Bank Runs, Welfare and Policy Implications*

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Abstract

This paper studies the welfare implications of various government policies that have been used to prevent bank runs. The benchmark model suggests that a bank run is a business-cycle-state-related phenomenon and it leads to the failure of the risk-sharing mechanism provided by the banking sector. Extensions of the model show that a number of policy instruments, including the suspension of convertibility of deposits, the taxation on short-term deposits, reserve requirement and blanket guarantee, turn out to be inefficient. Instead, I propose that a limited-coverage deposit insurance scheme or capital requirements can be welfare-improving.

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1 Introduction

The banking sector is vulnerable to bank runs because, by nature, banks issue liquid liabilities but invest in illiquid assets. When a bank run occurs, agents rush to the banks and withdraw their funds as quickly as possible. Banks are driven into bankruptcy due to liquidity problems. The breakdown of the banking industry distorts capital allocation and in most situations adds downward pressure to the real economy.

Historically, bank runs occurred frequently in Europe in the 19th century, and plagued the United States until the reform of the Federal Reserve System after the crisis of 1933. Over the past two or three decades, the bank run phenomenon has hit most emerging countries (see Lindgren et al 1996). Recent work by Kaminsky and Reinhart (1999, 2000) suggests a new phenomenon since the 1980s in that bank runs have also played a very important role in the so-called "twin crises" episodes.

Given the frequent occurrence of bank runs and the associated destabilizing costs, various policy instruments have been implemented to avoid the undesirable phenomena. In early time, policymakers paid more attention on crisis resolution, or, how to stop a bank run once it occurs. Such policy instruments include the suspension of convertibility of deposits and a penalty on short-term deposits (see Dwyer and Gilbert 1989). More recently, the policymakers have shifted their emphasis to crisis prevention. The proposed policies include holding appropriate provisions and capital reserves, strengthening banks' self-regulation, and designing deposit insurance schemes (see FSF 2001). In this paper, I try to explore the welfare effects of these policy instruments. The question will be addressed in two levels. First, can these policies successfully stop a bank run once it has occurred? Second, and more importantly, what are the *ex ante* effects of these policies, or, how does the introduction of these instruments change the operations of the banking sector?

To start the analysis, it is important to explain the microeconomic underpinnings of bank runs. There are two general views. One group of economists, including Diamond and Dybvig (1983), Cooper and Ross (1998), Chang and Velasco (2000, 2001), Park (1997) and Jeitschko and Taylor (2001), consider bank runs as self-fulfilling prophecies, unrelated to

the state of the real economy. There exist two equilibria in the banking sector. On the one hand, if no agent expects that a bank run will happen, the risk-sharing mechanism provided by the banking sector functions well and the economic resources are allocated in an efficient way. On the other hand, if all agents anticipate a bank run, then they all have the incentive to withdraw their deposits immediately and a bank run occurs as expected. Which of the two equilibria happens depends on the expectations of agents, which, unfortunately, are not addressed in their models.

The second view, as reflected in the empirical studies of Gorton (1988), Calomiris and Gorton (1991), Calomiris and Mason (2003), and recent theoretic work by Allen and Gale (1998), Zhu (2001) and Goldstein and Pauzner (2004), considers bank runs as a phenomenon closely related to the state of the business cycle. Allen and Gale (1998) show that the business cycle plays an important role in generating banking crises. They also show that bank runs can be first-best efficient and central bank intervention may be undesirable in some situations. Zhu (2001) develops a two-stage model in which agents make withdrawal decisions sequentially. He shows that bank runs happen only when agents perceive a low return on bank assets, and banks may deliberately choose a bank-run contract over a run-proof alternative. Goldstein and Pauzner (2004) show that when agents receive slightly noisy signals regarding the fundamentals, the economy will feature a unique equilibrium in which the occurrence of bank runs is determined by the state of the business cycle.

This paper follows the business cycle origin model developed in Allen and Gale (1998) for three major reasons. First, the model predicts that the occurrence of bank runs is related to economic fundamentals rather than a "sunspot" phenomenon. This prediction is consistent with recent empirical studies. Second, the model features a unique equilibrium and the probability of bank runs can be endogenously determined. This property eliminates the undesirable indeterminacy in the analysis. Third, and more importantly, the Allen-Gale framework allows us to study how the banks and agents will react to the government policies (or, the *ex ante* effects), which is absent from much of the existing literature and almost impossible in the multiple-equilibrium framework.

The benchmark model illustrates that the banking sector provides a risk-sharing mecha-

nism against the uncertainty in investors' liquidity needs. However, it can also be the source of instability because of the potential bank run problems. As a bank run is related with costly liquidation of bank assets, the equilibrium in a market economy is suboptimal.

Extensions of the model explore the welfare implications of various government policies. The main results are as follows. First, suspension of convertibility of deposits is both ex post and ex ante inefficient in preventing runs because it cannot distinguish between those with true liquidity needs and those who are running on the banks. Therefore, although bank runs are successfully stopped, it is very likely that some agents with true liquidity needs cannot withdraw their deposits in a timely manner, while other agents who do not have genuine liquidity needs will have their deposits repaid.

Second, neither taxation on short-term deposits nor liquidity /reserve requirement is efficient in preventing runs. While both of them are intended to increase the stability of the banking industry, they introduce a new distortion by restricting the banks' ability to invest in the more efficient way. This investment distortion could make a representative agent even worse.

Third, deposit insurance is an *ex post* efficient policy in preventing bank runs, but it is *ex ante* inefficient due to the "moral hazard" problems. Because the deposit insurance authority cannot perfectly monitor the banks' investment behavior, banks always have the incentive to behave aggressively by offering high interest rates. However, this paper proposes that substituting the full-coverage deposit insurance scheme with an interest-cap deposit insurance scheme can overcome the moral hazard problems and help the economy to achieve the socially optimal outcome.

Finally, imposition of a capital requirement, or equivalently an capital/asset ratio requirement, is an efficient policy to prevent bank runs in the limit. As the capital requirement increases, the market equilibrium gradually converges to the social optimum. The problem is, however, that the capital requirement might be very high to improve the welfare level significantly.

The remainder of this paper is organized as follows. Section 2 lays out the benchmark model and defines the competitive equilibrium in the market. Section 3 analyzes the welfare

properties of the competitive equilibrium in comparison with two types of socially optimal allocations. Section 4 discusses the welfare effects of six different policies. Section 5 concludes.

