.

The details of the dynamic game under partial termination are the same as those under stochastic termination except that, if $K_t^d < \underline{K}_t$, the size of the assets becomes $K_t^d/\underline{K}_t$ of the initial size. Under partial termination, we need to use the same regulatory tools as we did under stochastic termination except that, if $z > 0$ is the amount of undercapitalization in period t, the regulator liquidates $z/\underline{K}_t$ of the current risky assets and the bank continues operation with the size of the risky assets equal to $(1 - z/\underline{K}_t)$ of the risky assets at the beginning of period t. The following proposition summarizes the result with the proof as shown above.

Proposition 3 *When we assume that partial termination of a bank's assets scales down all the cash flows including the costs associated with effort, the optimal allocation can be implemented by the combination of the capital regulation with dividend payment d_t and partial termination rule p_t, and the risk-based deposit insurance premium $\widehat{x}_t$, where $s_t = \prod_{l=1}^{t} s_0(1-p_l)$, $\widehat{x}_t = s_{t-1}(\mu_1 - \psi) - K_{t-1}(\beta^{-1} - 1)$ when $\mu_1 - \mu_0 \geq \psi$, $\widehat{x}_t = s_{t-1}[\frac{\psi}{\mu_1-\mu_0}\mu_0 - y_t(\frac{\psi}{\mu_1-\mu_0} - 1)] - K_{t-1}(\beta^{-1}-1)$ when $\mu_1-\mu_0 < \psi$ and $K_{t-1} < \overline{K}_t^1$, $\widehat{x}_t = s_{t-1}\mu_0 - K_{t-1}(\beta^{-1}-1)$ when $\mu_1-\mu_0 < \psi$ and $K_{t-1} > \underline{K}_t^0$, and finally p_t and d_t are the same as defined in Proposition 2.*

This result has an important practical implication because, if it is difficult for a government to use stochastic termination in practice, this result implies that the government can use partial termination instead and still attain the same optimal outcome.

5 Comparative statics

5.1 Liquidation value and capital requirements

In Section 3, I showed that the initial capital requirement $\overline{K}_0$, the dividend threshold $\overline{K}_t$ and the termination threshold $\underline{K}_t$ depend on the shape of the continuation function. Note that in the *i.i.d.* setting, the continuation function is stationary and thus $\overline{K}_t = \overline{K}$ and $\underline{K}_t = \underline{K}$ for all $t \geq 0$. In this subsection, I investigate how the continuation function changes its shape as I change the liquidation value L. In particular, I am interested in the correlation between the recovery value and the optimal capital requirements, $\overline{K}$ and $\underline{K}$. I define $w^M = \inf\{w : v'(w) \leq 0\}$. Then, w^M maximizes v, so that $v(w) < v(w^M)$ for $w < w^M$. I also define L^m as the value of L such that $v(w^M; L) = L$. Given the value of $J = 0$, depending on the value of L, I have the following three different cases for the shape of the continuation function v.

(Case 1) Suppose the liquidation value L is equal to or greater than the maximum total continuation utility. That is, the recovery value is close to the first-best value of the assets. Then, $l \leq -1$ and $\underline{w} = \infty$. Thus, in this case, it is optimal to terminate the bank with probability one for any value of K_t, and the continuation function is linear. This case shows that it is crucial to have costly liquidation in order to have a strictly concave continuation function.

(Case 2) Suppose L is equal to or greater than L^m but less than the maximum total continuation utility. This is the case where the recovery value is relatively high. Then, $-1 < l_t \leq 0$ and $w^M \leq \underline{w} < \overline{w}$. Thus, if the bank's capital K_t^d is above $\underline{K} = \underline{w}$, the bank is not terminated, and otherwise, the bank faces stochastic termination by the regulator. Since $w^M \leq \underline{w}$, the optimal allocation is on the Pareto frontier and $v(\cdot)$ is decreasing and concave in $w \in [\underline{w}, \overline{w}]$.

(Case 3) Suppose L is less than L^m. Then, $l_t > 0$ and $w^M > \underline{w}$. Again, if $K_t^d \geq \underline{K} = \underline{w}$, the bank is not terminated, and otherwise, the bank faces stochastic termination. Since $w^M > \underline{w}$, the optimal continuation function at the end of period t now has an increasing region. If the banker's continuation utility is between $\underline{w}$ and w^M, this continuation is Pareto-inferior, because both the banker and the regulator would like to replace it with a new, Pareto-improving allocation. However, since I assume that renegotiation is impossible, and that the regulator can commit to the allocation, the continuation function is a pseudo-Pareto frontier. This inefficient region is important, as the regulator might use this low continuation utility ex-post to provide an incentive/threat to the banker.

To illustrate the above 3 cases and show the relationship between the liquidation value and the capital thresholds, I calibrate the model using the following parameters:

β	δ	$\underline{y} - \psi$	$\overline{y} - \psi$	$\mu_1 - \psi$	J	D	T
0.9	0.95	-0.005	0.015	0.005	0	1	∞

.

The annual ROAs of all regulator-insured US thrift institutions[16] between 1984 and 2002 have the mean 0.449%, the standard deviation 0.515%, the maximum 1.122%, and the minimum -0.391%. Thus, for computational simplicity, I choose $\mu - \psi = 0.5\%$, $\sigma = 0.5\%$, $\underline{y} - \psi = -0.5\%$, and $\overline{y} - \psi = 1.5\%$. Then, I simulate the return distribution after subtracting the costs of effort by the truncated normal distribution with the mean 0.005, the standard deviation 0.005 and the support $[-0.005, 0.015]$. Note that I assume $\mu_1 - \psi > \mu_0$ in this calibration.

[16] I chose thrift institutions rather than commercial banks because thrift institutions are more likely to be terminated under PCA while commercial banks, especially large and systemically important banks, are less likely to be terminated.

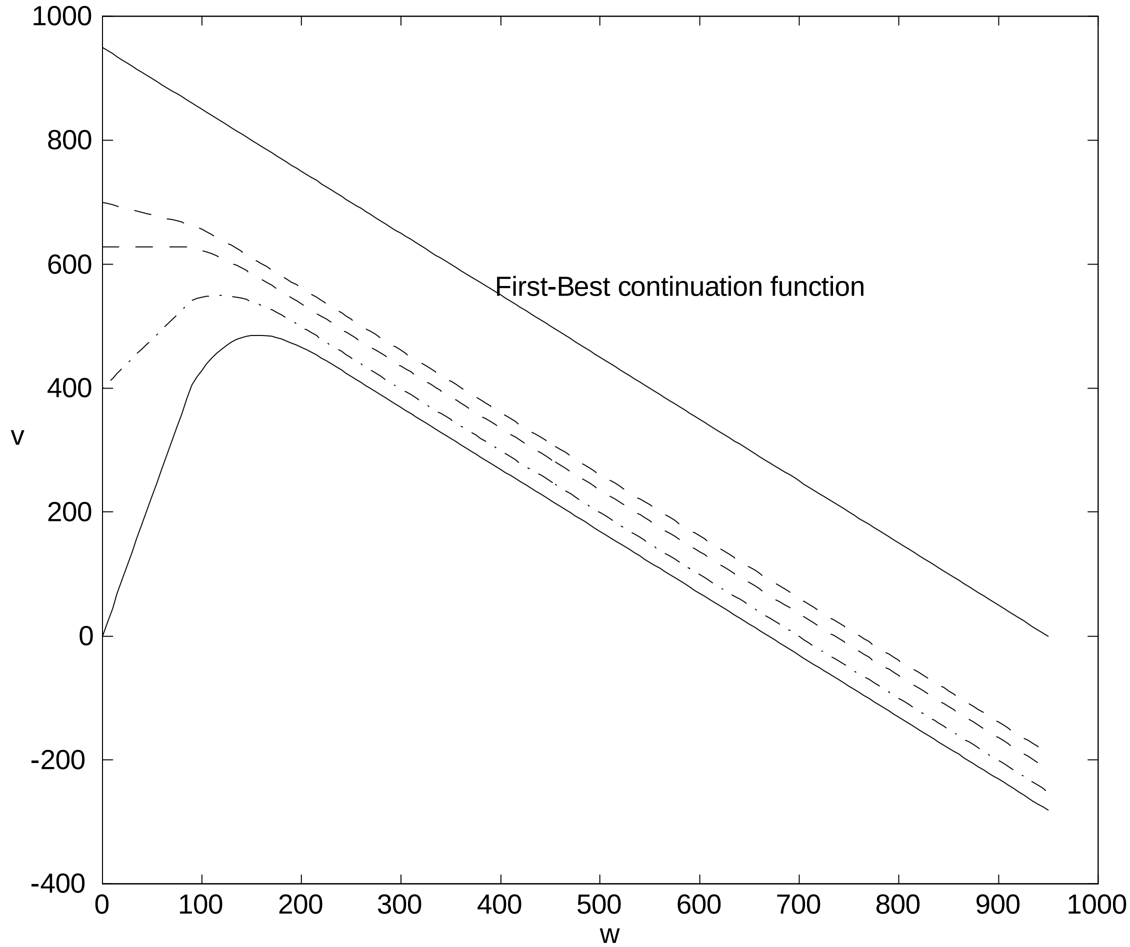

Figure 5: Liquidation Values and Continuation Functions

Figure 5 shows an example for each case. In Figure 5, the unit is basis point, so that 100 means 1%. Note that the termination threshold is the same for each case. In particular, the termination threshold is determined as $\beta(\mu_1 - \psi - \underline{y})$. Thus, as long as the means and the lower bounds of the return distributions of two banks are the same, the termination thresholds for both banks should be the same. This property implies that, if two banks have the return distributions with the same mean and the same support but different variance, the termination thresholds for the two banks are the same, but that if two banks have the return distributions with the same mean and the same variance but different support, then the termination thresholds are different from each other.

