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Deposit insurance and regulation in a Diamond-Dybvig banking model with a risky technology*

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Summary. Three deposit insurance schemes are studied in a version of the Diamond-Dybvig banking model with a risky technology. The schemes include a full deposit guarantee and two alternatives which people have suggested as ways to limit the moral hazard problem of deposit insurance: deductible and coinsurance. Regulation to suppress the moral hazard problem under each scheme takes the form of solvency and incentive compatibility constraints. When the regulation is relaxed slightly, as it might be under regulatory error, the insurer's payout is lower under the alternatives than under the full guarantee. However, the coinsurance and deductible schemes are less effective at preventing bank runs than the full guarantee. Moreover, in some environments, even the full guarantee itself does not provide enough reassurance to rule out bank runs.

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1 Introduction

In a fractional reserve banking system, banks hold illiquid portfolios. Given their long-term assets, banks could not meet their promises to redeem short-term liabilities if depositors chose to withdraw all at once. The inherent instability of a fractional reserve banking system gives deposit insurance a role in reassuring depositors. Yet deposit insurance itself does not come without cost. It may distort bank behavior, making a bailout from the deposit insurance fund more likely. Kareken and Wallace [8], among others, have explored this moral hazard problem of deposit insurance, but only in environments without explicit benefits to banking and therefore without clear benefits to deposit insurance.

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Diamond and Dybvig [3] were the first to model an environment in which banking arises endogenously. The illiquid portfolio of the Diamond-Dybvig bank allows depositors to optimally share preference risk, yet also makes possible bank run equilibria. Economists have used many variations of the Diamond-Dybvig model to explore banking issues. Jacklin [6] and [7] modified the model's trading restrictions, Postlewaite and Vives [10] extended the number of periods in the model, Bhattacharya and Gale [1] modified the investment technology, Chari and Jagannathan [4] modeled random shocks to information on asset returns, Villamil [11] made the technology risky, and Lin [9] modeled a continuum of agent types. However, no one has used the Diamond-Dybvig model to explore the benefits and costs of deposit insurance. Diamond and Dybvig themselves devised a deposit insurance scheme, but one which Wallace [12] showed to be infeasible.

This paper explores three deposit insurance schemes in a version of the Diamond-Dybvig model with a risky technology but no aggregate preference risk. The risky technology provides additional scope for deposit insurance to affect the allocation of investment. The deposit insurance schemes include a full deposit guarantee and two alternatives, coinsurance and deductible, which people have proposed as ways to limit the moral hazard problem of deposit insurance (see Boyd and Rolnick [2]).

I find that for some specifications of preferences and technology, a full deposit guarantee prevents bank runs and allows agents to achieve the benefits of banking. However, for other environments, the deposit guarantee does not cover enough resources to rule out bank runs. The intuition here is the following. While the risky technology gives rise to state-dependent liabilities, deposit guarantees are modeled after federal deposit insurance, and hence cover only state-independent liabilities. So, in environments where the state-dependent liabilities (subordinated debt and equity) are large, the deposit guarantee may not provide adequate reassurance.

Regulation that suppresses moral hazard takes the form of two constraints on the bank's choice of liabilities and assets. The first, called a solvency constraint, requires the bank to be able to meet its deposit promises in each state, provided agents request the deposit withdrawal designed for their preference type. Note that the solvency constraint does not require the bank to choose its assets and deposit promises so that it could meet its promises under *any* possible set of withdrawal requests. Such a requirement would rule out the illiquidity that gives banking a role in the model. In contrast, the solvency constraint corresponds to a real-world requirement that banks hold assets that can be liquidated to meet *typical* withdrawal requests.

The second constraint, called an incentive compatibility constraint, requires the bank to design liabilities that appeal to the preference type for which they were intended. The incentive compatibility constraint corresponds to a real world regulatory review of a bank's assets and liabilities to ensure consistency with the bank's predicted timing of deposit withdrawal requests.

Moral hazard is held in check by these regulatory constraints, but re-emerges under the full deposit guarantee if regulators relax the solvency constraint even slightly. The bank would take advantage of such a regulatory error, bumping up against the relaxed constraint and thereby requiring a bailout. The greater the regulatory error, the larger the bailout.

Relaxing the solvency constraint under a deposit guarantee with coinsurance leads to a bailout, but one not as large as under the full deposit guarantee. Under a deposit guarantee with a deductible, a slight relaxation of the solvency constraint leads to no bailout at all. However, in some environments the full guarantee prevents runs, but the coinsurance and deductible schemes do not. So, lessening moral hazard requires trading off some of the power of deposit insurance to prevent bank runs.

2 The model

The economy has three dates, $t = 0, 1, 2$. There is no uncertainty as to the state of the world at dates 0 or 1. At date 2 the world will be in one of two states, $s \in S \equiv \{g, b\}$. The probability that the world will be in state s is $p(s)$, where $p(s) > 0$ and $p(b) + p(g) = 1$.

There are two generations of agents. The generation born at date 0 lives through all three periods. The generation born at date 2 lives only during that period. This second generation has sufficient endowments of the date 2 good to provide an adequate tax base for the deposit insurance guarantees discussed later. Their utility is increasing in the date 2 good. The first generation has N members, where N is a large member. These first generation agents are together at date 0, physically separated from each other at date 1, and together again at date 2. Each is endowed with one unit of a divisible investment good at date 0 and with nothing else. At date 1, these agents learn their type, which is private information. There is no aggregate uncertainty about types. Each agent has preferences given by

$$U(c) \equiv \sum_{h=1}^{2} P(h) \sum_{s \in S} p(s) u^h(c_1^h, c_2^h(s)),$$

where $h \in H \equiv \{1, 2\}$ is type, $P(h)$ is both the probability of an agent turning out to be type h and the proportion of the population that will be type h, c_1^h is the date 1 consumption of an agent of type h, and $c_2^h(s)$ is the date 2 consumption of an agent of type h in state $s \in S$. Here c stands for the bundle $(c_1^1, c_1^2, c_2^1(g), c_2^2(g), c_2^1(b), c_2^2(b))$. The utility that a person of type h gets from consuming x at date 1 and y at date 2, $u^h(x, y)$, is differentiable and increasing in x and y for each $h \in H$. Let u_x^h and u_y^h be the partial derivatives of u with respect to x and y. Agents' preferences satisfy $u_x^1/u_y^1 > u_x^2/u_y^2$, for all (x, y). Thus type 2 has the flatter indifference curve at any consumption bundle (x, y) and is the more patient consumer.