2 Benchmark model

The benchmark model is based on the framework developed by Allen and Gale (1998). There are three periods: $T = 0, 1, 2$. Two investment technologies are available in period 0: a storage technology and a risky technology. The storage technology is riskless: it yields a constant return of 1 in period 1 or 2. The risky asset yields a long-term return of R, which is randomly distributed between $[0, \infty]$ with a probability distribution function of $f(R)$. Besides, the risky asset is illiquid in that its liquidation value in period 1 is $(1-\tau)R$, where τ refers to the cost of early liquidation.[1] The risky asset is more productive in the long run but less efficient in the short run on the assumption that $(1-\tau)E(R) < 1 < E(R)$.[2]

There are a continuum of ex ante identical agents who have an endowment of 1 unit of consumption good at period 0. Agents are subject to a preference shock in the interim period. A fraction (α) of these agents turn out to be impatient, implying that they derive utility from period 1 consumption only; the others $(1-\alpha)$ will be patient, who only care for period 2 consumption. Their utility functions are

$$u^1(c_1, c_2) = u(c_1) \tag{1}$$

$$u^2(c_1, c_2) = u(c_2) \tag{2}$$

respectively, where $u(\cdot)$ satisfies $u'(\cdot) > 0$ and $u''(\cdot) < 0$.

The banking sector is perfectly competitive. In period 0, banks compete with each other by offering demand-deposit contracts which specify a short-term interest rate (r_1) and a long-

[1] The determination of liquidation value is exogenous in this paper. Some existing papers, such as Krugman (1998b) and Backus et al (1999), may shed light on future study in this direction. This paper employs the proportional liquidation value out of two considerations. First, due to a liquidity crunch, the assets are always sold at a lower price. Second, since the information is perfect in this model, the liquidation value of an asset should be associated with its true value.

[2] This is a necessary condition. A sufficient condition is $E[u[(1-\tau)R]] < u(1) < E[u(R)]$, where $u(\cdot)$ is the utility function for a representative agent.

term interest rate (r_2). Individual agents then decide whether to deposit their endowments with the bank or not.[3] After receiving the deposits, each bank chooses its optimal portfolio allocation between the safe asset ($1 - i$) and the risky asset (i).

In the interim period, the uncertainties in consumer types and asset return are resolved. Each agent learns his own preference type, and observes the return on bank assets. Agents then decide whether to withdraw their deposits from the banks or not.

There are two important assumptions following Allen-Gale framework. First, in either period 1 or period 2, if the bank's assets cannot meet the depositors' withdrawal demand, the banks should divide the assets equally among those withdrawing. Second, if there are more than one equilibrium, only the Pareto efficient equilibrium will be chosen. The other Pareto dominated equilibria, the so-called "inessential equilibria", are considered to occur with a probability of zero.[4]

Since the banking sector is competitive, a representative bank must earn a zero profit in equilibrium. Combined with the contract implementation rule, if a bank's own investment is zero (i.e., deposits make up 100% of the liabilities in the bank's balance sheet), it would choose a demand deposit contract that specifies only the short term interest rate r_1 and divides the remaining assets among all late consumers.[5]

Moreover, a bank run occurs in period 1 only when the asset return is low. The threshold return, R^*, is determined by the point where patient agents would get a payment of r_1 if they choose not to withdraw their deposits. When the return is lower, the long-term interest rate is lower than the short-term interest payment, therefore all investors will choose to run on the banks. Banks are forced to liquidate the risky assets and everyone gets a same amount of payment. When the return is higher, all patient agents would choose to wait in period

[3]To simplify the algebra, I assume that each agent has only two choices: either to deposit all his endowments or to deposit nothing. The main conclusions in this paper remain robust when agents are allowed to deposit a fraction of their endowments. Besides, if agents are indifferent between two contracts, they randomly pick up the deposit bank.

[4]Zhu (2001) and Goldstein & Pauzner (2004) provide the equilibrium-selection mechanism in which the Pareto dominated equilibrium can be eliminated.

[5]This is the standard demand deposit contract considered in Allen and Gale (1998). It can be considered as a contract that promised an extremely high long-term interest rate. The banks couldn't meet the promised payment in period 2 and therefore every late consumer gets an equal amount of payment according to the rule.

1 and receive a higher long-term interest payment. The inessential bank-run equilibrium, based on the equilibrium-selection assumption, is ruled out.

Combining these results, the competitive equilibrium in a market economy could be specified in the following problem:

$$
\begin{aligned}
\max_{\mathrm{r_1,i}} \quad & E[\gamma u(c_1(R)) + (1-\gamma)u(c_2(R)] && (3)\\
\text{s.t.} \quad & \gamma c_1(R) \leq 1 - i + iR(1-\tau) \\
& \gamma c_1(R) + (1-\gamma)c_2(R) \leq 1 - i + iR \\
& c_1(R) = r_1 && \text{if } \gamma = \alpha \\
& c_2(R) = \tfrac{1-i+iR-r_1\alpha}{1-\alpha} && \text{if } \gamma = \alpha \\
& c_1(R) = c_2(R) = 1 - i + (1-\tau)iR && \text{if } \gamma = 1 \\
& \gamma = \alpha \text{ if } 1 - i + iR < r_1 && \text{and } \gamma = 1 \text{ otherwise}
\end{aligned}
$$

In a competitive market, a representative bank maximizes the investors' expected utility taking into account the equilibrium outcomes in period 1. The first two conditions specify the budget constraint in period 1 and period 2, respectively. The other constraints refer to the withdraw outcomes and interest payments in every state. When the return is high, only impatient agents withdraw their deposits in period 1. Early consumers get the promised short term interest and late consumers divide the remaining assets in period 2. When the return is low, every agent chooses to run on the bank. Bank has to liquidate all of the risky assets below their intrinsic value, and each agent gets a payment that is less than the promised short-term interest rate. The aggregate early withdrawal, γ, turns out to be 1 in the latter case.

3 Socially optimal allocation

In this section, I introduce two types of socially optimal allocations and compare them with the equilibrium outcome in a market economy. Given the existence of two kinds of risk (the idiosyncratic risk in preference type and the aggregate risk in asset return) in the economy, a social planner can provide a risk-sharing mechanism through setting up a national bank

and allocating the resources according to the true liquidity needs of investors. Depending on different types of risk involved, I define two types of socially optimal allocations.

The first type of socially optimal allocation ("A-G optimum") is as defined as in Allen and Gale's paper, in which the idiosyncratic preference risk is completely diversified. In particular, the optimal outcome can be defined in the following problem (where γ is the amount of early withdrawal):

Definition 1 *(A-G optimum) An A-G optimum is defined by solving the following problem:*

$$\begin{aligned} \max_{r_1,i} \quad & E_R[\alpha u(r_1) + (1-\alpha)u(r_2(R))] \\ \text{s.t.} \quad & 1 - i \geq r_1\alpha \\ & r_2 = \tfrac{1-i+iR-r_1\alpha}{1-\alpha} \qquad \textit{if} \quad iR \geq (1-\alpha)r_1 \\ & r_1 = r_2 = 1 - i + iR \qquad \textit{if} \quad iR < (1-\alpha)r_1 \end{aligned} \tag{4}$$

In the optimal allocation, no costly liquidation would occur. When the asset return is high, all agents withdraw their deposits according to their true liquidity needs. When the asset return is low, the bank is not able to honor the promised payment. All depositors receive an equal amount of payment. The key difference between the optimal contract and the market equilibrium is that no risky assets are liquidated in period 1. Instead, the risky assets are carried over to period 2 and then divided among the remaining impatient agents. This optimal allocation diversifies the idiosyncratic preference risk completely without suffering the liquidation cost.