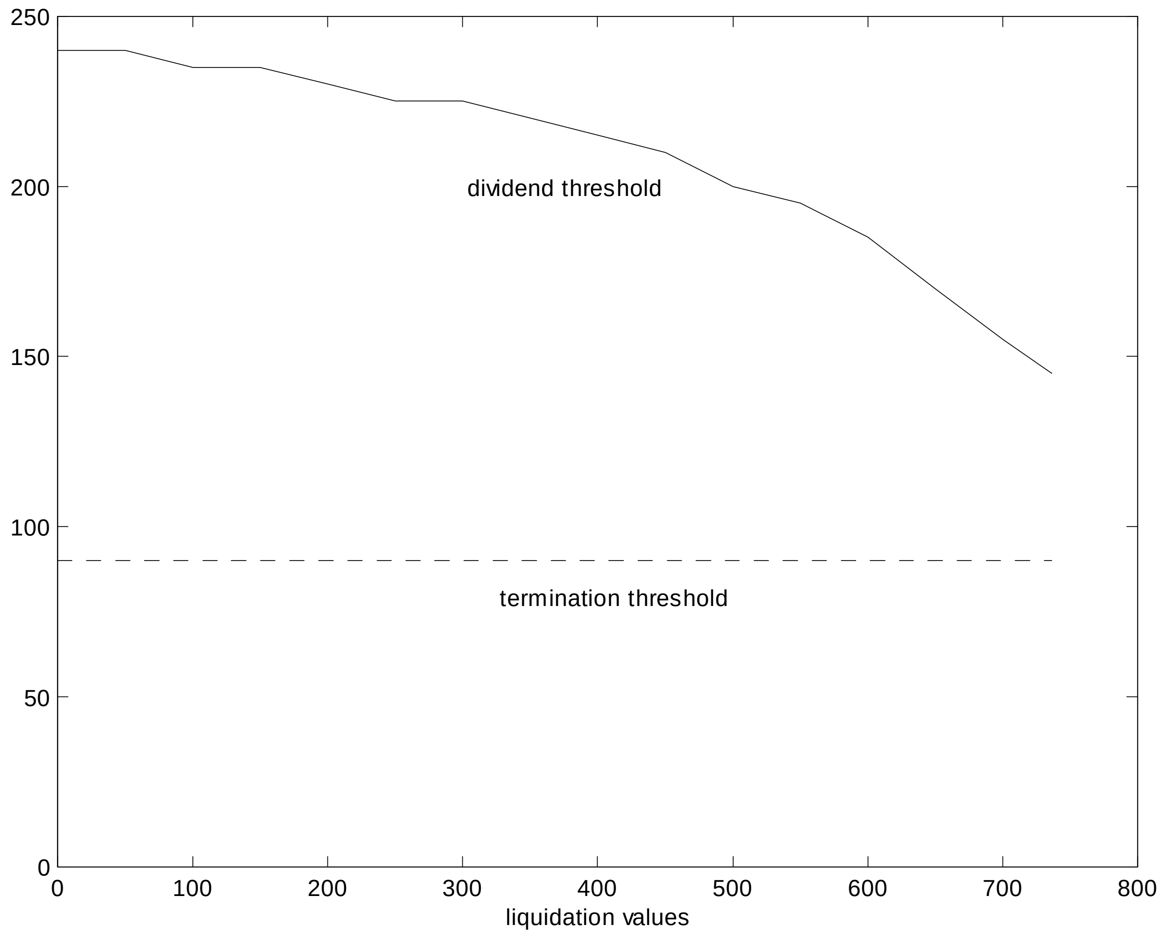

Figure 6: Liquidation Values and Capital Thresholds

Figure 6 shows the negative correlation of the liquidation value and the dividend threshold. Since the dividend threshold is also the optimal level of the initial required capital, this result implies that, other things being equal, the regulator requires a higher level of initial capital for a bank with a lower level of the liquidation value of its assets. The intuition for this result is as follows. When the liquidation value is lower, the regulator's continuation value decreases faster, as the banker's continuation value goes down and approaches the value of the outside option. Thus, the continuation function becomes lower around the dividend threshold, and the threshold for dividend payment is higher for the bank with a lower recovery value.

5.2 Mean-preserving spreads and capital thresholds

Suppose there are two banks with the same size D of the long-term assets, the same liquidation value L, the same value of ψ, the return distributions with the same mean, but different variances. I denote the probability density functions of bank 1 and bank 2 by f_1^e and f_2^e, respectively, and the standard deviations associated with f_1^e and f_2^e by σ_1^e and σ_2^e respectively, where $\sigma_1^e < \sigma_2^e$, $\forall e$. Thus, bank 2 is riskier than bank 1 in the sense of second order stochastic dominance (SOSD) or a mean-preserving spread. Then, the natural question is how to optimally set risk-based deposit insurance premiums and bank capital regulation for the two different banks. That is, is it optimal to impose a stricter capital regulation to the riskier bank or charge a higher deposit insurance premium for the riskier bank or do both?

In the framework of the traditional option-value approach to deposit insurance, higher risk entails higher deposit insurance premium, since deposit insurance payment is identical to a put option to a bank's assets. The option value increases as the riskiness of a bank increases as observed by Merton (1977). However, the deposit insurance premium in this paper is not calculated from a fair-pricing consideration, but from the consideration of resolving the incentive problems in the dynamic setting and inducing the ex-ante optimal allocations. In particular, the optimal deposit insurance premiums for both banks are of the same form: when $\mu_1 - \mu_0 \geq \psi$, $\widetilde{x}_{1t} = \widetilde{x}_{2t} = \mu_1 - \psi - K_{t-1}(\beta^{-1} - 1)$; when $\mu_1 - \mu_0 < \psi$ and $K_{t-1} < \overline{K}_t^1$, $\widetilde{x}'_{1t} = \widetilde{x}'_{2t} = \frac{\psi}{\mu_1 - \mu_0}\mu_0 - K_{t-1}(\beta^{-1} - 1) - y_t(\frac{\psi}{\mu_1 - \mu_0} - 1)$, etc. Thus, if bank 1 and bank 2 have the same level of book-value capital and the current-period profit realization, then both will pay the same amount of deposit insurance premium.

On the other hand, the shape of continuation functions for both banks are different. Specifically, when the liquidation value of the assets of both banks are the same, the optimal capital regulation prescribes that bank 2 should have the higher dividend threshold or initial required capital, i.e., $\overline{K_1} < \overline{K_2}$.

To show how we get this result, I again assume that $\mu_1 - \mu_0 \geq \psi$ holds. I denote by $\{v_1, v_1^c, v_1^y\}$ the stationary continuation functions of bank 1 under f_1^1, and by $\{v_2, v_2^c, v_2^y\}$

those of bank 2 under f_2^1. And I also denote by $\widetilde{v}_1^y$ the continuation function derived from v_1^c using the expectation over f_2^1. Then, from the property of the SOSD and the fact that v_1 is concave, $v_1^y(w) \geq \widetilde{v}_1^y(w)$ holds for all w and $v_1^y(w) > \widetilde{v}_1^y(w)$ for some w. By the Contraction Mapping Theorem, we have $v_1(w) \geq v_2(w)$ for all w and $v_1(w) > v_2(w)$ for some w. I can also show that $\overline{w}_1 \leq \overline{w}_2$. This is because $v_1(w) > v_2(w)$ but $\widetilde{w}_1 = \widetilde{w}_2 = \widetilde{w}$ where $\widetilde{w}_i = \inf \left\{ w \mid v_i'(w) \leq -\frac{\delta}{\beta} \right\}$, so that the slope of v_2 increases faster than that of v_1 as w decreases from $\widetilde{w}$.

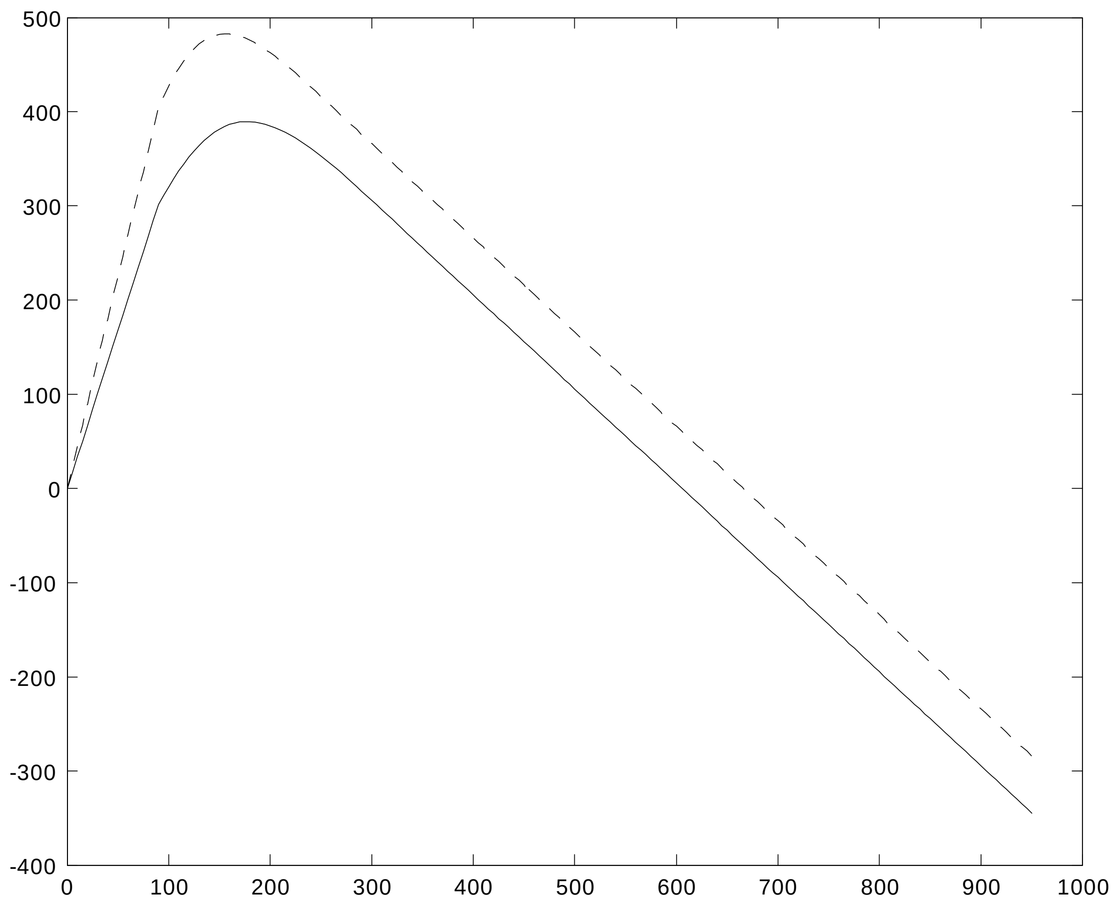

Figure 7: Mean-Preserving Spread and Continuation Function

Figure 7 illustrates an example of the above mean-preserving spread. The dotted line stands for the continuation function under the aforementioned truncated normal distribution (the return distribution of bank 1), and the solid line for the continuation function under the uniform distribution with the same mean and support (the return distribution of bank 2). In this example, the initial capital requirement of bank 1 is 2.4% while that of bank 2 is 2.95%.

In summary, an observed mean-preserving spread only affects the curvature or shape of the continuation function, not the deposit insurance premium schedule. Therefore, it is optimal to impose a stricter capital regulation to the riskier bank in the sense of SOSD, but to maintain the same deposit insurance premium schedule for both banks.