There are two technologies, one safe and one risky. Investment may be divided between the two technologies and must take place at date 0. Part or all of the gross returns on an investment in the safe or risky technology may be removed at date 1, but any goods removed must be consumed at once or lost. The safe technology has a gross return of 1 at date 1, or $R \geq 1$ at date 2. The risky technology has a gross return of $r < 1$ at date 1, or $R(s)$ for $s \in S$, at date 2. Assume $p(g)R(g) + p(b)R(b) \geq R$, and $R(b) \leq R \leq R(g)$.

There is a government with the ability to levy taxes on individuals. The government has no resources of its own.

3 Intermediation

Intermediation allows agents in the first generation to share preference risk. They draw up a contract at date 0 specifying the date 1 and date 2 withdrawals available to an agent who invests in the mutual organization at date 0. Date 1 and 2 withdrawals may depend on the type an agent claims to be at date 1. The date 2 withdrawal may also depend on the state of the world. Let B stand for the nonnegative fraction of the bank's assets invested in the safe technology. The consumption allocation c and technology choice B that solve the following problem will give the highest date 0 expected utility possible through banking without drawing on the resources of the date 2 generation.

The Upper-Bound on Date 0 Expected Utility Through Banking (No Taxes)

$$\max_{c,B} \sum_{h=1}^{2} P(h) \sum_{s \in S} p(s) u^h(c_1^h, c_2^h(s))$$

subject to

$$\sum_{h=1}^{2} P(h) c_1^h \leq B \tag{1}$$

(the date 1 physical resource constraint),

$$\sum_{h=1}^{2} P(h) c_2^h(s) \leq \left[B - \sum_{h=1}^{2} P(h) c_1^h \right] [R] + [(1-B)R(s)], \quad \forall s \in S, \tag{2}$$

(the date 2 physical resource constraints), and

$$\sum_{s \in S} p(s) u^h(c_1^h, c_2^h(s)) \geq \sum_{s \in S} p(s) u^h(c_1^i, c_2^i(s)), \quad \forall h, i \in H \tag{3}$$

(incentive compatibility).

The physical resource constraints require the bank to have enough resources in each state to cover its promises if agents ask for the withdrawal intended for their type. The incentive compatibility constraints require that, as of date 1 when an agent learns his type, the consumption allocation intended for his type gives him at least as much expected utility as the consumption allocation intended for the other type.

Since u^h is continuous, and the constraint sets are nonempty and compact, this maximization problem has a solution. Assume, for ease of exposition, that the solution is unique. Call the solution c^* and B^*.

As in Diamond and Dybvig, a set of liabilities which supports the upper bound on date 0 expected utility may be subject to the misrepresentation equilibria they call bank runs. Also as in Diamond and Dybvig, a suspension of convertibility scheme provides bank members with the upper bound on date 0 expected utility (see Hazlett [5]). Here, I explore deposit insurance as a substitute for suspension.

4 Bank liabilities, insurance schemes, and equilibrium

In accordance with actual U.S. deposit insurance, I assume that only state-independent liabilities qualify for guarantees. Optimal consumption allocations vary jointly with state and type declared, so in general they cannot be supported by a combination of state-independent deposits and a type-independent liability like equity. A version of subordinated debt, a date 2 payout which depends on state and type declared, may be needed. In therefore define three kinds of bank liabilities: deposits, subordinated debt, and equity. Subordinated debt has priority over equity, and deposits have priority over subordinated debt.

Definition 1. The bank promises the following bundle of deposit, subordinated debt and equity payouts to an agent who at date 0 invests one unit in the mutual bank.

I. Let $d \equiv (d_1^1, d_2^1, d_1^2, d_2^2)$, and $q \equiv (q^1, q^2)$, where d_t^h stands for the date t deposit promise to a person who declares type h, and q^h stands for the fraction of agents who declare type h. The bank will make date 1 deposit payouts as long as it has assets. If the bank's total assets before payouts at date 2 are less than $\sum_{h=1}^{2} q^h d_2^h$, then with no deposit insurance scheme in effect, the bank prorates date 2 deposits.

II. Let $L \equiv (L^1, L^2)$, where L^h stands for the subordinated debt promise to a person who declares type h. The bank will prorate the subordinated debt payouts if $\sum_{h=1}^{2} q^h L^h > \Psi(q, B, d, s)$, where $\Psi(q, B, d, s)$ is the assets left after date 2 deposit payouts. Formally, $\Psi(q, B, d, s) \equiv \max\{0, [\gamma][R] + [1 - B - \alpha] \cdot [R(s)] - [q^1 d_2^1 + q^2 d_2^2]\}$, where $\gamma \equiv \max\{0, B - [q^1 d_1^1 + q^2 d_1^2]\}$ is the amount of resources left in the safe technology after date 1 deposit payouts are made, and $\alpha = (1/r)\max\{0, q^1 d_1^1 + q^2 d_1^2 - B\}$ is the amount of resources pulled out of the risky technology to cover date 1 deposits. The above rule implies the actual subordinated debt payout to a person declaring type h, a payout I denote $\mathscr{L}^h(q, B, d, s, L)$.