Notice that in the A-G optimum, the long-term interest rate is state-contingent. In other words, the aggregate risk related with the state of business cycle still exists. This reflects the fact the the aggregate liquidity is dependent on the return of bank assets. However, if the social planner is allowed to use the profits in good states to subsidize the interest payment is bad states, the aggregate risk can also be removed. Hence, a new type of social optimal contract can be defined as follows.

Definition 2 *(First-best allocation) A first-best allocation is defined in the following prob-*

lem:

$$\begin{aligned} \max_{\mathrm{r_1,i}} \quad & \alpha u(r_1) + (1-\alpha)u(r_2) \\ \text{s.t.} \quad & 1 - i \geq r_1\alpha \\ & r_2 = \tfrac{1-i+i\cdot E(R)-r_1\alpha}{1-\alpha} \end{aligned} \tag{5}$$

The first-best optimum is similar to the A-G optimum except that the social planner is able to provide a smoothing device across the state of the business cycle. This is reflected in the budget constraint in period 2, in which the social planner doesn't need to make zero profit in *every* state. Instead, a representative agent gets a same amount of long-term interest rate regardless of the state of the economy.

Lemma 1 *The first-best allocation is characterized by:*

$$u'(r_1^f) = E(R) \cdot u'(r_2^f) \tag{6}$$

$$i^f = 1 - r_1^f\alpha \tag{7}$$

$$r_2^f = \frac{i^f \cdot E(R)}{1-\alpha}$$

Proof: see Appendix A.

Eq. (6) is the familiar Euler equation for an optimal contract, which balances the marginal cost and marginal benefit of changing interest rates in equilibrium. Eq. (7) implies that the social planner should hold a minimum amount of safe assets for interim payment, and invest all the remaining deposits in the more productive technology. This is not surprising because there is no bank run in the socially optimal contract and therefore extra liquidity holding is undesirable.

Proposition 1 *Comparing the above three allocations, a representative agent obtains the highest welfare in the first-best allocation and the lowest welfare in the competitive equilibrium. In other words, the equilibrium in the market economy is suboptimal.*

Proof: see Appendix B.

This optimality sequence is not surprising. Figure 1 provides an intuitive explanation. While the first-best allocation provides an insurance against both the idiosyncratic risk and the aggregate risk, the A-G allocation only diversifies the idiosyncratic risk. In a market economy, the banking sector also insures against the idiosyncratic risk. This risk-sharing mechanism functions well when the economy is in a good state. However, when the asset return turns out to be low, all agents have the incentive to run on the banks and this risk-sharing mechanism breaks down. Due to the existence of the liquidation costs, the economy suffers large welfare losses. This destabilization effect, which is related to the fragility of the banking sector, partially cancels out the risk-sharing benefit and makes the competitive equilibrium sub-optimal.

For illustration, I provide a numerical example. Suppose that the proportion of impatient agents (α), the distribution of the asset return (R), the liquidation cost (τ), and the form of the utility function are as follows:

$$\alpha = 0.5, \qquad R \sim lognormal(0.25, 0.5^2), \qquad \tau = 0.5,$$

$$u(c) = \frac{(c+1)^{1-\beta}-1}{1-\beta}, \text{ where } \beta = 2$$

From Lemma 1, it is easy to define the first-best allocation. The optimal contract features $r_1^f = 1.0160$, $r_2^f = 1.4317$ and $i^f = 0.4920$. The expected utility for a representative agent is $E(U^f) = 0.5464$.

Similarly, the A-G allocation can be solved from problem (4). The contract features is characterized by $r_1^{AG} = 1.112$ and $i^{AG} = 0.444$. An impatient agent gets a short-term interest rate of $r_1^{AG} = 1.112$ when the return $R \geq 1.2523$. The long-term interest rate is state-contingent and is determined by distributing the remaining assets among late consumers. When the return is lower than 1.2523, every agent gets a same amount of payment of $0.556 + 0.444R$. The expected utility of a representative agent is $E(U^{AG}) = 0.5317$, which is lower than under the first-best allocation.

The equilibrium contract in a market economy, which is defined in problem (3), features $r_1^m = 0.87$,[6] $i^m = 0.44$ and $E(U^m) = 0.5187$. In equilibrium, a representative bank chooses a contract under which bank runs occur when $R < 0.7045$. Moreover, the banks are willing to hold extra safe assets $(1 - i - r_1\alpha > 0)$ in equilibrium. Holding extra liquidity has two opposite effects. (1) It could be welfare-improving for two reasons. First, since the probability of default (bank runs) is decreasing in the holding of riskless assets $(1 - i)$, an extra liquidity holding will make the banking sector less vulnerable to runs. Second, if a bank run occurs, holding more safe assets will reduce the liquidation costs. (2) However, holding extra liquidity is costly in that when no bank runs occur, the late consumers will receive a lower payment because the safe asset is less productive in the long run. The numerical results suggest that it is not optimal for the banks to choose a run-proof contract. However, it could be better to choose a contract that features a smaller probability of bank runs.

4 Welfare analysis of various policies

In this section, I extend the benchmark model and discuss the welfare effects of six different government policies.

4.1 Suspension of convertibility of deposits

Suspension of convertibility of deposits allows the banks to suspend the payment when the early withdrawing reaches a certain level (α) in the interim period. In the 19th and early 20th century, this policy was widely used during banking panics (see Dwyer and Gilbert 1989). Even in recent financial crises, some similar policies were adopted as temporary crisis resolution measures. For example, Malaysia decided to impose a wide range of capital controls[7] soon after the occurrence of the 1997 East Asian crisis.

The suspension policy was adopted because it was considered to be able to put a restric-

[6]The short-term interest rate is lower than 1 in the competitive equilibrium. This is partly because the liquidation value is very low in this model. Banks are providing a risk-sharing mechanism to the agents by offering them a smoother consumption path.

[7]The government announcement in September 1998 prohibited citizens from taking more than USD 100 out of Malaysia.

tion on agents' expectations, eliminate possible bank runs and therefore achieve the social optimum. However, this welfare-improving effect is not guaranteed unless certain distribution rules are adopted within the same package.

Proposition 2 *In a market economy, suspension of convertibility of deposits alone is inefficient to prevent bank runs.*

Given the existence of the suspension policy, the aggregate withdrawal in period 1 is always α. The payoff function is therefore r_1 if an agent chooses to withdraw early and $\frac{1-i+iR-r_1\alpha}{1-\alpha}$ if he chooses to wait. Intuitively, the agent will choose to wait when the return is high and to withdraw otherwise. In particular, when $R < \frac{r_1-1+i}{i}$, every agent has the incentive to withdraw his deposits early. The incentive to run on the banks when the return is low does not go away with the suspension restriction. But given the existence of the suspension policy, only a fraction (α) of agents are able to withdraw their deposits in period 1. Since the suspension policy cannot distinguish the true liquidity needs of individual agents, there is no guarantee that only impatient agents would receive early payment. In the worst scenario, all impatient agents are forced to wait and the policy brings about a severe misallocation of assets.