6 Discussion

6.1 Model-implied regulation vs. current practice

The model-implied structure of deposit insurance premiums resemble the structure of deposit insurance premiums currently applied in many countries. Laeven (2002) shows that 29 out of 71 countries surveyed as of end-year 2000 have risk-based deposit insurance premiums, and that the most commonly used measures of bank risk include capital adequacy, CAMEL-like ratings, and supervisory ratings. For example, the current risk-based deposit insurance premium in the US has a capital dimension and a CAMELS-rating dimension as shown in Table 1.

(Table 1) Deposit Insurance Premium Assessment Rates in US (unit: basis point)

	CAMELS Rating 1, 2	CAMELS Rating 3	CAMELS Rating 4, 5
Well Capitalized	0	3	17
Adequately Capitalized	3	10	24
Undercapitalized	10	24	27

The model-implied risk-based deposit insurance premiums also have a capital dimension and, under some circumstances, a current-profit dimension.

The model-implied capital regulation has a number of similarities and differences with the current PCA. For example, the US PCA has the following classification structure.

(Table 2) Classification of Banks in US PCA[17]

	Total Risk-Based Capital Ratio		Tier 1 Risk-Based Capital Ratio		Tier 1 Leverage Ratio		Tangible Equity Ratio
Well Capitalized	$\geq 10\%$	and	$\geq 6\%$	and	$\geq 5\%$	and	$> 2\%$
Adequately Capitalized	$\geq 8\%$	and	$\geq 4\%$	and	$\geq 4\%$	and	$> 2\%$
Undercapitalized	$\geq 6\%$	or	$\geq 3\%$	or	$\geq 3\%$	and	$> 2\%$
Significantly Undercapitalized	$< 6\%$	or	$< 3\%$	or	$< 3\%$	and	$> 2\%$
Critically Undercapitalized	-		-		-		$\leq 2\%$

First, the regulatory scheme proposed in this paper implements the ex-ante optimal allocation without the possibility of renegotiation, hence it concords with the idea of ex-ante specification of all contingent action rules of the regulators by law and the minimal amount of regulatory discretion, as stipulated by the current PCA.

Second, the current PCA basically prohibits dividend payments, once a bank is classified as undercapitalized and likely to be terminated. The model-implied capital regulation has a range of capital levels where dividends are not allowed, even though the probability of termination is zero. Considering that *undercapitalized* banks are rarely terminated, that

[17] Tier 1 or core capital mainly comprises permanent shareholders' equity, i.e., common stock and disclosed reserves or retained earnings. Tier 2 or supplementary capital comprises loan loss reserves, subordinated debts, asset revaluation reserves, hybrid capital instruments, etc. Total capital is the sum of Tier 1 and Tier 2 capital. The total risk-based capital ratio is the ratio of total capital to risk-weighted assets. Risk-weighted assets are calculated by applying different risk weights (0% to 100%) to each type of assets. The Tier 1 risk-based capital ratio is the ratio of Tier 1 capital to risk-weighted capital. The Tier 1 leverage ratio is the ratio of Tier 1 capital to total assets. See BIS (1988) for the formal definitions of capital. The tangible equity ratio is the ratio of 'the total of Tier 1 capital plus cumulative preferred stock and related surplus less intangibles except qualifying purchased mortgage servicing rights' to 'the sum of total assets less intangible assets except qualifying purchased mortgage servicing rights'.

significantly undercapitalized banks are more likely terminated, and that *critically undercapitalized* banks are almost certainly terminated, the model-implied capital regulation is similar to the current PCA. Both have a region of no (or rare) termination and no dividends. $\overline{K}_t$ and $\underline{K}_t$ in the model roughly correspond to the upper bound and the lower bound of capital ratios for the *undercapitalized* category.

Third, in contrast to the current PCA, the model-implied capital regulation prescribes probabilistic termination by the regulator, where the probability of termination increases proportionately as the level of capital decreases below the threshold $\underline{K}_t$. The current PCA does prescribe a gradual intervention rule conditional on the level of capital, but it only allows deterministic termination, not stochastic termination.[18]

Finally, the idea of providing a subsidy to raise the level of capital up to the lower bound once a bank survives stochastic termination is not in line with the current PCA. In PCA, recapitalization by the banker in the form of issuing new equity is allowed to raise the level of capital up to the lower bound and, if not recapitalized promptly, the bank is closed with probability one. Thus, the current PCA does not allow bailout by the government. On the other hand, stochastic termination in this paper entails stochastic bailout.

There are many papers in favor of constructive ambiguity of government policy. Freixas (2000) shows that the optimal bailout policy of the lender of last resort can be a mixed strategy under some circumstances. He interprets this result as confirmation of "constructive ambiguity". He argues that this result is in line with the central bankers' claim that it is efficient for them to have discretion in lending to individual institutions.

Mishkin (1999) prescribes "constructive ambiguity" to deal with the moral hazard problem created by a "too-big-to-fail" policy toward large financial institutions. He uses this term

[18] In US PCA, well or adequately capitalized banks are not subject to any form of intervention. On the other hand, undercapitalized banks are subject to increasingly severe mandatory sanctions as their capital deteriorates. For all undercapitalized banks, constraints are imposed such as restrictions on distributing dividends and expanding total assets. Significantly undercapitalized banks must restore capital by selling stocks or be merged. Critically undercapitalized banks are subject to liquidation or complete asset sale.

to provide room for judgment by supervisors. He argues that, since FDICIA allowed regulators to use a systemic-risk exception to the closure policy, constructive ambiguity about classifying or not a specific bank in distress as too-big-to-fail will reduce the moral hazard problem. Note that constructive ambiguity in this context implies a contingent rule.

The stochastic termination rule in this paper is a set of mixed strategies: the probability of termination increases and the probability of bailout decreases, as the capital level decreases below a threshold. In practice, given the current level of bank capital $0 < K_t < \underline{K}_t$, a regulator committing to any forms of public lottery with the probability of termination $1 - K_t/\underline{K}_t$ and the probability of bail-out $K_t/\underline{K}_t$ can implement the stochastic termination rule. Note that this stochastic termination/bailout rule is not a form of discretion, but a randomization between termination and recapitalization, with the probability of termination based on the level of capital. Also, note that the legal structure of some countries might not allow the implementation of stochastic termination of a problem bank based on the level of capital. I showed in Section 4 that in this case the authorities can instead use partial and deterministic termination, and still attain the same optimal outcome.

6.2 Ex-post and ex-ante forbearance

In the model, if a bank becomes undercapitalized and subject to stochastic termination, but recapitalized by the regulator after surviving the stochastic termination, the bank stays in business, which is a form of ex-post forbearance. It is even possible that a bank which experiences consecutive periods of bad performance is repeatedly recapitalized, if the bank is lucky enough to survive successive stochastic termination.

However, despite the possibility of ex-post forbearance, the optimal termination policy itself is *prompt* in the ex-ante sense. When a bank's book-value capital is below a threshold, the regulator does terminate the bank stochastically. One way to understand this more clearly is to contrast it with partial termination which is prompt and deterministic.

In Section 2, we assumed that the regulator is a monopolistic regulator who imposes high initial capital requirement so that the banker enjoyed no rent. Suppose, on the contrary, that the regulator enjoyed no rent and the banker enjoys a positive rent when she acquires the charter to open a bank. Now the initial capital requirement is very low, and the regulator will exert ex-ante forbearance over time. That is, the regulator tolerates a bank operating with a very low or even a negative level of capital.

As an example, suppose the banker initially pays $K_0^* = \underline{w}_0 \ll \overline{w}_0$ as the initial capital, and the regulator promises $w_0 = \overline{w}_0$ to the bank as the continuation value. The banker is likely to enjoy dividends from period 1 on, while the level of book-value capital is low. Now there is a discrepancy between K_0 and w_0. The optimal allocation in the stationary setting should preserve this difference $(\overline{w}_0 - \underline{w}_0)$ over time so that the deposit insurance premium is set to satisfy $w_t^d - K_t = w_0^1 - K_0$. The level of capital imitates the dynamics of the banker's continuation utility, but with a constant gap. Then, a string of bad performances for the bank together with the deposit insurance premium will diminish the level of capital. However, even when the capital is exhausted, the banker is not subject to stochastic termination until the level of capital falls down to a very low level.[19]

7 Conclusion

This paper proposes a new approach of designing prudential regulation of banks as a mechanism to implement the socially optimal allocation. This paper extends the model of DeMarzo and Fishman (2004) by considering explicitly hidden choice of risk in addition to private information on returns and limited commitment by the banker. This paper shows that when

[19] The US experience with S&Ls in the 1980s may correspond to this case. In the early 1980s, the regulator in charge of the S&Ls amended the accounting method to allow them to use overly estimated franchise values as intangible capital in order to avoid termination of failed S&Ls. The introduction of a notional capital is a good example for ex-ante regulatory forbearance. See Chapter 4 of FDIC (1997) for details of this regulatory forbearance and the regulatory accounting principles in the 1980s.

the cost of exerting the high level of effort is larger than the improved expected return from exerting the high level of effort, it is possible that, under the contracting frictions of private information and limited commitment, it is socially optimal to induce the low effort when the bank is well capitalized, while optimal to induce the high effort when the bank is undercapitalized. This result is interesting because it tells the regulator to induce the high or low effort by the banker conditional on the level of bank capital.

The implementation result generally matches the current practice in many countries, i.e., the combination of PCA based on book-value capital and the risk-based deposit insurance premium. However, the important discrepancy is that the model-implied regulation suggests introduction of stochastic, or alternatively partial, termination rule be preferable to the deterministic and full termination rule in the current PCA.

Finally, it should be noted that the capital-ratio thresholds in the current Basel-type regulation are determined by a value-at-risk method, and thus many papers on bank capital regulation assumes exogenously given capital-ratio thresholds. This paper, on the other hand, derives the capital-ratio thresholds endogenously from the continuation function in every period. In this paper, the regulator determines the threshold levels of capital considering whether it is beneficial for the regulator to continue the bank or terminate it, and whether a bank's performance is good enough to pay dividends.

This paper is very stylized and as such it does not bear full resemblance to actual practices. There are practical issues that are not addressed in the paper, which calls for extensions of the model in a number of ways. First, it would be interesting to incorporate the possibility of recapitalization by the banker, which changes the level of book-value capital at every period. In practice, it is very costly to issue new equity when a bank is classified as undercapitalized, and the bank equityholders may not have enough incentive to issue new equity, since the benefit of the recapitalization may end up mostly with the regulator and the debtholders of the bank.[20] Nevertheless, I think it would be an important extension of this paper to consider the possibility of costly and compulsory recapitalization. Another extension would

[20] I thank Paul Kupiec for pointing this out.

be to consider the optimal regulation in a many-banks-one-regulator setup where there is a positive and negative spillover effects of the closure of one bank on the others. Incorporating these extensions will enrich the model and help us evaluate the extant prudential regulation.

Appendix I: recursive method

Lemma 1 shows that history can be summarized by the state variable w_t.