III. Let $e(q, B, d, s, L) \equiv \Psi(q, B, d, s) - \sum_{h=1}^{2} q^h \mathscr{L}^h(q, B, d, s, L)$, where $e(q, B, d, s, L)$ is the equity payout.

I define three deposit insurance schemes, each of which is a type of guarantee on date 2 deposit payouts.

Definition 2

I. Full Guarantee: If the bank's total assets before payouts at date 2 are less than $\sum_{h=1}^{2} q^h d_2^h$, the government seizes the bank's assets and taxes the date 2 generation to pay (d_2^1, d_2^2).

II. Coinsurance: If the bank's total assets before payouts at date 2 are less than $\sum_{h=1}^{2} q^h d_2^h$, the government sizes the bank's assets and taxes the date 2 generation to raise X percent of the difference between $\sum_{h=1}^{2} q^h d_2^h$ and total bank assets. Bank members receive prorated shares of (d_2^1, d_2^2).

III. Deductible: If the bank's total assets before payouts at date 2 are less than Y percent of $\sum_{h=1}^{2} q^h d_2^h$, the government seizes the bank's assets and taxes the date 2 generation to pay Y percent of (d_2^1, d_2^2).

I now define equilibrium.

Definition 3. For a particular government deposit insurance scheme and bank date 0 choice of B, d, and L, an equilibrium is a date 1 declaration of type for every bank member such that each member's declaration maximizes his date 1 expected utility given the declarations of the others.

5 Equivalence between the upper-bound problem and the bank's problem under Deposit Insurance I, II, and III

The bank chooses its assets and liabilities to maximize date 0 expected utility. Suppose that the bank assumes its members will tell the truth about their type when incentive compatibility holds. Then, under a particular set of regulations and any of the deposit insurance schemes, the bank solves the same problem solved to find the upper bound on date 0 expected utility. The three constraints below, with $\varepsilon = 0$, form the particular set of regulations that make the bank's problem under any of the deposit insurance schemes equivalent to the upper bound problem.

$$\sum_{h=1}^{2} P(h) d_1^h \leq B \tag{4}$$

$$\sum_{h=1}^{2} P(h)[d_2^h] \leq \left[B - \sum_{h=1}^{2} P(h) d_1^h \right] [R] + [(1-B)R(b)] + \varepsilon \tag{5}$$

$$\sum_{s \in S} p(s) u^h(d_1^h, d_2^h + \mathscr{L}^h(P, B, d, s, L) + e(P, B, d, s, L))$$
$$\geq \sum_{s \in S} p(s) u^h(d_1^i, d_2^i + \mathscr{L}^i(P, B, d, s, L) + e(P, B, d, s, L)), \quad \forall h, i \in H, \tag{6}$$

where $P \equiv (P(1), P(2))$, the true proportions of the population that are each type.

When $\varepsilon = 0$, inequalities (4) and (5) are solvency-under-no-misrepresentation constraints, requiring that the bank be able to cover its deposit promises at each date and in each state as long as members truthfully declare their type. Constraint (5) with $\varepsilon > 0$ represents a relaxation of this constraint for date 2, which will be considered later. I interpret $\varepsilon > 0$ as regulatory error. Constraint (6) is an incentive compatibility constraint that applies as of date 1 when individuals learn their type. Incentive compatibility requires that individuals who believe others will be telling the truth get expected utility at least as high from liabilities designed for their own type as they get from liabilities designed for the other type.

The regulation helps clarify the role of subordinated debt as a state-dependent and, therefore, unguaranteed liability. Constraint (5) limits d, but not L, to promises the bank can cover regardless of the state of the world. Thus, the regulation prevents the bank from offering big deposit payouts that are apparently noncontingent, but which the bank could not in fact cover in the bad state.

The following lemma formalizes the claim that the bank solves the same problem under the regulation and any of the three deposit insurance schemes as it solves in the upper bound problem. The proof for this lemma and all of the following propositions and claims are given in the appendix, unless otherwise noted.

Lemma 1. Let $\varepsilon = 0$. (i) Any allocation satisfying (1)–(3) with (2) at equality is the truth telling equilibrium allocation of a portfolio satisfying (4)–(6) under any of the deposit insurance schemes.

(ii) Any portfolio that satisfies (4)–(6) has a truth telling equilibrium allocation which satisfies (1)–(3) under any of the deposit insurance schemes.

6 Results

Deposit Insurance I: the full guarantee

Proposition 1 shows that the full guarantee with appropriate regulation substitutes for suspension in some environments, but not in others. Even with full date 2 deposit guarantees, bank runs occur in environments where substantial portions of the date 2 liabilities must take the form of subordinated debt and equity, neither of which qualifies for the guarantee. Proposition 2 shows that without the incentive compatibility constraint, the bank designs non-incentive compatible liabilities that allow it to abuse the deposit guarantee. Proposition 3 shows that if regulators relax the solvency constraint, the bank will bump up against the relaxed constraint and require a bailout.

Proposition 1. Suppose the bank maximizes date 0 expected utility subject to Deposit Insurance I, the assumption that bank members will not misrepresent their type, and inequalities (4), (5) and (6) with $\varepsilon = 0$.

(i) There are environments (i.e. preferences and technologies) where there exist a liability structure and technology choice consistent with the bank's problem and under which the unique equilibrium consumption allocation is c^*.

(ii) There are environments where, for any liability structure that solves the bank's problem, there are equilibria with misrepresentation, i.e. bank runs.

To prove part (i), I use an environment without risk. For a more complicated environment in which the full deposit guarantee substitutes for suspension, see the proof to Proposition 4 part (ii). To prove part (ii) of Proposition 1, I consider an environment with risk in which both $c_2^{1*}(b)$ and $c_2^{2*}(b)$ are small relative to date 2 consumption in the good state. By the solvency constraint, the date 2 deposit promises must be no greater than $(c_2^{1*}(b), c_2^{2*}(b))$. With most of the date 2 payouts not guaranteed, there exist equilibria in with the patient misrepresent their type when they believe others will do so. See Hazlett [5] for the proof of part (ii).