To summarize, the suspension policy alone has two effects. On the one hand, it protects the banks from runs and avoids the costly liquidation of risky assets in period 1. On the other hand, it causes the "misallocation effect" as there is no guarantee that only those agents with true liquidity needs will get paid in period 1.[8]

This misallocation effect can be removed if the suspension policy is implemented together with a distribution rule. Under the new distribution rule, once a suspension policy is implemented, the bank should make sure that every agent gets an equal amount of payment. It is relatively straightforward to show that the combination of these two rules could achieve the A-G optimum.

[8]Gorton (1985) also points out that the suspension policy is not efficient if the proportion of impatient consumers (α) is stochastic and unknown ex ante. In comparison, Proposition 2 is even stronger in that it implies that, even there is no uncertainty in the aggregate liquidity shock and α is known in advance, the suspension policy is not efficient either.

4.2 Taxation on short-term deposits

A second policy that has been used during banking crises is the imposition of taxes (or penalties) on early withdrawals. It is argued that this policy could prevent bank panics indirectly by increasing the cost of early consumption. In practice, Chile imposed a tax on short-term capital outflows in the early 1990s. The question is: is this policy an efficient way to prevent bank runs?

Suppose that the government imposes a tax rate t on short-term deposits, and then returns the collected taxes to all agents as a lump sum transfer. Obviously, under this tax regime, it is the after-tax payoff that affects the patient agents' withdrawal decisions. Taking into account the early-withdraw tax and government transfer, the after-tax payments are:

$$c_1(R) = (1-t)r_1 + tr_1\alpha \text{ if } \gamma = \alpha \tag{8}$$

$$c_2(R) = \begin{cases} 1-i+iR(1-\tau) \text{ if } \gamma = 1 \\ \dfrac{1-i+iR-r_1\alpha}{1-\alpha} + tr_1\alpha \text{ if } \gamma = \alpha \\ 1-i+iR(1-\tau) \text{ if } \gamma = 1 \end{cases} \tag{9}$$

$$c_1(R) \leq c_2(R) \tag{10}$$

The incentive compatibility constraint (Eq. 10) implies that a bank run would occur when the return is low. When $R < R^* \equiv \frac{r_1(1-t)(1-\alpha)+r_1\alpha-1+i}{i}$, patient agents will choose to run on the bank and everyone gets the same amount of payment. However, when $R \geq R^*$, the long-term interest rate is higher than the short-term interest rate so long as no bank runs occur. Therefore, patient agents would report their preference types truthfully.

The banks' optimization problem is:

$$\max_{r_1,i} \int_0^{R^*} u(1-i+iR(1-\tau))f(R)dR + \int_{R^*}^{\infty}[\alpha u(r_1(1-t)+\alpha r_1 t) + (1-\alpha)u(\tfrac{1-i+iR-r_1\alpha}{1-\alpha} + \alpha r_1 t)]f(R)dR \tag{11}$$

$$\text{s.t} \quad 1-i \geq r_1\alpha$$

where R^* is defined as above.

The taxation policy aims to prevent banks runs by reducing the short-term consumption, thereby inducing the patient agents not to run on the banks. However, this policy is

inefficient as the early consumption tax introduces distortions to banks' investment decisions. In particular, banks are now confronted with a dilemma. If they wish to maintain the after-tax short-term interest rate at the initial level, they have to invest less in the risky assets, therefore suffering the productivity loss. However, if they wish to maintain the level of investment in the more productive assets, the after-tax short-term interest rate has to be reduced, thereby damaging the risk-sharing benefit. This conflict will usually lead to under-investment phenomenon and cause welfare losses. Moreover, the bank-run phenomenon still could arise unless the tax is extremely high.

Proposition 3 *The imposition of tax on early withdrawing will cause investment distortion and make the equilibrium outcome even worse.*

Proof: In problem (11), it is interesting to notice that a contract (r_1, i) under a tax regime (with tax rate t) will lead to the same outcome as a contract that features $r_1' = r_1(1-t)+\alpha r_1 t$ and $i' = i$.

(i) $R^{*\prime} = \frac{r_1'-1+i'}{i'} = \frac{r_1(1-t)+\alpha r_1 t-1+i}{i} = R^*$. It implies that under both contracts, a bank run occurs if and only if $R < R^*$.

(ii) $r_2'(R) = \frac{1-i'+i'R-r_1'\alpha}{1-\alpha} = \frac{1-i+iR-r_1\alpha}{1-\alpha} + \alpha r_1 t = c_2(R)$. It means that when no bank runs occur, the late consumers get the same amount of consumption under the two regimes.

Therefore, to find the equilibrium outcome under the tax regime is exactly the same as in the benchmark model except that the liquidity constraint (period 1 budget constraint) changes from $1-i \geq r_1'\alpha$ to $1-i \geq r_1\alpha$. Since r_1' is smaller than r_1 when $t > 0$, the range of i diminishes. The new optimization problem must yield an inferior solution to the benchmark model, suggesting that the taxation policy will only make things even worse.

4.3 Reserve/liquidity requirement

A common practice in bank regulation is to mandate that banks hold a certain fraction of their deposits in the form of cash or high-liquidity assets. This reserve requirement, or liquidity requirement, is treated as very important because it is believed that more liquidity holdings can improve the health of individual banks and avoid bank runs.

However, the liquidity requirement also brings about undesirable effects. Suppose the reserve ratio requirement is rr, or, the minimum ratio of riskless assets is rr. A representative bank's problem is exactly the same as solving problem (3), except under an extra restriction that the holding of riskless assets must be greater than the minimum requirement ($1-i \geq rr$). Therefore, the equilibrium outcome under reserve requirement cannot be better than the market equilibrium. When the reserve requirement is binding, a representative agent is actually worse off because the banks' ability to invest in the more productive technology has been restrained.

4.4 Full-coverage deposit insurance (FCDI) scheme

The role of deposit insurance has been a very controversial topic. In some early work (Diamond and Dybvig 1983), deposit insurance is considered as an efficient policy to achieve the social optimum. However, follow-up research suggests that policymakers should be more cautious. Cooper and Ross (2002) point out that deposit insurance scheme eliminates the occurrence of bank runs but at the same time reduces agents' incentive to monitor the banks. Krugman (1998a), after the 1997 East Asian crisis, argues that the implicit deposit insurance policy causes a severe moral hazard problem and leads to imprudent "overinvestment", which is the core element in the economic crash. A related debate is the role of the IMF. Some economists (Sachs 1998, Radelet and Sachs 1998) argue that a lender of last resort is an efficient way to prevent self-fulfilling financial panics; therefore the IMF should be expanded and a larger amount of funds should be provided more quickly when financial crises occur. At the other extreme, Schwartz (1998) and Calomiris (1998) criticise the IMF for acting as lender of last resort, arguing that such action causes moral hazard problems and in the long run increases the fragility of the world financial system. They suggest that IMF bailout schemes should be avoided.