Lemma 1 *Suppose* $w_{t-1}(h_{t-1}, \lambda_t) = w_{t-1}(h'_{t-1}, \lambda_t)$, *where* $h_{t-1} \neq h'_{t-1}$. *Then,* $c_t^*(h_{t-1}, \lambda_t, y_t) = c_t^*(h'_{t-1}, \lambda_t, y_t)$ *and* $p_t^*(h_{t-1}, \lambda_t, y_t) = p_t^*(h'_{t-1}, \lambda_t, y_t)$.

Proof. Suppose we are at a node reached at the end of period $t-1$ after a history h_{t-1} and $\lambda_t = 0$. Let $\{c_s, p_s\}_{s=t}^{\infty}$ be an incentive-feasible allocation starting on this node and define Γ_{t-1}^* to be the set of all incentive-feasible allocations starting on this node. Then, from the assumption of independence of Y_t over time, the history (h_{t-1}, λ_t) does not affect the future continuation. Thus, Γ_{t-1}^* is common knowledge at the end of period $t-1$, and independent of h_{t-1}. Given this set, I can derive the continuation function at the end of period $t-1$ from the following problem:

$$v_{t-1}(w) = \max_{\{c_s, p_s\}_{s=t}^{\infty} \in \Gamma_{t-1}^*} V_{t-1}(\{c_s, p_s\}_{s=t}^{\infty}) \quad s.t. \;\; W_{t-1}(\{c_s, p_s\}_{s=t}^{\infty}) = w.$$

This continuation function gives the highest possible utility attainable by the regulator given the continuation utility $W_{t-1} = w$ for the banker. Thus, any optimal incentive-feasible allocation will choose a point on $v_{t-1}(w)$ as a function of the history (h_{t-1}, λ_t). Therefore, the history (h_{t-1}, λ_t) can be summarized by the banker's continuation utility w_{t-1} at the end of period $t-1$. Therefore, if two different histories result in the same value of w_{t-1}, they will result in the same continuation from period t on, i.e., the problem is Markov in w_{t-1}. ■

Lemma 1 shows that w is a sufficient statistic in the dynamics of the optimal allocations, and thus the optimal contract exhibits a Markov property. I want to solve for the ex-ante Pareto-optimal allocations, and if I can use a recursive formulation, the allocations are easier to solve for. Lemmas 2 and 3 show that the principle of optimality holds. That is, the continuation function derived from PP is the same as that derived from $FE(w)$, and the optimal allocations derived from $PP(w)$ and FE coincide.

Lemma 2 *The solution v to FE, evaluated at w_0, gives the value of the maximum in $PP(w)$ when the initial state w is w_0.*

Proof. Let $\lambda_1 = 0$, i.e., the bank was not terminated before $t = 1$. Let the ex-ante optimal allocation $\{c_t^*, p_t^*\}_{t=1}^{\infty}$ from $PP(w)$ deliver $w_0 > 0$ to the banker and $V(w_0)$ to the regulator. Define the banker's utility from period 2 on given y_1 and $\lambda_2 = 0$ as $w(y_1) = E_1^{e^*}\left[\sum_{t=2}^{\infty}\beta^{t-1}(c_t^*(h_t \mid y_1) - \psi e_t^*)\right]$, where the period of termination τ is determined by $\{p_t^*(h_t \mid y_1)\}_{t=2}^{\infty}$. $(c_1^*(y_1), p_1^*(y_1), w(y_1))$ is in the constraint set of the maximization problem in FE and incentive compatible. Then, at the end of period 0, $(c_1^*(y_1), p_1^*(y_1), w(y_1))$ delivers no more utility to the regulator than $\delta E^{e^*}\left[y_1 - c(y_1) + [1 - p(y_1)]\, V\left(w(y_1)\right) + p(y_1)L\right]$, where $c(\cdot)$ and $p(\cdot)$ are the solution of FE. Therefore, $V(w_0) \leq v(w_0)$.

Now in FE, fix w_0. Let $\{c(\cdot), p(\cdot), w(\cdot)\}$ be the solution from FE, where the function V on the right hand side of FE comes from $PP(w)$. Given $\lambda_2 = 0$, for each y_1, there exists a continuation allocation $\{c_t^*(h_t \mid y_1),\ p_t^*(h_t \mid y_1)\}_{t=2}^{\infty}$ from $PP(w)$ that delivers $w(y_1; w_0)$ to the banker and $V(w(y_1; w_0))$ to the regulator. Note that $\{c(y_1), p(y_1)\}$ is incentive compatible and $\{c_t^*(h_t \mid y_1),\ p_t^*(h_t \mid y_1)\}_{t=2}^{\infty}$ is also ex-post incentive compatible, due to the independence assumption and time separability. That is, it is optimal to exert the optimal level of effort, tell the truth and not to quit after any realization of y_1. Thus, $V(w_0) \geq v(w_0) = \delta E^{e^*}\left[y_1 - c(y_1) + [1 - p(y_1)]\, V\left(w(y_1; w_0)\right) + p(y_1)L\right]$. ■

Once I prove $V(\cdot) = v(\cdot)$, then I can prove the following lemma.

Lemma 3 *(c^*, p^*) is an optimal allocation in $PP(w)$ if and only if it satisfies FE.*

Proof. Let $\{c_t^*, p_t^*\}_{t=1}^{\infty}$ be an optimal incentive-feasible allocation from $PP(w)$ with the initial value of the banker's continuation utility w_0 equal to w_0^*. Define $\{w_t^*\}$ as the sequence of the banker's continuation utility at the end of every period derived from $\{c_s^*, p_s^*\}_{s=t+1}^{\infty}$.

First, I show that, when $V(\cdot) = v(\cdot)$, the optimal incentive-feasible allocation $\{c_t^*, p_t^*\}_{t=1}^{\infty}$ from $PP(w)$ satisfies $V(w_{t-1}^*) = \delta E^{e^*}[y_t - c_t^* + (1-p_t^*)V(w_t^*) + p_t^* L]$, $t = 1, 2, 3, \cdots$. Since $\{c_t^*, p_t^*\}_{t=1}^{\infty}$ attains the maximum,

$$
\begin{aligned}
V(w_0^*) &= E_0^{e^*}\left[\sum_{t=1}^{\infty}\delta^t(y_t - c_t^*) + \delta^{\tau}L\right] \\
&= \delta E_0^{e^*}\left[y_1 - c_1^* + (1-p_1^*)E_1^{e^*}\left[\sum_{t=2}^{\infty}\delta^t(y_t - c_t^*) + \delta^{\tau}L\right] + p_1^* L\right] \\
&\geq E_0^{e^*}\left[\sum_{t=1}^{\infty}\delta^t(y_t - c_t) + \delta^{\widetilde{\tau}}L\right] \\
&= \delta E_0^{e^*}\left[y_1 - c_1 + (1-p_1)E_1^{e^*}\left[\sum_{t=2}^{\infty}\delta^t(y_t - c_t) + \delta^{\widetilde{\tau}}L\right] + p_1 L\right]
\end{aligned}
\tag{2}
$$

where $\{c_t, p_t\}_{t=1}^{\infty}$ is an incentive-feasible allocation from $PP(w)$ with $w_0 = w_0^*$, τ is a random variable representing the first period the bank is terminated under p^*, and $\widetilde{\tau}$ is a random variable representing the first period the bank is terminated under p. In particular, the inequality holds for all incentive feasible allocations with (c_1^*, p_1^*) and $w_1 = w_1^*$. Since that $\{c_t, p_t\}_{t=2}^{\infty}$ is an incentive-feasible allocation from $PP(w)$ with $w_1 = w_1^*$ implies that $\{(c_1^*, p_1^*), \{c_t^*, p_t^*\}_{t=2}^{\infty}\}$ be an incentive-feasible allocation from $PP(w)$ with $w_0 = w_0^*$, we have $E_1^{e^*}\left[\sum_{t=2}^{\infty}\delta^t(y_t - c_t^*) + \delta^{\tau}L\right] \geq E_1^{e^*}\left[\sum_{t=2}^{\infty}\delta^t(y_t - c_t) + \delta^{\widehat{\tau}}L\right]$, where $\{c_t, p_t\}_{t=2}^{\infty}$ is an incentive-feasible allocation from $PP(w_1^*)$. Hence, $E_1^{e^*}\left[\sum_{t=2}^{\infty}\delta^t(y_t - c_t^*) + \delta^{\tau}L\right] = V(w_1^*)$. Substituting this into (2) gives $V(w_{t-1}^*) = \delta E^{e^*}[y_t - c_t^* + (1-p_t^*)V(w_t^*) + p_t^* L]$, for $t = 1$. By induction, this holds for all t.

Second, I show that any allocation that satisfies $V(w_{t-1}^*) = \delta E^{e^*}[y_t - c_t^* + (1-p_t^*)V(w_t^*) + p_t^* L]$, $t = 1, 2, 3, \cdots$ when $V(\cdot) = v(\cdot)$ and also satisfies $\limsup_{t\to\infty}\delta^t V(w_t^*) \leq 0$ attains the maximum in $PP(w)$.

Suppose that an incentive-feasible allocation $\{c_t^*, p_t^*\}_{t=1}^{\infty}$ with $w_0 = w_0^*$ satisfies $V(w_{t-1}^*) = \delta E^{e^*}[y_t - c_t^* + (1-p_t^*)V(w_t^*) + p_t^* L]$, $t = 1, 2, 3, \ldots$ and $\limsup_{t\to\infty}\delta^t V(w_t^*) \leq 0$. Then, it follows by induction that

$$
\begin{aligned}
V(w_0^*) &= E_0^{e^*}\left[\delta(y_1 - c_1^*) + \delta p_1^* L + \delta(1-p_1^*)V(w_1^*)\right] \\
&= E_0^{e^*}\left[\delta(y_1 - c_1^*) + \delta p_1^* L + \delta(1-p_1^*)E_1^{e^*}\left[\delta(y_2 - c_2^*) + \delta p_2^* L + \delta(1-p_2^*)V(w_2^*)\right]\right] \\
&= E_0^{e^*}\left[\begin{array}{c} \delta(y_1 - c_1^*) + \delta^2(1-p_1^*)(y_2 - c_2^*) + \delta p_1^* L + \\ \delta^2(1-p_1^*)p_2^* L + \delta^2(1-p_1^*)(1-p_2^*)V(w_2^*) \end{array}\right] \\
&\vdots \\
&= E_0^{e^*}\left[\sum_{t=1}^{n}\delta^t(y_t - c_t^*) + \delta^{\zeta} L\right] + E_0^{e^*}\left[\delta^n \prod_{t=1}^{n}(1-p_t^*)V(w_n^*)\right],
\end{aligned}
$$

where $\zeta = \max(\tau, n)$ and τ is the first time the bank is terminated. Note that $c_t = 0$ and $y_t = 0$ for $t > \tau$.