Proposition 2. Suppose the bank maximizes date 0 expected utility subject to Deposit Insurance I and constraints (4) and (5) with $\varepsilon = 0$, but not constraint (6). Then for some environments there are technology choices and liability structures that require bailouts and have higher date 0 expected utility than c^*.

In the example in the proof, the bank designs a set of non-incentive compatible liabilities with a generous set of deposits for the patient and a miserly set of deposits for the impatient. The bank would have adequate resources to fund these deposits if people behaved according to type, but of course everyone wants the generous deposits supposedly designed for the patient.

Proposition 3. Suppose the bank maximizes date 0 expected utility subject to Deposit Insurance I, the assumption that members will not misrepresent their type, and inequalities (4), (5) and (6) with $\varepsilon > 0$. Then, any solution to the bank's problem has a truth telling equilibrium that requires a bailout equal to ε in the bad state.

To prove Proposition 3, I present a utility-maximization problem whose solution gives higher expected utility than c^*. This solution can be achieved as a truth telling equilibrium allocation of the bank's problem described in Proposition 3. The solution also gives higher expected utility than does any truth telling equilibrium from a banking portfolio in which constraint (5) does not bind. See Hazlett [5] for the proof.

Deposit Insurance II: coinsurance

Proposition 4 shows that coinsurance does not prevent runs in some environments where the full guarantee does. So, adopting coinsurance means losing some of the benefits of deposit insurance. Proposition 5 shows that the bank will require a bailout if the solvency constraint is slightly relaxed, as it might be under regulatory error. However, the bank does not require as large a bailout under coinsurance as it would if regulators made the same mistake under the full deposit guarantee.

Proposition 4. There exist environments in which (i) if the bank maximizes date 0 expected utility subject to Deposit Insurance II, the assumption that bank members will not misrepresent their type, and constraints (4), (5) and (6) with $\varepsilon = 0$, then for any liability structure and technology choice that solve the bank's problem, there are misrepresentation equilibria, while (ii) if the bank maximizes date 0 expected utility subject to Deposit Insurance I, the assumption that members will not misrepresent, and (4), (5) and (6) with $\varepsilon = 0$, then there exist a liability structure and technology choice such that c^* is the unique equilibrium allocation.

To prove Proposition 4, I use an environment in which c^* has the impatient consuming only at date 1 and the patient consuming only at date 2. Here $X = 80$, meaning that a bailout would equal 80% of the difference between total date 2 deposit liabilities and the bank's date 2 assets. So, if the bank were to run out of resources at date 1, the deposit guarantee would provide the patient with no more than 80% of $c_2^{2*}(b)$. With that guarantee, there exist equilibria in which the patient misrepresent their type and the bank depletes its resources at date 1. In the same environment with a full deposit guarantee, the patient prefer their guaranteed date 2 deposit payout of $c_2^{2*}(b)$ over the date 1 deposit payout intended for the patient.

Proposition 5. Suppose the bank maximizes date 0 expected utility subject to Deposit Insurance II, the assumption that members will not misrepresent their type, and constraints (4), (5), (6) and (7) with $\varepsilon > 0$, where (7) is the incentive compatibility of the payouts the bank will make under truth telling. Then, any solution to the bank's problem has a truth telling equilibrium with higher expected utility than that of c^* and requires a bailout.

The proposition is that with the solvency constraint relaxed ($\varepsilon > 0$), there exists an incentive compatible portfolio which improves on c^* and requires a bailout. From Lemma 1, we know that for the bank to improve on c^*, it must receive a bailout. All that remains is to show that there exists some incentive compatible portfolio in the feasible set which improves on c^*. To do so, I consider the case where deposits satisfy the following equality, which is feasible given the relaxed solvency constraint:

$$\sum_{h=1}^{2} P(h)d_2^h = \left[B - \sum_{h=1}^{2} P(h)d_1^h\right]R + [1-B]R(b) + \Gamma, \text{ for some } \Gamma \in [0, \varepsilon]. \tag{5'}$$

Here the bank promises date 2 deposits which exceed its state b resources by the amount Γ. Under truth-telling, the state b bailout would be $(X/100)\Gamma$. Thus the bank takes advantage of regulatory error by promising deposits which it cannot completely cover even with a bailout. In the proof of Proposition 5, I present a problem which is equivalent to the problem solved by a bank taking advantage of the regulatory error. Using this problem, I show that it is possible to improve locally on the upper bound.

Deposit Insurance III: deductible

Proposition 6 shows that the deductible scheme does not prevent runs in some environments where the full guarantee does. Like coinsurance, adopting the deductible scheme means giving up some of the power of the full guarantee in preventing runs. Proposition 7 shows that under a slight relaxation of the solvency restriction, the bank does not take advantage of the insurance. Unlike coinsurance, adopting the deductible means that the bank does not choose liabilities which result in a bailout when regulators err slightly.

Proposition 6. There exist environments in which (i) if the bank maximizes date 0 expected utility subject to Deposit Insurance III, the assumption that bank members will not misrepresent their type, and constraints (4), (5) and (6) with $\varepsilon = 0$, then for any liability structure and technology choice that solve the bank's problem, there are misrepresentation equilibria, while (ii) if the bank maximizes date 0 expected utility subject to Deposit Insurance I, the assumption that members will not misrepresent, and (4), (5) and (6) with $\varepsilon = 0$, then there exist a liability structure and technology choice such that c^* is the unique equilibrium allocation.

To prove Proposition 6, I use the same environment as in the proof of Proposition 4, with a deductible of 80%. Again, c^* has the impatient consuming only at date 1 and the patient consuming only at date 2. The patient are guaranteed only 80% of their date 2 deposits, a guarantee which can be no greater than 80% of $c_2^{2*}(b)$. This guarantee does not reassure the patient, whereas a full guarantee would.