This section explores the ex post and ex ante effects of an FCDI scheme, or a blanket guarantee scheme. Under an FCDI scheme, the central bank (or a public authority) guarantees depositors the promised interest rate payment when the banks are insolvent. And the funding source comes from the insurance premium collected from the banks. Throughout

this paper, I assume that the banks pay the insurance premium out of their own funds rather than out of deposits. This assumption is important for two reasons. First, if the insurance premium comes out of deposits, it is easy to show that this deposit insurance system cannot be sustainable. Since the banks have nothing to lose, they would always choose to offer very high interest rates from the beginning and to request for a bail-out from the deposit insurance authority in period 2. Hence the insurance scheme breaks down. Second, when the banks have to pay the insurance premium out of their own pockets, the form of demand deposit contract will change. In particular, the contract would specify both a non-state-contingent short-term interest rate (r_1) and a non-state-contingent long-term interest rate (r_2). In a competitive market, a representative bank makes positive profits in good states, loses partial or all of its own money in bad states, and its expected profit is zero.

Under an FCDI scheme, a bank pays the insurance premium (δ). Agents receive a short-term interest rate of r_1 or a long-term interest rate of r_2 as promised. So long as $r_1 \leq r_2$, no patient agent has the incentive to misreport his preference type. As a result, no bank runs happen in period 1.

Lemma 2 *A full-coverage deposit insurance plan is ex post efficient in that it can eliminate bank runs and avoid costly liquidation.*

A more interesting problem is whether the FCDI scheme is ex ante efficient. To put it another way, how will the banks respond to the FCDI scheme in choosing the deposit contract and portfolio structure? And how high an insurance premium should be charged in order to keep the plan sustainable?

I first study the behavior of banks under a given insurance premium δ. The banks' problem is:

$$\max_{r_1, r_2} \quad \alpha u(r_1) + (1-\alpha)u(r_2) \tag{12}$$

$$\text{s.t.} \quad 1 - i \geq r_1 \alpha \tag{13}$$

$$R^* = \frac{r_1\alpha + r_2(1-\alpha) - 1 + i}{i}$$

$$\int_{R^*}^{\infty} i(R - R^*) \cdot f(R) dR \geq \delta \tag{14}$$

$$i = argmax \ \int_{R^*}^{\infty} i(R - R^*) \cdot f(R)dR$$

The objective function reflects the fact that there is no bank run in period 1 when an FCDI plan exists. All impatient agents get a consumption of r_1 and all patient agents receive r_2. The first constraint is the usual budget constraint in period 1. The second constraint specifies the threshold return R^* below which a rescue package is needed. It comes from the condition that $\frac{1-i+iR^*-r_1\alpha}{1-\alpha} = r_2$. When $R > R^*$, banks are able to earn positive profits. When $R < R^*$, banks are insolvent and a rescue package is implemented by the deposit insurance authority. The third constraint is the incentive compatibility constraint for banks to join the insurance plan, which states that banks must be able to earn enough profits to cover the insurance premium payment. The last constraint determines the choice of portfolio structure, which should maximize the banks' expected profits in equilibrium.

Lemma 3 *The equilibrium contract (r_1, r_2) in problem (12) should satisfy the following conditions:*

$$1 - i = r_1\alpha \tag{15}$$

$$\int_{R^*}^{\infty} i(R - R^*) \cdot f(R)dR = \delta \tag{16}$$

$$u'(r_1) = u'(r_2) \cdot E[R|R \geq R^*] \tag{17}$$

where $R^* = \frac{r_2(1-\alpha)}{1-r_1\alpha}$.

Proof: see Appendix C.

In equilibrium, both the budget constrain and the incentive compatibility constraint are binding. First, banks would choose to hold no excess liquidity and to maximize their investments in the more productive technology. The underlying reason lies in the fact that the deposit insurance authority has promised to bail out when the return is low. By maximizing the investment on risky assets, the banks could maximize their profits. Second, the incentive compatibility constraint is binding because the expected profit for a representative bank must be zero in a competitive market.

Eq. (17) is the familiar Euler equation. The intuition is as follows: if the short-term interest rate is reduced by an amount of $\triangle r$, the agent will suffer a loss of $u'(r_1) \cdot \triangle r$ in the

short run. But the long run payment will be increased by $E[R|R \geq R^*] \cdot \triangle r$.[9] In equilibrium, the marginal cost and marginal benefit should be equalized.

Notice the difference between the first-order conditions in the first-best allocation and in the FCDI system. In the first-best environment, the marginal rate of transformation is determined by the unconditional mean of asset return. In the latter case, however, the banks do not care about the losses for the deposit insurance authority. Therefore, the marginal rate of transformation is related to the conditional mean of asset return. This "extortion effect", which refers to the fact that banks ignore the negative externality of higher bailout costs and offer very high interest rates, prevents the economy from achieving the first-best optimum.

Lemma 4 *Under the full-coverage deposit insurance plan, the first-best allocation is feasible but not chosen in the market economy.*

Proof: I first show that the first-best allocation contract (r_1^f, r_2^f, i^f) is feasible when the central bank charges an insurance fee of $\delta^f = \int_{E(R)}^{\infty} i^f [R - E(R)] \cdot f(R) dR$. Under this FCDI scheme,

- Banks can make enough profits to cover the insurance premium payment. From Lemma 1, $r_2^f(1-\alpha) = i^f \cdot E(R)$ and $i^f = 1 - r_1^f \alpha$, therefore $R^* = \frac{r_2^f(1-\alpha)}{1-r_1\alpha} = E(R)$. From the definition of δ^f, the expected profit for the banks equals the insurance premium payment.

- The bailout costs can be covered by the insurance premium payment because

$$\begin{aligned} & \int_0^{R^*} [r_1^f \alpha + (1-\alpha) r_2^f - (1 - i^f + i^f R)] \cdot f(R) dR \\ = & \int_0^{E(R)} i^f [E(R) - R] \cdot f(R) dR \\ = & \int_{E(R)}^{\infty} i^f [R - E(R)] \cdot f(R) dR \\ = & \delta^f \end{aligned}$$

[9] Consider the profit function for the banks. Banks lose nothing when $R < R^*$ (central bank will bail out) and gain the profits when $R \geq R^*$. The $\triangle r$ increment in risky assets will bring the banks an expected profit of $E[R|R \geq R^*] \cdot \triangle r$.