Then, using the condition $\limsup_{t\to\infty} \delta^t V(w_t^*) \leq 0$, $V(w_0^*) \leq E_0^{e^*}\left[\sum_{t=1}^{\infty}\delta^t(y_t - c_t^*) + \delta^{\tau} L\right]$ holds. Also, since $\{c_t^*, p_t^*\}_{t=1}^{\infty}$ is an incentive-feasible allocation, we get $V(w_0^*) \geq E_0^{e^*}\left[\sum_{t=1}^{\infty}\delta^t(y_t - c_t^*) + \delta^{\tau} L\right]$.

■

Appendix II: proofs of propositions and corollary

Proof of Proposition 1.

(Step 1)

Let $v_t^c(\cdot)$ be the continuation function just before the banker and the regulator consume and either the banker or the regulator or both terminate the bank. Suppose a concave continuation function $v_t(\cdot)$ at the end of the period t is given. Then, the optimal consumption is derived from the following problem:

$$
\begin{aligned}
v_t^c(w_t^c) = \quad & \max_{c_t(\cdot)} \quad v_t(w_t) - c_t \\
& s.t. \quad w_t + c_t = w_t^c \\
& \qquad c_t \geq 0.
\end{aligned}
$$

The regulator will use the cheaper method between providing the banker with one unit of consumption and promising him one unit of continuation utility. Since $v_t(\cdot)$ is concave, $c_t(w_t^c) = \max(w_t^c - \overline{w}_t, 0)$ and now $w_t = \min(w_t, \overline{w}_t)$.

Since the banker has the outside option $J_t = 0$, if $w_t^c < 0$, he will terminate the bank. So v_t^c will be defined for $w_t^c \geq 0$. Since $v_t(w_t)$ is defined over $w_t \geq \underline{w}_t$, $v_t(w_t) = -\infty$ for $0 < w_t < \underline{w}_t$, and $(0, L)$ is located to the left of $v_t(\cdot)$, the regulator can expand the continuation function using probabilistic termination. The regulator can enjoy all continuation utilities on the convex hull of $v_t(\cdot)$ and $(0, L)$. Given $w_t^c \leq \underline{w}_t$, in an optimal allocation, the regulator either terminates the bank and sets $w_t = 0$ with probability $p_t(w_t^c) = \frac{\underline{w}_t - w_t^c}{\underline{w}_t}$, or allows the bank to continue operation and sets $w_t = \underline{w}_t$ with probability $1 - p_t(w_t^c)$. Therefore, after the banker consumes c_t and survives stochastic termination, the relevant range of w_t becomes an interval $[\overline{w}_t, \underline{w}_t]$. Finally, $v_t^c(\cdot)$ is also concave.

(Step 2)

$<$ Case 1: $\mu_1 - \mu_0 \geq \psi$ $>$

Given $v_t^c(\cdot)$, consider the continuation function $v_t^y(\cdot)$ before the choice of e_t and the realization of Y_t. The regulator cannot observe the choice of e_t and the realization of Y_t, but she wants the banker to choose $e_t = 1$ and $\widehat{y}_t = y_t$. Thus, she must provide him with an incentive to exert high effort and report truthfully by appropriately choosing the continuation utility function $w_t^c(\cdot)$. Finally, $w_t^c(Y_t; w_t^y)$ should be chosen to maximize the regulator's expected utility. Thus, I need to solve the following main problem:

$$\begin{aligned}
v_t^y(w_t^y) = \quad & \max_{w_t^c(Y_t)} \quad E^1[Y_t + v_t^c(w_t^c(Y_t))] \\
& s.t. \quad E^1[w_t^c(Y_t)] - \psi \geq E^0[w_t^c(Y_t)] && (IC1) \\
& \qquad\ \ w_t^c(Y_t) \geq w_t^c(y) + Y_t - y, \quad \forall y \leq Y_t && (IC2) \\
& \qquad\ \ E^1[w_t^c(Y_t)] - \psi = w_t^y && (PK)
\end{aligned}$$

The first constraint is an incentive-compatibility constraint for the banker such that it is optimal to exert high effort. The second is the other incentive-compatibility constraint such that it is optimal for the banker to tell the truth about the realization of returns. The last constraint is the promise-keeping constraint for the banker.

Before I solve the above problem, I define the following relaxed problem:

$$\begin{aligned} v_t^y(w_t^y) = \quad & \max_{w_t^c(Y_t)} \quad E^1[Y_t + v_t^c(w_t^c(Y_t))] \\ & s.t. \quad w_t^c(Y_t) \geq w_t^c(y) + Y_t - y, \quad \forall y \leq Y_t \qquad (IC2) \\ & \qquad E^1[w_t^c(Y_t)] - \psi = w_t^y \qquad (PK) \end{aligned}$$

To solve the relaxed problem, note that from $(IC2)$, $w_t^{c\prime}(y) \geq 1$ should hold. Given w_t^y, the promise-keeping constraint determines the mean of the random function $w_t^c(Y_t)$. Since $v_t^c(\cdot)$ is concave, it is optimal to minimize the variability of $w_t^c(Y_t)$. The solution of the relaxed problem is thus $w_t^c(Y_t) = w_t^y + \psi - \mu_1 + Y_t$. When we substitute $w_t^c(Y_t) = w_t^y + \psi - \mu_1 + Y_t$ into $(IC1)$, $(IC1)$ holds. Thus, the solution of the main problem is $w_t^c(Y_t) = w_t^y + \psi - \mu_1 + Y_t$. Once I have $v_t^y(w_t^y) = \mu_1 + E^1\left[v_t^c(w_t^c(Y_t))\right]$, $v_t^y(\cdot)$ is also concave.

$<$ Case 2: $\mu_1 - \mu_0 < \psi$ $>$

Now we need to consider that the regulator will choose every period to induce either $e_t = 1$ or $e_t = 0$ depending on the value of w_t^y summarizing the history. The regulator's choice of $w_t^c(Y_t)$ is more complicated since we need to consider the possibility of randomization of the regulator to concavify the continuation function. Given $v_t^c(\cdot)$, consider the continuation function $v_t^y(\cdot)$ before the choice of e_t and the realization of Y_t.

First, we calculate the continuation function when the regulator wants the banker to choose $e_t = 1$ and $\widehat{y}_t = y_t$. I need to solve the following main problem:

$$\begin{aligned} v_t^y(w_t^y; e_t = 1) = \quad & \max_{w_t^c(Y_t)} \quad E^1[Y_t + v_t^c(w_t^c(Y_t))] \\ & s.t. \quad E^1[w_t^c(Y_t)] - \psi \geq E^0[w_t^c(Y_t)] \qquad (IC1) \\ & \qquad w_t^c(Y_t) \geq w_t^c(y) + Y_t - y, \quad \forall y \leq Y_t \qquad (IC2) \\ & \qquad E^1[w_t^c(Y_t)] - \psi = w_t^y \qquad (PK) \end{aligned}$$

This problem is the same as in Case 1, but now the solution from the relaxed problem violates $(IC1)$. Thus, the regulator needs to choose a different solution. From $(IC2)$, I know that $w_t^c(Y_t) = \alpha + \gamma Y_t$, where $\gamma \geq 1$. From the promise-keeping constraint, $E^1[\alpha + \gamma Y_t] - \psi = w_t^y$. Thus, $w_t^c(Y_t) = w_t^y + \psi + \gamma(Y_t - \mu_1)$. Substituting this into $(IC1)$, I get $\gamma(\mu_1 - \mu_0) \geq \psi$. Since $v_t^c(\cdot)$ is concave and higher γ implies a mean-preserving spread in w_t^c, the regulator will pick the lowest possible γ satisfying $(IC1)$ and $(IC2)$ in order to minimize the variability of w_t^c. Thus, the solution will have $\gamma = \psi/(\mu_1 - \mu_0)$, and $w_t^c(Y_t) = w_t^y + \psi + \frac{\psi}{\mu_1 - \mu_0}(Y_t - \mu_1)$. Once I have $v_t^y(w_t^y; e_t = 1) = \mu_1 + E^1\left[v_t^c(w_t^c(Y_t))\right]$, $v_t^y(\cdot; e_t = 1)$ is also concave.

Second, we calculate the continuation function when the regulator wants the banker to choose $e_t = 0$ and $\widehat{y}_t = y_t$. I need to solve the following problem:

$$
\begin{aligned}
v_t^y(w_t^y; e_t = 0) = \quad & \max_{w_t^c(Y_t)} \quad E^0[Y_t + v_t^c(w_t^c(Y_t))] \\
& s.t. \quad E^0[w_t^c(Y_t)] \geq E^1[w_t^c(Y_t)] - \psi && (IC1) \\
& \qquad\;\; w_t^c(Y_t) \geq w_t^c(y) + Y_t - y, \quad \forall y \leq Y_t && (IC2) \\
& \qquad\;\; E^0[w_t^c(Y_t)] = w_t^y && (PK)
\end{aligned}
$$

The first constraint is an incentive-compatibility constraint for the banker such that it is optimal to exert low effort. The second is the truth-telling constraint. The last constraint is the promise-keeping constraint for the banker.

Before I solve the above problem, I define the following relaxed problem:

$$
\begin{aligned}
v_t^y(w_t^y; e_t = 0) = \quad & \max_{w_t^c(Y_t)} \quad E^0[Y_t + v_t^c(w_t^c(Y_t))] \\
& s.t. \quad w_t^c(Y_t) \geq w_t^c(y) + Y_t - y, \quad \forall y \leq Y_t && (IC2) \\
& \qquad\;\; E^0[w_t^c(Y_t)] = w_t^y && (PK)
\end{aligned}
$$

The solution of the relaxed problem is $w_t^c(Y_t) = w_t^y - \mu_0 + Y_t$. When we substitute $w_t^c(Y_t) = w_t^y - \mu_0 + Y_t$ into $(IC1)$, $(IC1)$ holds. Thus, the solution of the main problem is $w_t^c(Y_t) = w_t^y - \mu_0 + Y_t$. Once I have $v_t^y(w_t^y; e_t = 0) = \mu_0 + E^0\left[v_t^c(w_t^c(Y_t))\right]$, $v_t^y(\cdot; e_t = 0)$ is also concave.

Therefore, we have $v_t^y(w_t^y; e_t = 1) = E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))]$ and $v_t^y(w_t^y; e_t = 0) = E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$. In the second stage at period t given $v_t^c(\cdot)$, if the regulator wants the banker to choose $e_t = 0$ and $\widehat{y}_t = y_t$, she will choose $w_t^c(Y_t) = w_t^y - \mu_0 + Y_t$, and if she wants him to choose $e_t = 1$ and $\widehat{y}_t = y_t$, she will choose $w_t^c(Y_t) = w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1)$. Thus, given a value of w_t^y, the regulator will choose to induce $e_t = 0$ if $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \leq E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$, and $e_t = 1$ if $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \geq E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$.