Proposition 7. Suppose the bank maximizes date 0 expected utility subject to Deposit Insurance III, the assumption that members will not misrepresent their type, and constraints (4), (5), (6) and (7) with a small $\varepsilon > 0$, where (7) is the incentive compatibility of the payouts the bank will make under truth telling. Then, any solution to the bank's problem has a truth telling equilibrium with allocation c^* and no bailout.

To prove Proposition 7, I note that to get any sort of bailout at all, the bank would have to devise a portfolio with a ratio of date 2 bank assets to date 2 total deposit liabilities that was less than Y. If ε is small, the distortion required to make the bank eligible for a bailout would lower expected utility below that of c^*.

7 Conclusions

In the Diamond-Dybvig banking model, the optimal sharing of preference risk among depositors explains bank illiquidity and bank runs. This paper presents the first feasible deposit insurance schemes which may suppress these bank runs, thereby permitting optimal risk-sharing. The paper explores the moral hazard disadvantages of deposit insurance as well as its advantages in preventing runs. Coinsurance and deductible schemes are found to lessen the moral hazard problem relative to a full guarantee. The cost of using these alternatives is that they are less effective at preventing runs.

Appendix

Proof of Lemma 1, Part (i). Suppose c' and B' are an allocation and technology choice satisfying (1), (2) and (3), with (2) at equality. Define $B\sim = B'$, $d\sim_1^h = c_1'^h$, $d\sim_2^h = c_2'^h(b)$, and $L\sim^h = c_2'^h(g) - c_2'^h(b)$, for all h in H. By the definition of the portfolio and because c' and B' satisfy (1), the portfolio satisfies (4). Likewise, by the definition of the portfolio and because constraint (2) is satisfied at equality, the portfolio satisfies (5) with $\varepsilon = 0$.

I now show that c' is the allocation under the portfolio, truth telling and any of the deposit insurance schemes I, II or III. Suppose every bank member tells the truth. Then a person of type h receives $d\sim_1^h = c_1'^h$ at date 1. Note that because (4) is satisfied, the bank has sufficient resources to cover these promises. In state b at date 2, a person declaring type h gets $d\sim_2^h = c_2'^h(b)$. Because (5) holds at equality with $\varepsilon = 0$, the bank has sufficient resources to cover these deposit promises, with no residual. In state g at date 2, a person declaring type h gets $d\sim_2^h + L\sim^h = c_2'^h(g)$. Because (2) holds at equality, the bank has just enough resources to cover these promises.

By (3), c' is incentive compatible. Since c' is the allocation under $B\sim$, $d\sim$, $L\sim$, truth telling, and Deposit Insurance I, II, or III, the portfolio satisfies (6). The existence of a truth telling equilibrium under this portfolio is a direct consequence of the incentive compatibility of the allocation under truth telling. QED

Proof of Lemma 1, Part (ii). Suppose B'', d'', and L'' satisfy (4), (5) and (6) with $\varepsilon = 0$. From (6) we know that the allocation under truth telling is incentive compatible. So, this portfolio has a truth telling equilibrium. Consider the truth telling equilibrium. At date 1, a member of type h gets $c_1^h = d_1''^h$. Then, because d'' and B'' satisfy (4), the allocation satisfies (1). At date 2, a type h member gets $c_2^h(s) = d_2''^h + \mathscr{L}^h(P(1), B'', d'', s, L'') + e(P(1), B'', d'', s, L'')$. Because equity and subordinated debt are both residuals, (5) with $\varepsilon = 0$ implies (2). QED

Proof of Proposition 1, Part (i). Suppose there is no risk, so that $R(b) = R = R(g)$. Let $r = 0.5$.

Claim. The following liability structure and technology choice satisfy (4)–(6) and have a truth telling equilibrium with allocation c^*. Let $d_1^h = c^{*h}_1$, $d_2^h = c^{*h}_2$, $L^1 = L^2 = 0$, and $B = B^*$.

Proof. Because c^* satisfies (1), the portfolio satisfies (4). Because c^* satisfies (2) at equality, the portfolio satisfies (5) at equality. Then, under truth telling and Deposit Insurance I, the portfolio has the allocation c^*. Because c^* is incentive compatible, the portfolio satisfies (6), and has a truth telling equilibrium with allocation c^*. QED

Claim. Under the above portfolio, truth telling is the unique equilibrium.

Proof. Suppose there is an equilibrium with misrepresentation. Then someone must be lying about their type. The first person in line will not lie. With the entire date 2 allocation guaranteed, he is choosing between c^{*1} and c^{*2}, which are incentive compatible. No subsequent person will lie. As long as everyone before him has told the truth, the bank has enough resource to provide each individual with the choice between c^{*1} and c^{*2}. QED

We know from the Lemma that c^* is the best possible outcome consistent with the bank's problem. In this environment, there exist a liability structure and technology choice consistent with the bank's problem and under which the unique equilibrium allocation is c^*. QED

Proof of Proposition 2. Environment: $u^1 = \ln(c_1^1 + 0.01c_2^1)$, $u^2 = \ln(c_1^2 + c_2^2 + 1)$, $r = 0.5$, $R = R(g) = R(b) = 2$, $P(1) = 0.5$.

Claim. In this environment, $c^{*1}_1 = 1.25$, $c^{*2}_1 = c^{*1}_2 = 0$, $c^{*2}_2 = 1.5$, $B^* = 1$, and $U(c^*) = 0.57$.

Proof. See Hazlett [5].

Consider the following liability structure and technology choice: $d_1^1 = d_2^1 = 0$, $d_1^2 = 1$, $d_2^2 = 2$, $L^1 = L^2 = 0$, $B = 1$, which satisfy (4) and (5).