Unfortunately, the first-best allocation will not be chosen in the market economy. Comparing the two Euler equations, it is obvious that banks will not choose the first-best contract. Instead, banks will offer the depositors higher interest rates and the expected bailout costs for the central bank are higher than δ^f.

To maintain a credible FCDI scheme, the central bank has to charge a higher insurance premium δ^* that is able to cover its bailout costs. In equilibrium,

$$\int_0^{R^*} i(R^* - R) \cdot f(R)dR = \delta^*$$

Combining with the equilibrium conditions (15)-(17), the self-sustainable market equilibrium $(r_1^*, r_2^*, i^*, \delta^*)$ under an FCDI scheme is characterized by:

$$\begin{cases} r_2^*(1-\alpha) & = & (1 - r_1^*\alpha)E(R) \\ u'(r_1^*) & = & u'(r_2^*) \cdot E[R|R \geq E(R)] \\ \delta^* & = & \int_0^{E(R)} i^*[E(R) - R] \cdot f(R)dR \\ i^* & = & 1 - r_1^*\alpha \end{cases}$$

Proposition 4 *A full-coverage deposit insurance brings stability into the banking sector and improves the welfare of investors. However, it cannot achieve the first-best optimum due to the "moral hazard" problem.*[10]

I still use the numerical example to illustrate the welfare effects of the FCDI scheme. Figure 2 shows the contracts that the banks will choose under different levels of insurance fees. When the insurance fee increases, the banks will offer a lower average interest rate, the deposit insurance authority's balance sheet improves, and the welfare for a representative agent is lower. In particular, the starred points illustrate the fact that the first-best allocation will not be realized under the deposit insurance scheme (when $\delta = \delta^f$) as a result of the moral hazard problems. Instead, the equilibrium contract in which the premium payments can fully cover the bailout costs features: $\delta^* = 0.1677$, $r_1^* = 0.8321$, $r_2^* = 1.6993$, $i^* = 0.584$ and $E(U^*) = 0.5419$. It is inferior to the first-best allocation.

[10] The moral hazard consequences of deposit insurance schemes have also been discussed in previous studies. See Bryant (1980), Gennotte and Pyle (1991) and Matutes and Vives (1996).

4.5 Interest-cap deposit insurance (ICDI) scheme

Due to the existence of moral hazard problems under the FCDI scheme, policymakers have been looking for different variants of deposit insurance plans to mitigate or to remove this adverse effect. Two major variants were proposed in the recent report by the Financial Stability Forum (2001): a limited-coverage deposit insurance scheme and coinsurance. The limited-coverage deposit insurance scheme protects the principal and interest of each depositor up to a certain limit.[11] The coinsurance system specifies that only a proportion of deposits (including interest) are protected. In this subsection, I propose that a similar variant of deposit insurance scheme, which I refer to as the "interest-cap deposit insurance" (ICDI) scheme, can remove the moral hazard problems and achieve the first-best optimum.

Under an ICDI scheme, the maximum protection each depositor can receive is his principal and a certain amount of interest that does not exceed a predetermined cap $(\overline{r} - 1)$. In other words, the maximum payment a depositor can receive upon bank default is $\overline{r}$.[12] As shown below, a well-designed ICDI can overcome the conflict of interests between the deposit insurance authority and deposit banks, and achieve the first-best social optimum. By setting the interest cap on protection, the deposit insurance authority indirectly imposes a cap on the interest rate that a deposit bank would offer to agents.

Proposition 5 *An interest-cap insurance scheme is efficient in preventing bank runs and can achieve the first-best social optimum.*

Proof: see Appendix D.

In particular, an ICDI scheme with $\overline{r} = r_2^f$ and deposit insurance premium $\delta^f = \int_{E(R)}^{\infty} i^f[R - E(R)] \cdot f(R)dR$ is able to achieve the first-best social optimum. Appendix D shows that, under this ICDI scheme, banks will choose the first-best contract $(r_1 = r_1^f,\ r_2 = r_2^f)$. On the one hand, the banks will not choose a lower r_2 because they always have the incentive to maximize the utilization of deposit insurance. More importantly, on the other hand, the

[11] For example, the maximum protection for each depositor is USD 100,000 in the United States and CAD 60,000 in Canada.

[12] In this model, this ICDI scheme is actually the same as the limited-coverage deposit insurance scheme. They differ when agents are heterogeneous.

banks have no incentive to increase the interest rate offer as under the FCDI scheme. Under the FCDI scheme, the banks choose to increase the long-term interest rate and reduce the short-term interest rate (to maintain expected zero profit). The marginal cost of the lower short-term interest rate will be compensated by the fact that the long-term interest rate is higher *in all states*. However, under the ICDI scheme, this incentive no longer exists because a representative agent cannot earn a higher long-term interest rate when banks are insolvent due to the existence of a coverage limit. Therefore, the initial moral hazard problem, in which banks increase the central bank's bailout costs through offering higher interest rates, no longer exists under the specific ICDI scheme.[13]

One important implication from Appendix D is that the ICDI scheme should cover both the principal and part of (or all) interest rate payments. This is not surprising. The maximum protection must be greater than the short-term interest rate to induce the agents not to run on the banks.[14]

4.6 Capital requirement

Another widely used tool in bank regulation is the imposition of a capital requirement. In general terms, a capital requirement specifies how much equity a bank should hold for each unit of deposits. This equity can be invested in either technology and can be used to repay the depositors when asset returns are low. Throughout this paper, I use κ to represent the capital requirement for each unit of deposit.[15] From the definition, the capital requirement relates to the banks' own funds.

Suppose individual banks invest $1 - i + \kappa$ in the safe assets and i in the risky assets. The existence of capital reduces the probability of bank runs because it increases the banks' solvency ability. Using the same methodology, equilibrium aggregate early withdrawal, γ,

[13]This conclusion is based on the assumption that all banks are faced with the same productivity shock. In reality, considering the fact that banks are also confronted with idiosyncratic productivity shocks with different distribution, a uniform interest cap is not able to catch this heterogeneity.

[14]In practice, the deposit insurance authority may choose a lower interest cap or the coinsurance scheme out of other concerns that are missing in this model, such as to reduce the bailout costs of deposit insurance schemes, or to increase the large agents' incentive to monitor the banks.

[15]Obviously, a capital requirement of κ is equivalent to a capital ratio of $\frac{\kappa}{1+\kappa}$ because assets = liabilities = deposits + capital.

equals α when $R \geq \frac{r_1-(1-i+k)}{i}$ and $L = 1$ otherwise. There are three possible outcomes (see Figure 3):

(1) $R < R_1$, where $R_1 \equiv \frac{r_1-(1-i+k)}{i}$

When the return on risky assets is very low, the bank default is unavoidable. All agents rush to banks to withdraw their deposits. A bank run happens and banks lose their entire capital.