Let $\widetilde{v}_t^y(w_t^y) = \max[v_t^y(w_t^y; e_t = 1), v_t^y(w_t^y; e_t = 0)]$. Moreover, since $v_t^y(\cdot; e_t = 1)$ and $v_t^y(\cdot; e_t = 0)$ are both concave, $\widetilde{v}_t^y(\cdot)$ is not concave whenever $v_t^y(\cdot; e_t = 1)$ and $v_t^y(\cdot; e_t = 0)$ intersect. Thus, the regulator is willing to introduce the randomization scheme to concavify the continuation function and enjoy higher utility. I denote by $v_t^y(\cdot)$ the convex hull of $\widetilde{v}_t^y(\cdot)$. In particular, if $v_t^y(w_t^y; e_t = 1) > v_t^y(w_t^y; e_t = 0)$, $\forall w_t^y$, then $\widetilde{v}_t^y(w_t^y) = v_t^y(w_t^y; e_t = 1)$, $\forall w_t^y$, and if $v_t^y(w_t^y; e_t = 1) < v_t^y(w_t^y; e_t = 0)$, $\forall w_t^y$, then $\widetilde{v}_t^y(w_t^y) = v_t^y(w_t^y; e_t = 0)$, $\forall w_t^y$. More interestingly, suppose $v_t^y(\cdot; e_t = 1)$ and $v_t^y(\cdot; e_t = 0)$ intersect at $w_t^y = \widehat{w_t^X}$. Let $\widehat{w_t^{y1}}$ be the value of w_t^y of the tangent point on the convex hull associated with $v_t^y(\cdot; e_t = 1)$, and $\widehat{w_t^{y0}}$ be the value of w_t^y of the tangent point on the convex hull associated with $v_t^y(\cdot; e_t = 0)$. Then, when $w_t^y \leq \widehat{w_t^{y1}}$, $v_t^y(w_t^y) = v_t^y(w_t^y; e_t = 1)$, and when $w_t^y \geq \widehat{w_t^{y0}}$, $v_t^y(w_t^y) = v_t^y(w_t^y; e_t = 0)$. Also, I denote by $\widehat{p}_t$ the probability used for randomization for the convex hull. In particular, if $\widehat{w_t^{y1}} < w_t^y < \widehat{w_t^{y0}}$, $\widehat{p}_t = (\widehat{w_t^{y0}} - w_t^y)/(\widehat{w_t^{y0}} - \widehat{w_t^{y1}})$. Then, for $\widehat{w_t^{y1}} < w_t^y < \widehat{w_t^{y0}}$, $v_t^y(w_t^y) = \widehat{p}_t v_t^y(\widehat{w_t^{y1}}) + (1-\widehat{p}_t) v_t^y(\widehat{w_t^{y0}})$. Figure A.II.1 shows an example in which the regulator chooses randomization between two continuation functions. Finally, $v_t^y(w_t^y)$ is also concave since it is a convex hull of concave functions.

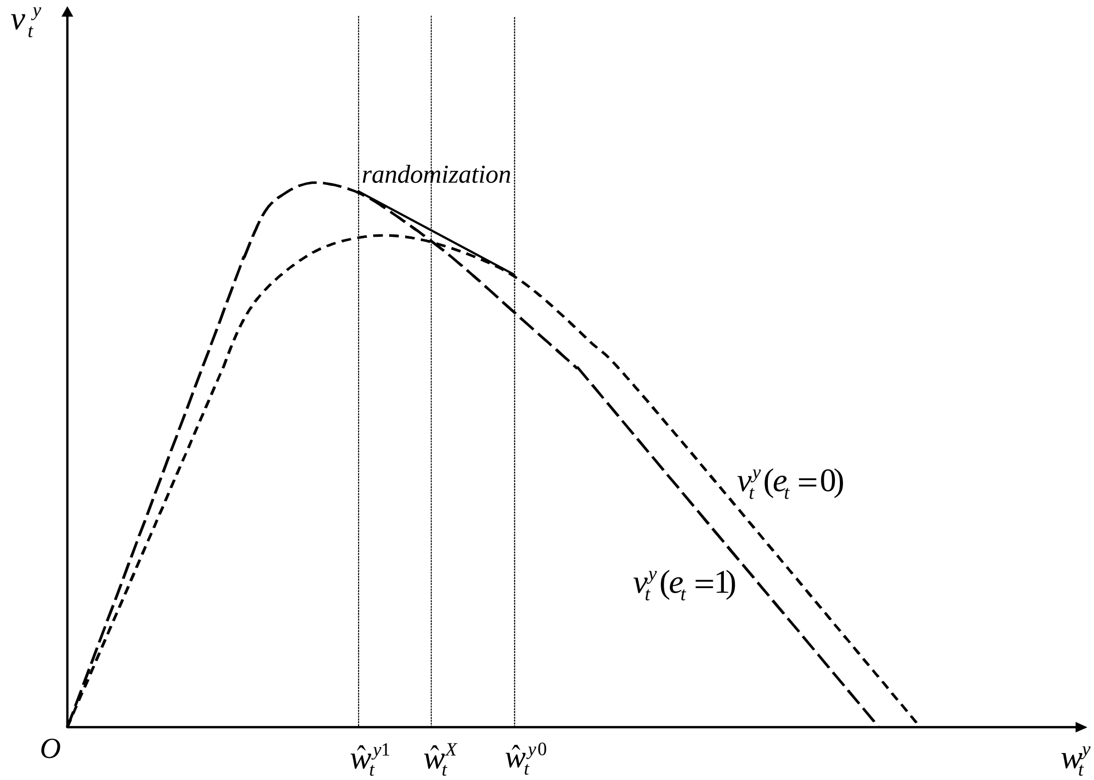

Figure A.II.1: Continuation Function with Randomization over Efforts

(Step 3)

Moving from period t to period $t-1$ involves discounting the continuation utilities of the banker and the regulator, so $w_{t-1} = \beta w_t^y$ and $v_{t-1} = \delta v_t^y$. Given $v_t^y(\cdot)$, the continuation function at the end of period $t-1$ is $v_{t-1}(w_{t-1}) = \delta v_t^y(\beta^{-1} w_{t-1})$. Finally, $v_t(\cdot)$ is also concave. Note that $\overline{w}_{t-1}^1 \equiv \beta \widehat{w_t^{y1}}$, and $\underline{w}_{t-1}^0 \equiv \beta \widehat{w_t^{y0}}$.

So far, I have solved for the continuation functions starting from $v_t(\cdot)$ to $v_{t-1}(\cdot)$. Therefore, starting from the linear $v_T(w_T)$, I can recursively solve for the continuation function at all stages and at all periods down to $v_0^c(w_0^c)$. When $T \to \infty$, I get the time-invariant continuation function $v(\cdot)$ at the end of every period.

The long-run behavior of the optimal allocation is determined by the dynamics of the state variable w over time and stages. The evolution of the state variable is as follows:

(1) If $\mu_1 - \mu_0 \geq \psi$,

$$w_{t-1} \Rightarrow \quad w_t^c = \beta^{-1} w_{t-1} + \psi - \mu_1 + y_t \Rightarrow \quad w_t = \begin{cases} \min(\overline{w}_t,\ \max(w_t^c, \underline{w}_t)) & \text{if } \lambda_{t+1} = 0 \\ \text{or} \quad 0 & \text{if } \lambda_{t+1} = 1. \end{cases}$$

(2) If $\mu_1 - \mu_0 < \psi$,

(i) when $w_{t-1} \leq \overline{w}_{t-1}^1$,

$$w_{t-1} \Rightarrow \quad w_t^c = \beta^{-1} w_{t-1} + \psi + \tfrac{\psi}{\mu_1 - \mu_0}(y_t - \mu_1) \Rightarrow \quad \begin{array}{l} w_t = \min(\overline{w}_t',\ \max(w_t^c, \underline{w}_t')) \\ \quad \text{if } \lambda_{t+1} = 0 \\ \text{or} \quad 0 \\ \quad \text{if } \lambda_{t+1} = 1; \end{array}$$

(ii) when $w_{t-1} \geq \underline{w}_{t-1}^0$,

$$w_{t-1} \Rightarrow \quad w_t^c = \beta^{-1} w_{t-1} + y_t - \mu_0 \Rightarrow \quad w_t = \begin{cases} \min(\overline{w}_t',\ \max(w_t^c, \underline{w}_t')) & \text{if } \lambda_{t+1} = 0 \\ \text{or} \quad 0 & \text{if } \lambda_{t+1} = 1; \end{cases}$$

(iii) when $\overline{w}_{t-1}^1 < w_{t-1} < \underline{w}_{t-1}^0$,

$$w_{t-1} \Rightarrow \begin{array}{ll} w_t^c = \widehat{w_t^{y1}} + \psi + \tfrac{\psi}{\mu_1 - \mu_0}(y_t - \mu_1) & \Rightarrow w_t = \min(\overline{w}_t', \max(w_t^c, \underline{w}_t')) \\ \text{with prob. } \widehat{p}_t & \quad \text{if } \lambda_{t+1} = 0 \\ \text{or } = \widehat{w_t^{y0}} + y_t - \mu_0 & \quad \text{or} \quad 0 \\ \text{with prob. } 1 - \widehat{p}_t & \quad \text{if } \lambda_{t+1} = 1. \end{array} \quad \blacksquare$$

Proof of Corollary 1.

In the first stage of period 0, the regulator chooses the initial transfer K_0 and the initial continuation utility of the banker w_0^c to maximize her utility $K_0 + v_0^c(w_0^c)$ subject to the banker's participation constraint $w_0^c \geq K_0$. Since the regulator will absorb all the rent, she will choose $K_0 = w_0^c$ and the potential banker will accept the allocation. The optimal choice of K_0 by the regulator is $K_0^* = w_0^{c*} \in [\overline{w}_0, \infty)$. However, if $w_0^{c*} > \overline{w}_0$, in the second stage of period 0, the regulator will choose $c_0(w_0^{c*}) = w_0^{c*} - \overline{w}_0$ and $w_0^* = \overline{w}_0$ holds. Thus, the regulator, without loss of generality, chooses $K_0^* = w_0^{c*} = w_0^* = \overline{w}_0$. $\blacksquare$

Proof of Proposition 2.