Claim. Given the above portfolio, it is a dominant strategy for each type to declare type 2, and the date 0 expected utility in this unique equilibrium is greater than $U(c^*)$.

Proof. Note that the bank can fully fund the date 1 deposit promises, since the bank would have to pay out at most $Nd_2^1 = N$ at date 1, exactly the resources the bank has. Also, the deposit insurance scheme fully guarantees the date 2 deposit promises.

For any equity payout E, declaring type 2 gives an impatient person higher utility than does truth telling: $\ln(1.02 + 0.01E) > \ln(0.01E)$. Likewise, for any equity payout E, truth telling gives a patient person higher utility than does declaring type 1: $\ln(4 + E) > \ln(1 + E)$. Since one's equity payout is independent of type declared, declaring type 2 is a dominant strategy for everyone.

The expected utility at date 0 is $P(1)\ln(d_1^2 + 0.01d_2^2) + P(2)\ln(d_1^2 + d_2^2 + 1) = 0.70 > U(c^*)$. QED

Claim. In the unique equilibrium for the environment above, the bank requires a bailout.

Proof. The bank's resources are depleted at the end of date 1. The date 2 payout of $2N$ comes entirely from the bailout. QED
QED

Proof of Proposition 4, Part (i). Environment: $u^1 = -(c_1^1 + 0.01c_2^1(s))^{-1}$, $u^2 = -(c_1^2 + c_2^2(s))^{-1}$, $r = 0.5$, $R(b) = 1$, $R = 2$, $R(g) = 4$, $P(1) = 0.5$, $p(g) = 0.5$.

Let $X = 80$.

Claim. In this environment, $c^{*1}_1 = 1.18$, $c^{*2}_1 = 0$, $c^{*1}_2(b) = c^{*1}_2(g) = 0$, $c^{*2}_2(b) = 1.44$, $c^{*2}_2(g) = 2.04$, $B^* = 0.9$.

Proof. See Hazlett [5].

Claim. Any liability structure and technology choice that has a truth telling equilibrium with allocation c^* also has misrepresentation equilibria.

Proof. Any liability structure that has a truth telling equilibrium allocation of c^* has $d^1_1 = 1.18$, and $d^2_1 = 0$, since only deposits can support date 1 consumption. Also, $d^1_2 = 0$, and $d^2_2 \leq 1.44$, since deposits are state-independent and therefore d^h_2 can be no greater than the minimum of $c^{*h}_2(b)$ and $c^{*h}_2(g)$, for type h in H, if the portfolio is to support c^*.

Regardless of the portfolio supporting c^*, if 80.5% of the population declare type 1, then the bank runs out of resources at date 1. To see that the bank's resources are depleted at date 1 when $q = 0.805$, note that when $q = 0.763$, all of the resources in the safe technology, $B = 0.9$, are used up. The resources invested in the risky technology have a date 1 return of $r = 0.5$, so once another 4.2% of the population has declared type 1, the bank runs out of resources: $(1 - B)r = 0.05$, and $0.05/1.18 = 0.042$. Then the only possible date 2 payouts will come from the deposit insurance guarantee of eighty percent of the total claim, which would mean $0.8d^2_2$ for each person declaring type 2.

Believing that $q \geq 0.805$ is a self-fulfilling prophesy under any portfolio supporting c^*. A patient person who believes $q \geq 0.805$ and is among the first 80.5% of the population in line will misrepresent because $u^2(d^1_1) > u^2(0.8d^2_2)$. An impatient person who believes $q \geq 0.805$ and is among the first 80.5% of the population in line will declare type 1 because $u^1(d^1_1) > u^1(0.8d^2_2)$. If $d^2_2 > 0$, then people in line after the resources run out will declare type 2 so that they can collect on the deposit insurance guarantee rather than getting nothing. If $d^2_2 = 0$ then people in line after the resources run out are indifferent between declaring type 1 or 2, since either option gives them an allocation of zero at each data. QED

Because the bank's problem is equivalent to the upper bound problem, the bank's solution will have a truth telling equilibrium with allocation c^*. Any such solution in this environment has misrepresentation equilibria. QED

Proof of Proposition 4, Part (ii). Under the same environment as above, when the bank solves its problem under Deposit Insurance I, the unique equilibrium allocation is c^*.

Claim. The following liability structure and technology choice satisfy (4)–(6) and have a truth telling equilibrium with allocation c^* under Deposit Insurance I: $B = B^* = 0.9$, $d^1_1 = c^{*1}_1 = 1.18$, $d^2_1 = c^{*2}_1 = 0$, $d^1_2 = c^{*1}_2(g) = c^{*1}_2(b) = 0$, $d^2_2 = c^{*2}_2(b) = 1.44$, $L^1 = c^{*1}_2(g) - c^{*1}_2(b) = 0$, $L^2 = c^{*2}_2(g) - c^{*2}_2(b) = 0.6$.

Proof. See Hazlett (1995).

Claim. Under the above portfolio, truth telling is the unique equilibrium.

Proof. Suppose there is an equilibrium with misrepresentation. Then someone must lie about his type. If the first person in line is a patient type, he will not lie. He has the choice between d_1^1 at date 1 and not less than d_2^2, from the deposit insurance guarantee, at date 2. Since $d_2^2 > d_1^1$, this patient person will truthfully declare. An impatient person would choose d_1^1 over anything less than $100d_1^1 = 118$ at date 2, which is considerably more than the bank could possibly offer at date 2. So if the first person in line is impatient, this person would not lie. Nor will any subsequent person of either type lie, since with each preceding person telling the truth, the bank always has enough resources to offer people a choice between date 1 consumption of d_1^1 and date 2 consumption of at least d_2^2, but not so much as to make the impatient prefer consuming at date 2. QED

Proof of Proposition 5. I present the following problem and show equivalence between it and the bank's problem when the bank takes advantage of the relaxed solvency constraint, i.e. when constraint (5) in the bank's problem is replaced by

$$\sum_{h=1}^{2} P(h)d_2^h = \left[B - \sum_{h=1}^{2} P(h)d_1^h\right]R + [1-B]R(b) + \Gamma, \tag{5'}$$

for some $\Gamma \in [0, \varepsilon]$. Then, using the problem presented below, I show it is possible to improve locally on c^*. From Lemma 1, improving on c^* requires a bailout.