(2) $R_1 \leq R < R_2$, where $R_2 \equiv \frac{r_1\alpha+r_2(1-\alpha)-(1-i+k)}{i}$

When the return is within the intermediate level, the banks are not in immediate danger of default and patient agents are willing to wait in the interim period and no bank runs happen. But banks have to use all their capital to repay the demand-deposit contracts. Patient agents receive a payment of $r_2^e = \frac{1-i+k+iR-r_1\alpha}{1-\alpha}$, which is higher than r_1 but less than the promised long-term interest rate, r_2.

(3) $R \geq R_2$

When the return on risky assets is high, all late consumers receive the promised interest rate, r_2, in period 2. Bank runs never occur. The payoff function for banks is subtler. Define $R_3 \equiv \frac{r_1\alpha+r_2(1-\alpha)-(1-i)}{i}$. When $R_2 \leq R \leq R_3$, banks have to use part of their capital collateral to pay the late consumers. When $R \geq R_3$, the capital collateral is untouched and the banks earn positive profits.

Combining the above analysis, under a certain capital requirement (κ), the optimization problem for a representative bank is:

$$\max_{r_1,r_2} \quad \int_0^{R_1} u[1-i+\kappa+iR(1-\tau)] \cdot f(R)dR \tag{18}$$

$$+ \int_{R_1}^{R_2} [\alpha u(r_1) + (1-\alpha)u(\frac{1-i+\kappa+iR-r_1\alpha}{1-\alpha})] \cdot f(R)dR$$

$$+ \int_{R_2}^{\infty} [\alpha u(r_1) + (1-\alpha)u(r_2)] \cdot f(R)dR$$

$$\text{s.t.} \quad i \text{ maximizes } \int_0^{R_2} -\kappa \cdot f(R)dR + \int_{R_2}^{\infty} i(R-R_3) \cdot f(R)dR \tag{19}$$

$$\int_0^{R_2} -\kappa \cdot f(R)dR + \int_{R_2}^{\infty} i(R-R_3) \cdot f(R)dR \geq \kappa[E(R)-1] \tag{20}$$

$$1-i+\kappa \geq r_1\alpha \tag{21}$$

The objective function, which specifies the expected utility for a representative agent,

consists of three parts that correspond to three possible outcomes. Eq. (19) states that the choice of portfolio structure should maximize the banks' expected profits. Eq. (20) is the incentive compatibility constraint for individual banks, which suggests that the expected profits for banks should at least cover the opportunity costs of the collateral assets in equilibrium. Since the risk-neutral bankers can always invest their equity assets in the more productive technology and obtain an expected return of $E(R)$, the banking sector should assure them the same payoff. Eq. (21) specifies the minimum holding of riskless assets.

The welfare effects of this policy, accordingly, are different in different states of the economy. When the return is high ($R \geq R_2$), both idiosyncratic risk and aggregate risk are eliminated. Agents receive constant payments based on their true liquidity needs. When the return is within the intermediate level ($R_1 \leq R < R_2$), impatient agents receive a constant payoff but the patient agents receive a state-contingent payoff. Therefore only the idiosyncratic risk is diversified. The banking sector defaults in period 2 but no bank runs happen in period 1. When the return is low ($R < R_1$), banks go into bankruptcy in period 1 and the risk-sharing mechanism breaks down. The destabilization effect leads to costly liquidation and welfare losses.

To summarize, imposition of a capital requirement gives the banks a partial defense against bank runs without causing new distortions. It cannot eliminate the occurrence of bank runs, though. However, as the capital requirement increases, the threshold returns R_1 and R_2 decrease, suggesting that the probability of default and the probability of bank runs are smaller. Therefore the risk-sharing benefit dominates and the market equilibrium gradually converges to the first-best optimum.

Proposition 6 *As κ increases, the equilibrium contract in a market economy converges gradually to the first-best optimum.*

Proof: see Appendix E.

Figure 4 provides the results from numerical simulations. The horizontal axis represents the capital ratio ($\frac{\kappa}{1+\kappa}$). As the capital ratio increases, the equilibrium contract in the market economy, including the interest rate structure, and investment portfolio, converges to the

first-best optimum. Besides, the banking sector becomes more stable as a higher capital requirement is imposed.

However, a potential problem with the capital requirement policy is the speed of convergence. Theoretically, the market equilibrium converges to the social optimum only as the capital ratio approaches 100%. In the given numerical example, the welfare in the market equilibrium reaches the A-G optimum when the capital ratio is about 12%, and is equivalent to the outcome under the FCDI scheme ($\delta^* = 16.77\%$) when the capital ratio is 38%. Such level of capital requirement is obviously very high. The scope of the risk-sharing mechanism is therefore largely limited by the ability of bank owners to raise capital, an issue ignored in this paper but could be extremely important in practice.

5 Conclusion

This paper proposes a model in which bank runs are closely related to the state of the business cycle. Extensions of the model study the welfare effects of six different policies: suspension of convertibility of deposits; taxation on short-term deposits; reserve requirement; full-coverage deposit insurance schemes; interest-cap deposit insurance schemes and capital requirements.

The results suggests that policymakers should be cautious in implementing these rules as most of them would cause side effects or even hurt the performance of the banking sector. The preliminary analysis in this paper proposes that an interest-cap deposit insurance scheme can successfully prevent bank runs without causing moral hazard problems. Moreover, the capital requirement might be helpful in mitigating the welfare losses related with bank runs. Nevertheless, these conclusions are far from a complete answer to the issue of banking stability. Some potentially important issues are still missing in this paper, such as information imperfection, information asymmetry among agents, idiosyncratic shocks faced by individual banks and the cost of raising bank capital. Furthermore, it will also be interesting to analyze the welfare effect of combined policies in preventing bank runs.

References

[1] Allen, Franklin and Douglas Gale (1998): "Optimal Financial Crises", *Journal of Finance*, vol LIII, August, pp 1245-84.

[2] Backus, David, Silverio Foresi and Liuren Wu (1999): "Liquidity and Contagion in Financial Markets", working paper.

[3] Basle Committee on Banking Supervision (1988): "International Convergence of Capital Measurement and Capital Standards".

[4] Bryant, John (1980): "A model of Reserves, Bank Runs, and Deposit Insurance", *Journal of Banking and Finance*, vol 4, pp 335-44.

[5] Calomiris, Charles (1998): "The IMF's Imprudent Role as Lender of Last Resort", *CATO Journal*, vol 17, no 3, pp 275-94.

[6] Calomiris, Charles and Gary Gorton (1991): "The Origins of Banking Panics, Models, Facts, and Bank Regulation", in Glenn Hubbard (ed): *Financial Markets and Financial Crises* (University of Chicago Press, Chicago).

[7] Calomiris, Charles and Joseph Mason (2003): "Fundamentals, Panics and Bank Distress During the Depression", *American Economic Review*, vol 93 no 5, pp 1615-47.

[8] Chang, Roberto and Andres Velasco (2000): "Banks, Debt Maturity and Financial Crises", *Journal of International Economics*, vol 51, pp 169-94.