(Part 1)

In order to replicate the behavior of the optimal allocation, I need to find a deposit insurance premium $\widetilde{x}_t$ such that the law of motion of the level of book-value capital K_t replicates the law of motion of the banker's continuation utility w_t. In the initial period, the banker sets aside the initial capital $K_0 = \overline{K}_0 = \overline{w}_0$ in the form of cash. Then, the regulator allows the banker to take deposit of 1 dollar and invest it into the risky assets. In period 1, from the assumption that the banker uses all realized return y_1 to increase capital and the assumption that capital is held with cash, after the banker pays the deposit insurance premium, the level of capital becomes $K_1^d = K_0 + y_1 - \widetilde{x}_1$. Let $\widetilde{x}_1 = \mu_1 - \psi - K_0(\beta^{-1} - 1)$, when $\mu_1 - \mu_0 \geq \psi$. Then $K_1^d = w_1^c$. Now when $\mu_1 - \mu_0 < \psi$, we need to consider three different subcases. First, when $K_0 < \overline{K}_1^1$, we let $\widetilde{x}_1' = \frac{\psi}{\mu_1 - \mu_0}\mu_0 - K_0(\beta^{-1} - 1) - y_1(\frac{\psi}{\mu_1 - \mu_0} - 1)$; Second, when $K_0 > \underline{K}_1^0$, we let $\widetilde{x}_1' = \mu_0 - K_0(\beta^{-1} - 1)$; Third, when $\overline{K}_1^1 \leq K_0 \leq \underline{K}_1^0$, we let $\widetilde{x}_1' = \left[\frac{\psi}{\mu_1 - \mu_0}\mu_0 - K_0(\beta^{-1} - 1) - y_1(\frac{\psi}{\mu_1 - \mu_0} - 1)\right] + \left[\beta^{-1}(K_0 - \overline{K}_1^1)\right]$ with probability $\widehat{p}_1$, and $\widetilde{x}_1' = [\mu_0 - K_0(\beta^{-1} - 1)] - \left[\beta^{-1}(\underline{K}_1^0 - K_0)\right]$ with probability $1 - \widehat{p}_1$, where $\widehat{p}_1 = (\underline{K}_1^0 - K_0)/(\underline{K}_1^0 - \overline{K}_1^1)$. Then we get $K_1^d = w_1^c$.

Now the termination probability $p_1 = \max[\left(\underline{K}_1 - K_1^d\right)/\underline{K}_1, 0]$ is the same as the termination probability p_1^* in the ex-ante optimal allocation, the dividend $d_1 = \max\left(K_1^d - \overline{K}_1, 0\right)$ is the same as the banker's consumption c_1^*, and the randomization over two levels of efforts $\widehat{p}_t$ is also the same as the optimal randomization $\widehat{p}_t^*$ in the ex-ante allocation. In the optimal allocation, if the bank survives the stochastic termination, the regulator provides a higher continuation utility $\underline{w}_1$. Likewise, in this implementation, the regulator provides a subsidy or recapitalization, so that the level of capital becomes $\underline{K}_1 = \underline{w}_1$. After dividend payments and stochastic termination, $K_1 = w_1$. This can be repeated in all subsequent periods $t \geq 2$. Therefore, the law of motion of K_t^d and K_t replicates that of w_t^c and w_t, respectively, and I get $d_1(K_0, y_1) = c_1^*(w_0, y_1)$ and $p_1(K_0, y_1) = p_1^*(w_0, y_1)$.

(Part 2)

$<$ Case 1: $\mu_1 - \mu_0 \geq \psi$ $>$

Along the equilibrium path with $e_t = 1$ and $\widehat{y}^t = y^t$, the banker's continuation utility at the end of period t is given by $w_t = K_t$. Since $K_t \geq \underline{K}_t = \underline{w}_t$, I have $w_t \geq \underline{w}_t > J_t = 0$, so that the banker has no incentive to quit early or become undercapitalized without fully using the capital. From the definition of K_t^d, every dollar that the bank uses for private consumption, rather than for building up capital, leads to a reduction of w_t^c and K_t^d by one dollar. This is true even if the banker eats the capital up to the point where K_t^d is below $\underline{K}_t$. Therefore, the banker has no incentive to underaccumulate capital, and the strategy of the banker to use all realized profit to accumulate capital every period is optimal. Finally, given that $\widehat{y}_t = y_t$, the banker will choose $e_t = 1$, since $E_t^1 [d_t - \psi + w_t] > E_t^0 [d_t + w_t]$ holds for all t.

$<$ Case 2: $\mu_1 - \mu_0 < \psi$, $K_{t-1} < \overline{K}_t^1$ $>$

By the same proof in Case 1, the banker has no incentive to quit early or become undercapitalized without fully using the capital. From the definition of K_t^d, every dollar that the bank uses for private consumption, rather than for building up capital, leads to a reduction of w_t^c and K_t^d by $\frac{\psi}{\mu_1 - \mu_0}(> 1)$ dollar. Therefore, the banker will use all realized profit to accumulate capital. Finally, given that $\widehat{y}_t = y_t$, it is weakly optimal for the banker to choose $e_t = 1$, since $E_t^1 [d_t - \psi + w_t] = E_t^0 [d_t + w_t]$ holds.

$<$ Case 3: $\mu_1 - \mu_0 < \psi$, $\underline{K}_t^0 < K_{t-1}$ $>$

Similarly, the banker has no incentive to quit early or become undercapitalized without fully using the capital. From the definition of K_t^d, every dollar that the bank uses for private consumption, rather than for building up capital, leads to a reduction of w_t^c and K_t^d by one dollar. Therefore, the banker will use all realized profit to accumulate capital. Finally, given that $\widehat{y}_t = y_t$, the banker will choose $e_t = 0$, since $E_t^0 [d_t + w_t] > E_t^1 [d_t - \psi + w_t]$ holds.

$<$ Case 4: $\mu_1 - \mu_0 < \psi$, $\overline{K}_t^1 < K_{t-1} < \underline{K}_t^0$ $>$

Similarly, the banker has no incentive to quit early or become undercapitalized without fully using the capital. From the definition of K_t^d, every dollar that the bank uses for private consumption, rather than for building up capital, leads to a reduction of w_t^c and K_t^d by either one dollar or $\frac{\psi}{\mu_1-\mu_0}(>1)$ dollar. Therefore, the banker will use all realized profit to accumulate capital. Finally, given that $\widehat{y}_t = y_t$, when the regulator decides to induce $e_t = 1$ following randomization and charges $\left[\beta^{-1}(K_{t-1} - \overline{K}_t^1)\right]$ to the banker, it is weakly optimal for the banker to choose $e_t = 1$, since $E_t^1 \left[d_t - \psi + w_t\right] = E_t^0 \left[d_t + w_t\right]$ holds. On the other hand, when the regulator decides to induce $e_t = 0$ following randomization and subsidizes $\left[\beta^{-1}(\underline{K}_t^0 - K_{t-1})\right]$ to the banker, the banker will choose $e_t = 0$, since $E_t^0 \left[d_t + w_t\right] > E_t^1 \left[d_t - \psi + w_t\right]$ holds. ■

Appendix III: an example of Proposition 1 (3)

We assumed in Section 2.1 that $F^0(y) > F^1(y)$ holds for all $y \in [\underline{y}, \overline{y}]$, so that $\mu_1 > \mu_0$. Here, I provide an example for Proposition 1 (3), where the regulator chooses to induce $e_t = 1$ even though $\mu_1 - \mu_0 < \psi$. In particular, I pick a set of parameters, under which the regulator prefers to induce high effort in each period for a set of histories, even though it is optimal to induce low effort in the first-best sense.

In the second stage at period t given $v_t^c(\cdot)$, if the regulator wants the banker to choose $e_t = 0$ and $\widehat{y}_t = y_t$, she will choose $w_t^c(Y_t) = w_t^y - \mu_0 + Y_t$, and if she wants him to choose $e_t = 1$ and $\widehat{y}_t = y_t$, she will choose $w_t^c(Y_t) = w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1)$. Thus, given a value of w_t^y, the regulator will choose to induce $e_t = 0$ if $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \leq E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$, and $e_t = 1$ if $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \geq E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$.

Before we compare the determinants of the relative size of $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))]$ and $E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$, we need to consider the upper bound of each expected value. Since $v_t^c(\cdot)$ is concave, $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \leq \mu_1 + v_t^c(E^1[w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1)]) = \mu_1 + v_t^c(w_t^y + \psi)$ and $E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)] \leq \mu_0 + v_t^c(E^0[w_t^y - \mu_0 + Y_t]) =$

$\mu_0 + v_t^c(w_t^y)$, with equalities when $v_t^c(\cdot)$ is linear. Note that when $v_t^c(\cdot)$ is linear with the slope -1, $\mu_1 + v_t^c(w_t^y + \psi) = \mu_1 + v_t^c(w_t^y) - \psi < \mu_0 + v_t^c(w_t^y)$. Thus, when $v_t^c(\cdot)$ is almost linear, the regulator will induce $e_t = 0$ for all w_t^y. On the other hand, when $v_t^c(\cdot)$ is highly concave, the regulator may want to induce $e_t = 1$ for some w_t^y. In particular, from the results in comparative statics, we know that when L is large, the continuation function is almost linear, whereas when L is small, the continuation function is highly concave. Suppose $L = 0$. Then, when w_t^y is large and close to the dividend threshold $\overline{w}_t$, then $v_t^c(\cdot)$ is almost linear around $v_t^c(\overline{w})$, so that we can expect that the regulator will induce $e_t = 0$. On the other hand, when w_t^y is small and close to the termination threshold $\underline{w}_t$, then $v_t^c(\cdot)$ is highly concave around $v_t^c(\overline{w})$, so that we can expect that the regulator might want to induce $e_t = 1$.

The relative size of $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))]$ and $E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$ is determined by the following 4 factors. (1) Since $\frac{\psi}{\mu_1-\mu_0} > 1$, $\frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1)$ has a larger support than $Y_t - \mu_0$, and as $\frac{\psi}{\mu_1-\mu_0}$ increases, the support becomes larger. Since $v_t^c(\cdot)$ is concave in general, a larger support means a smaller value in expectation, other things being equal. Thus, in order to have $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \geq E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$, we need to set $\frac{\psi}{\mu_1-\mu_0}$ close to 1, which implies that the first-best continuation function, $v^{fb,0}(w) \equiv \delta\mu_0/(1-\delta) - w$, is close to the continuation function with $e_t^* = 1$, $\forall t$ and without any frictions, $v^{fb,1}(w) \equiv \delta(\mu_1 - \psi)/(1-\delta) - w$; (2) As was pointed out above, the more concave $v_t^c(\cdot)$ is, the more likely the regulator will induce $e_t = 1$. Therefore, we need to set L close to 0; (3) Given a value of w_t^y, $w_t^c(Y_t; e_t = 1)$ has $w_t^y + \psi$ as the center of the support, while $w_t^c(Y_t; e_t = 0)$ has w_t^y as the center. Since $v_t^c(\cdot)$ is concave, increasing and then decreasing, and has slope -1 beyond $\overline{w}_t$. a large ψ implies that the v_t^c becomes larger on average. Therefore, we need to pick a small value for ψ; (4) Finally, since $v_t^c(\cdot)$ is concave, from the results in comparative statics, we know that a mean-preserving spread lowers the continuation function, other things being equal. Thus, we can expect that, when F^0 has a much larger variance than F^1, while maintaining the property that $F^0(y) > F^1(y)$ holds for all $y \in [\underline{y}, \overline{y}]$, then we are more likely to have $E^1[Y_t + v_t^c(w_t^y + \psi + \frac{\psi}{\mu_1-\mu_0}(Y_t - \mu_1))] \geq E^0[Y_t + v_t^c(w_t^y - \mu_0 + Y_t)]$.