Choose B, $c_1^1, c_2^1(b)$, $c_1^2, c_2^2(b)$, M^1, M^2 and Δ so as to maximize

$$\sum_{h=1}^{2} P(h) \sum_{s \in S} p(s) u^h(c_1^h, c_2^h(s))$$

subject to

$$\Delta \in [0, \varepsilon], \tag{0'}$$

$$\sum_{h=1}^{2} P(h)c_1^h \leq B, \tag{1}$$

$$\sum_{h=1}^{2} P(h)c_2^h(b) = \left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \left(\frac{X}{100}\right)\Delta, \tag{2a'}$$

$$c_2^h(g) = \begin{cases} c_2^h(b)\dfrac{\left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \left(\frac{X}{100}\right)[\Delta + (1-B)(R(b) - R(g))]}{\left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \left(\frac{X}{100}\right)\Delta} \\ \text{if} \left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(g) \leq \left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \Delta, \text{ or} \\ c_2^h(b)\dfrac{\left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \Delta}{\left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \left(\frac{X}{100}\right)\Delta} \\ + \dfrac{1}{P(h)}\left(\dfrac{M^h}{M^1 + M^2}\right)[(1-B)(R(g) - R(b)) - \Delta] \text{ otherwise}, \forall h \in H. \end{cases} \tag{2b'}$$

$$\sum_{s\in S} p(s)u^h(c_1^h, c_2^h(s)) \geq \sum_{s\in S} p(s)u^h(c_1^i, c_2^i(s)), \quad \forall h, i \in H, \tag{3}$$

and

$$p(b)u^h(c_1^h, d_2^h) + p(g)u^h\left(c_1^h, d_2^h + \max\left\{0, \frac{M^h}{P(h)[M^1+M^2]}[(1-B)(R(g)-R(b))-\Delta]\right\}\right)$$

$$\geq p(b)u^h(c_1^i, d_2^i) + p(g)u^h\left(c_1^i, d_2^h + \max\left\{0, \frac{M^i}{P(i)[M^1+M^2]}[(1-B)(R(g)-R(b))-\Delta]\right\}\right),$$

$$\forall h \in H, \tag{6'}$$

where

$$d_2^h = c_2^h(b)\frac{\left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \Delta}{\left[B - \sum_{h=1}^{2} P(h)c_1^h\right]R + [1-B]R(b) + \left(\frac{X}{100}\right)\Delta}.$$

Claim. (i) Any allocation satisfying (0′), (1), (2a′), (2b′), (3) and (6′) is the truth telling equilibrium allocation under Deposit Insurance II of a Portfolio that satisfies (4), (5′), (6) and (7).

(ii) Any portfolio that satisfies (4), (5′), (6) and (7) has a truth telling equilibrium allocation under Deposit Insurance II which satisfies (0′), (1), (2a′), (2b′), (3) and (6′).

Proof. See Hazlett [5].

Claim. There exists an allocation which satisfies (0′), (1), (2a′), (2b′), (3) and (6′) and which improves on c^*.

Proof. We have c^* feasible when $\Delta = 0$. Then (3) and (6′) are identical constraints, where (3) is the incentive compatibility of actual payouts under truth telling, and (6′) is the incentive compatibility of the promised payouts. If (3) does not bind under c^* for either type, then unused resources could be moved into the consumption allocation for one or both types without violating either incentive compatibility constraint. This movement would increase expected utility. If (3) binds under c^*, then it could bind for at most one type, so suppose without loss of generality that (3) binds for type h. Holding $c_1^i, c_1^h, c_2^i(b)$ and B constant, increase Δ slightly above zero to $\Delta^\wedge$, so that $c_2^h(b)$ rises slightly to $c^{\wedge h}_2(b)$. Note that (2a′) permits this change.

From (2b′) we have that, if $R(b) = R(g)$ or $B^* = 1$, then $c_2^i(g) = c^{*i}_2(b) = c^{*i}_2$, and $c_2^i(g) = c^{\wedge i}_2(b) = c^{\wedge i}_2$. Then (3) holds at strict inequality: $u^h(c^{*h}_1, c^{\wedge h}_2) > u^h(c^{*i}_1, c^{*i}_2)$, and $u^i(c^{*i}_1, c^{*i}_2) > u^i(c^{*h}_1, c^{\wedge h}_2)$.

Then, because $\Delta^\wedge$ is small and (3) holds at strict inequality, (6′) holds:

$$u^h\left(c^{*h}_1, c^{\wedge h}_2 \frac{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R + \Delta^\wedge}{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R + \left(\frac{X}{100}\right)\Delta^\wedge}\right) > u^h\left(c^{*i}_1, c^{*i}_2 \frac{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R + \Delta^\wedge}{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R + \left(\frac{X}{100}\right)\Delta^\wedge}\right),$$

and

$$u^i\left(c^{*i}_1, c^{*i}_2\frac{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R+\Delta^\wedge}{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R+\left(\frac{X}{100}\right)\Delta^\wedge}\right) > u^i\left(c^{*h}_1, c^{\wedge h}_2\frac{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R+\Delta^\wedge}{\left[1-\sum_{h=1}^{2} P(h)c^{*h}_1\right]R+\left(\frac{X}{100}\right)\Delta^\wedge}\right).$$

Or, if $B^* < 1$ and, of course, $R(g) > R(b)$, then from (2b′) we have

$$c^h_2(g) = c^{\wedge h}_2(b)\frac{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \Delta^\wedge}{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \left(\frac{X}{100}\right)\Delta^\wedge}$$
$$+\frac{1}{P(h)}\left(\frac{M^{\wedge h}}{M^{\wedge 1}+M^{\wedge 2}}\right)[(1-B^*)(R(g)-R(b))-\Delta^\wedge],$$

and

$$c^i_2(g) = c^{*i}_2(b)\frac{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \Delta^\wedge}{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \left(\frac{X}{100}\right)\Delta^\wedge}$$
$$+\frac{1}{P(i)}\left(\frac{M^{\wedge i}}{M^{\wedge 1}+M^{\wedge 2}}\right)[(1-B^*)(R(g)-R(b))-\Delta^\wedge].$$

Because $\Delta^\wedge$ is small and $c^{\wedge h}_2(b) - c^{*h}_2(b)$ is small, $M^{\wedge 1}$ and $M^{\wedge 2}$ can be chosen to divide the residual $[1-B^*][R(g)-R(b)]-\Delta^\wedge$ so that the allocation in state g is the c^* allocation for both types. Then, only the $c^h_2(b)$ component differs from the c^* allocation. So, again, (3) holds at strict inequality:

$$p(b)u^h(c^{*h}_1, c^{\wedge h}_2(b)) + p(g)u^h(c^{*h}_1, c^{*h}_2(g)) > p(b)u^h(c^{*i}_1, c^{*i}_2(b))$$
$$+ p(g)u^h(c^{*i}_1, c^{*i}_2(g)),$$

$$p(b)u^i(c^{*i}_1, c^{*h}_2(b)) + p(g)u^i(c^{*i}_1, c^{*i}_2(g)) > p(b)u^i(c^{*h}_1, c^{\wedge h}_2(b))$$
$$+ p(g)u^i(c^{*h}_1, c^{*h}_2(g)).$$

Then, because (3) holds at strict inequality and $\Delta^\wedge$ is small, (6′) is satisfied:

$$p(b)u^h\left(c^{*h}_1, c^{\wedge h}_2(b)\frac{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \Delta^\wedge}{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \left(\frac{X}{100}\right)\Delta^\wedge}\right) + p(g)u^h(c^{*h}_1, c^{*h}_2(g))$$

$$> p(b)u^h\left(c^{*i}_1, c^{*i}_2(b)\frac{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \Delta^\wedge}{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \left(\frac{X}{100}\right)\Delta^\wedge}\right) + p(g)u^h(c^{*i}_1, c^{*i}_2(g)),$$

and

$$p(b)u^i\left(c^{*i}_1, c^{*h}_2(b)\frac{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \Delta^\wedge}{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \left(\frac{X}{100}\right)\Delta^\wedge}\right) + p(g)u^i(c^{*i}_1, c^{*i}_2(g))$$

$$> p(b)u^i\left(c^{*h}_1, c^{\wedge h}_2(b)\frac{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \Delta^\wedge}{\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + [1-B^*]R(b) + \left(\frac{X}{100}\right)\Delta^\wedge}\right) + p(g)u^i(c^{*h}_1, c^{*h}_2(g)).$$

Thus, it is possible to improve on c^*. QED

Since we can improve on c^* as shown above, the solution to the bank's problem will give higher expected utility than c^*. From Lemma 1, the solution requires a bailout. QED

Proof of Proposition 6, Part (i). Consider the same environment as in Proposition 4. Let $Y = 80$. The proof is the same as that for Proposition 4 part (i), except that here the guaranteed payout of $0.8d^2_2$ comes from the deductible scheme's 80% guarantee of total date 2 deposit liabilities.

Proof of Proposition 6, Part (ii). Same as proof of Proposition 4, Part (ii).

Proof of Proposition 7. I show that if ε is small relative to $\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right] \cdot R + (1 - B^*)R(b)$, then the bank will not devise a portfolio that gives it a bailout under truth telling, because the distortion required to make the bank eligible for a bailout would lower expected utility below that of c^*. Without a bailout, the bank's problem is equivalent to the upper bound problem, so the bank's solution has an equilibrium allocation of c^* under truth telling.

To get any sort of bailout at all, the bank would have to have a portfolio with a ratio of date 2 bank assets to date 2 total deposit liabilities that was less than Y. We assume that ε is such that the ratio of

$$\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + (1 - B^*)R(b)$$

to

$$\left[B^* - \sum_{h=1}^{2} P(h)c^{*h}_1\right]R + (1 - B^*)R(b) + \varepsilon$$

is significantly greater than Y. Thus, the only way to get a bailout under truth telling is if the total date 1 promises were increased significantly from those consistent with c^*, so that the total date 2 resources under truth telling were significantly less than those consistent with c^*. Then the bank receives a bailout equal to

$$\max\left\{0, Y\left(\left[B-\sum_{h=1}^{2} P(h)d_1^h\right]R+(1-B)R(b)+\varepsilon\right)\right.$$
$$\left.-\left(\left[B-\sum_{h=1}^{2} P(h)d_1^h\right]R+(1-B)R(s)\right)\right\}$$

in state s. The actual infusion of resources in either state is less than or equal to $Y\varepsilon$. This infusion comes at the cost of distorting the allocation away from c^* and towards very high total date 1 payouts and very low total date 2 payouts, relative to c^*. Let ε be small enough so that even with an infusion of $Y\varepsilon$ at date 2, the distortion away from c^* necessary to receive a bailout under truth telling lowers expected utility to less than that of c^*. It is possible to choose ε this small, because the smaller is ε, the smaller the infusion of resources, and the greater the distortion from c^*.

Without a bailout under truth telling, the bank's problem is equivalent to the upper bound problem, so the bank can achieve c^* as the allocation of a truth telling equilibrium. Thus, under truth telling, the bank's solution has an allocation of c^* and no bailout. QED

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