To show an example where the regulator induces high effort given certain histories, I choose the same parameter values in Section 5 with $L = 0$, $\mu_1 = 0.0060$, $\mu_0 = 0.0051$, $\psi = 0.0010$, $\underline{y} = -0.0040$ and $\overline{y} = 0.0160$. Let f^1 be the truncated normal distribution as in Section 5, and f^0 a half-normal-half-uniform distribution with a fatter left tail. Figure A.III.1 shows the distribution functions F^1 and F^0 corresponding to f^1 and f^0, respectively.

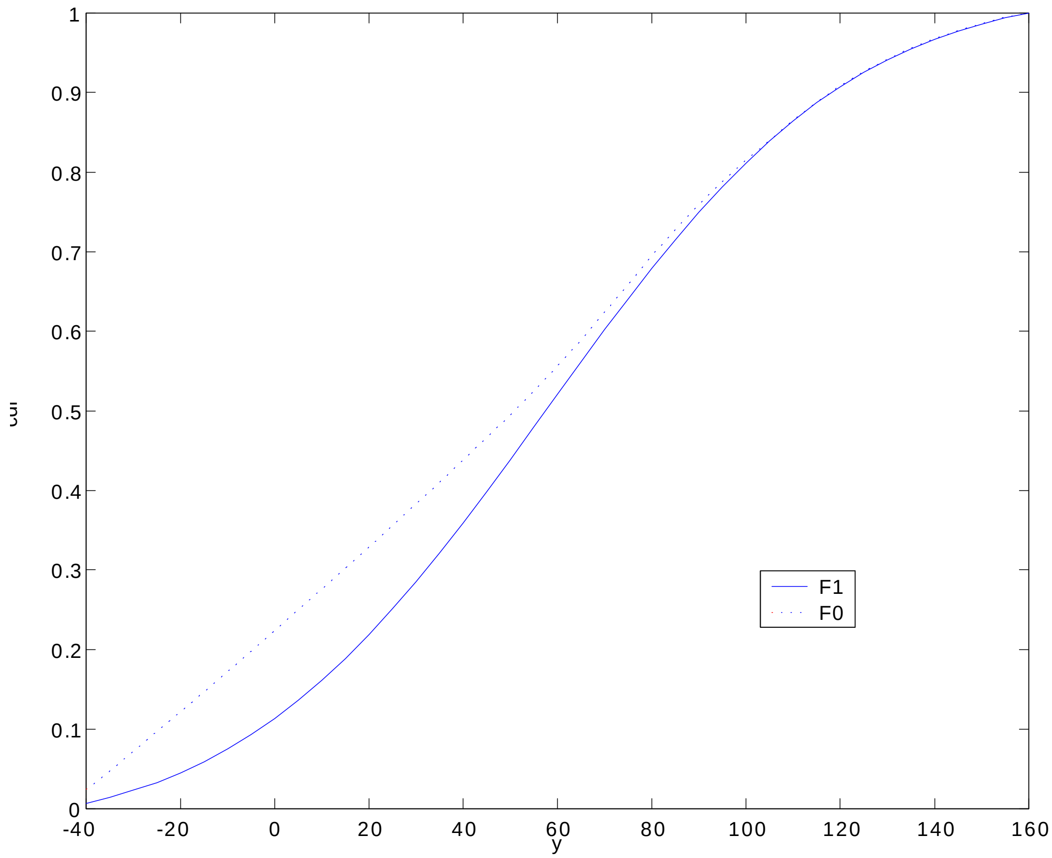

Figure A.III.1. Distribution Functions, F^0 and F^1

Given this set of parameters, we can calculate the continuation function under different choice of efforts by the regulator, as shown in Figures A.III.2 and A.III.3. By looking at $v_t^y(\cdot)$, we can see when the regulator wants to induce high effort or low effort or a randomization between these two. In particular, we have three regions in $v_t^y(\cdot)$. If w_t^y falls in the lower region, the regulator choose $e_t = 1$ with probability one, and induces high effort. This is because, even though it is socially costly to induce higher effort, the benefit from small variance due to high effort is greater than the cost. Given a relatively low continuation utility, it is hard for the regulator to give incentive by lowering the continuation utility more, so the regulator wants the banker to exert high effort and reduce the riskiness of the portfolio.

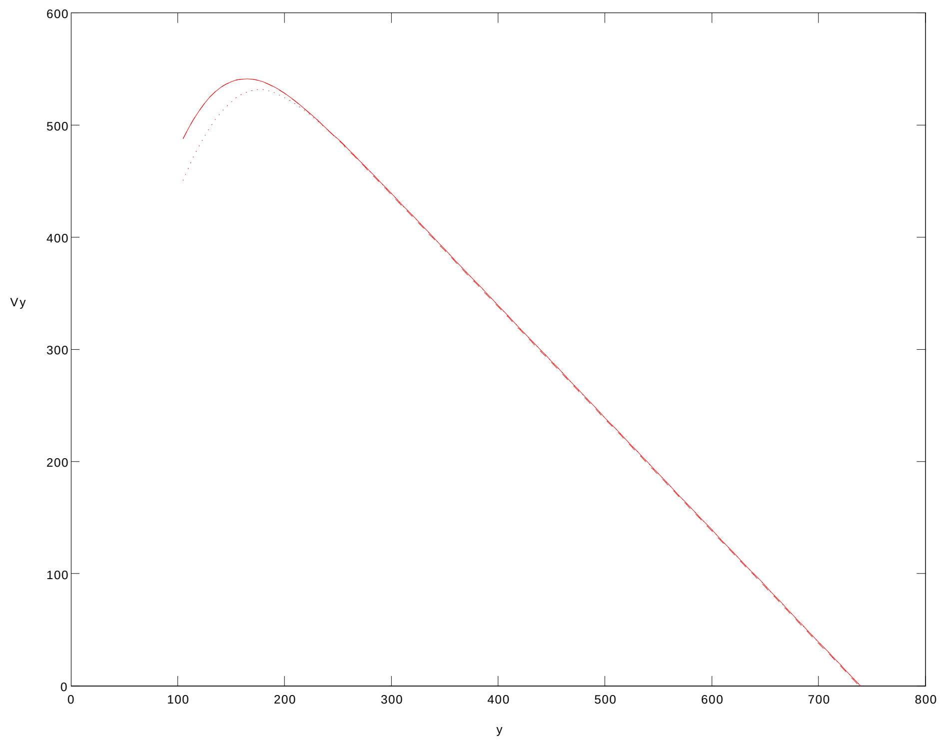

Figure A.III.2: Continuation Function v_t^y as a Convex Hull

On the other hand, if w_t^y falls in the high region, the regulator chooses $e_t = 0$ with probability one, and induces low effort. This is because, even though high effort reduces the variance and riskiness of the portfolio, the cost of inducing higher effort is larger than the benefit from small variance due to high effort. Given a relatively high continuation utility, it is easy for the regulator to give incentive by lowering the continuation utility more, so the regulator does not want the banker to exert costly effort. If w_t^y falls in the middle region, the regulator choose $e_t = 1$ with probability $\widehat{p}_t$ or $e_t = 0$ with probability $(1 - \widehat{p}_t)$. In this case, the regulator use randomization proportional to the level of w_t^y, with $\widehat{p}_t(w_t^y = \beta^{-1}\overline{w}_{t-1}^1) = 1$ and $\widehat{p}_t(w_t^y = \beta^{-1}\underline{w}_{t-1}^0) = 0$.

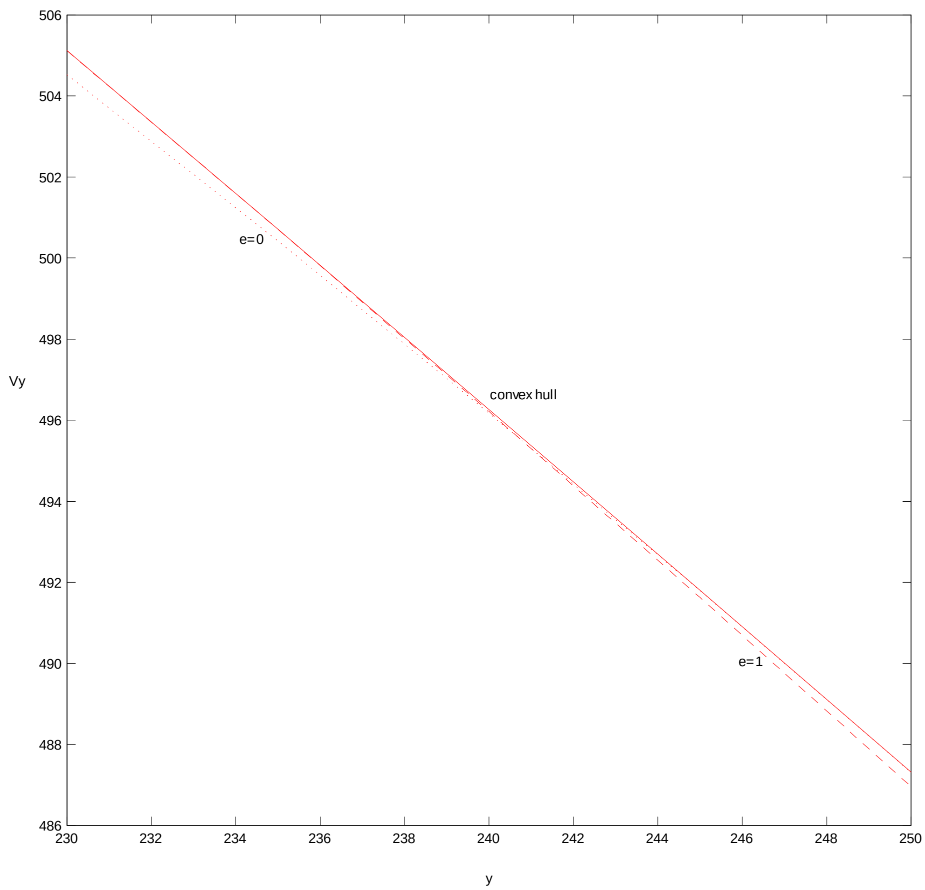

Figure A.III.3: Close-up of the Convex Hull

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