[9] —— (2001): "A Model of Financial Crises in Emerging Markets", *Quarterly Journal of Economics*, vol 116 no 2, May, pp 489-517.

[10] Cooper, Russell and Thomas W Ross (1998): "Bank Runs: Liquidity Costs and Investment Distortion", *Journal of Monetary Economics*, vol 41, pp 27-38.

[11] —— (2002): "Bank Runs: Deposit Insurance and Capital Requirements", *International Economic Review*, vol 43, pp 55-72.

[12] Diamond, Douglas W and Philip H Dybvig (1983): "Bank Runs, Deposit Insurance, and Liquidity", *Journal of Political Economy*, vol 91, pp 401-19.

[13] Dwyer, Gerald P and Alton Gilbert (1989): "Bank Runs and Private Remedies", *Federal Reserve Bank of St. Louis Review*, May/June, pp 43-61.

[14] Financial Stability Forum (2001): "Guidance for Developing Effective Deposit Insurance Systems", mimeo.

[15] Gennotte, Gerard and David Pyle (1991): "Capital Controls and Bank Risk", *Journal of Banking and Finance*, vol 15, pp 805-24.

[16] Goldstein, Itay and Ady Pauzner (2004): "Demand Deposit Contracts and the Probability of Bank Runs", *Journal of Finance*, forthcoming.

[17] Gorton, Gary (1985): "Banks' Suspension of Convertibility", *Journal of Monetary Economics*, vol 15, pp 177-93.

[18] —— (1988): "Banking Panics and Business Cycles", *Oxford Economic Papers*, vol 40, pp 751-81.

[19] Jeitschko, Thomas D and Curtis R Taylor (2001): "Local Discouragement and Global Collapse: A Theory of Information Avalanches", *American Economic Review*, vol 91, no 1, March, pp 208-24.

[20] Kaminsky, Graciela L and Carmen M Reinhart (1999): "The Twin Crises: the Causes of Banking and Balance-of-Payment Problems", *American Economic Review*, vol 89, no 3, June, pp 473-500.

[21] —— (2000): "On Crises, Contagion, and Confusion", *Journal of International Economics*, vol 51, no 1, June, pp 145-68.

[22] Krugman, Paul (1998a): "What Happened to Asia?", mimeo, MIT.

[23] —— (1998b): "Fire-Sale FDI", NBER Conference on Capital Flows to Emerging Markets.

[24] Lindgren, Carl-Johan, Gillian Garcia and Matthew Saal (1996): "Bank Soundness and Macroeconomic Policy", IMF.

[25] Matutes, Carmen and Xavier Vives (1996): "Competition for Deposits, Fragility and Insurance", *Journal of Financial Intermediation*, vol 5, pp 184-216.

[26] Park, Sangkyun (1997): "Risk-taking Behavior of Banks under Regulation", *Journal of Banking & Finance*, vol 21, pp 491-507.

[27] Radelet, Steven and Jeffrey Sachs (1998): "The Onset of the East Asian Financial Crisis", HIID working paper.

[28] Sachs, Jeffrey D (1998): "Alternative Approaches to Financial Crises in Emerging Markets", HIID working paper.

[29] Schwartz, Anna J (1998): "Time to Terminate the ESF and the IMF", *CATO Foreign Policy Briefing* no 48.

[30] Zhu, Haibin (2001): "Bank Runs without Self-Fulfilling Prophecies", in *Three Essays on Financial Crises*, PhD dissertation, Duke University.

Figure 1

Comparison of three different allocations

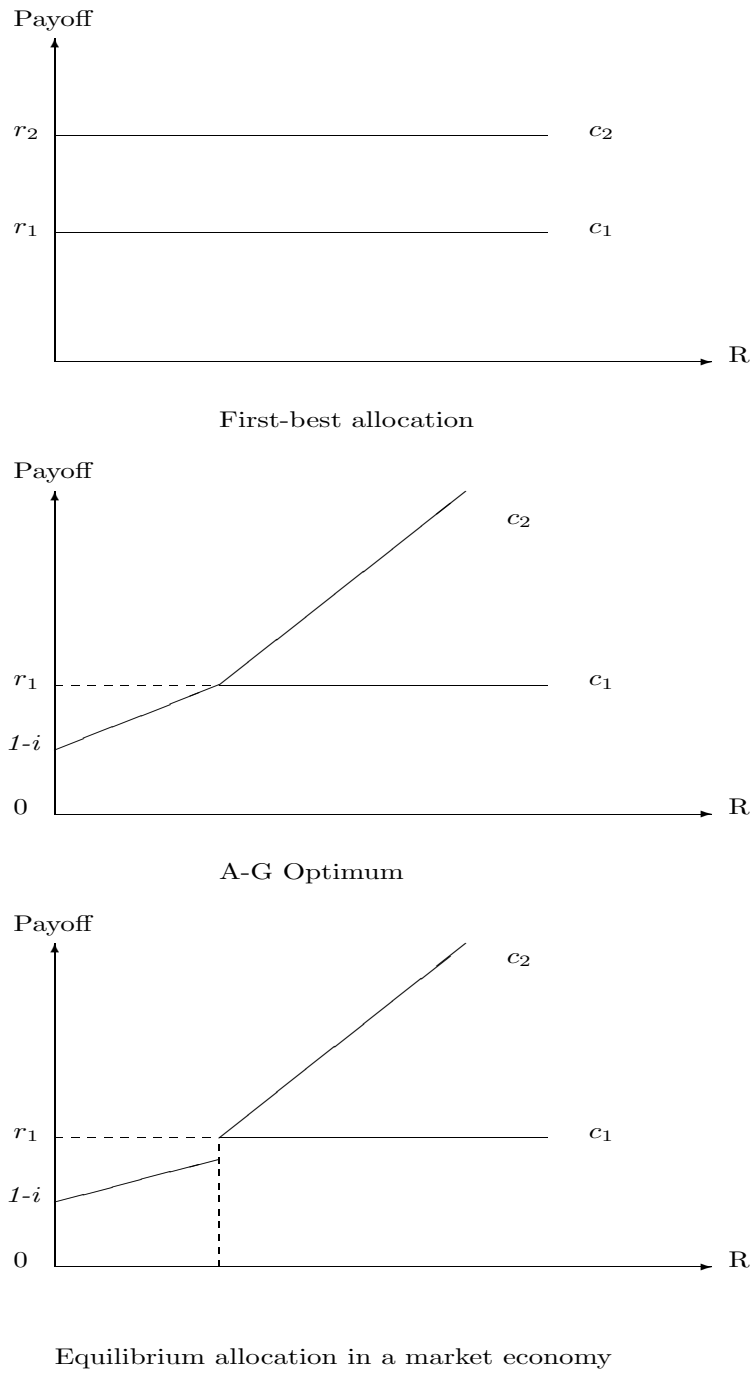


Figure 2

Optimal contracts under FCDI schemes

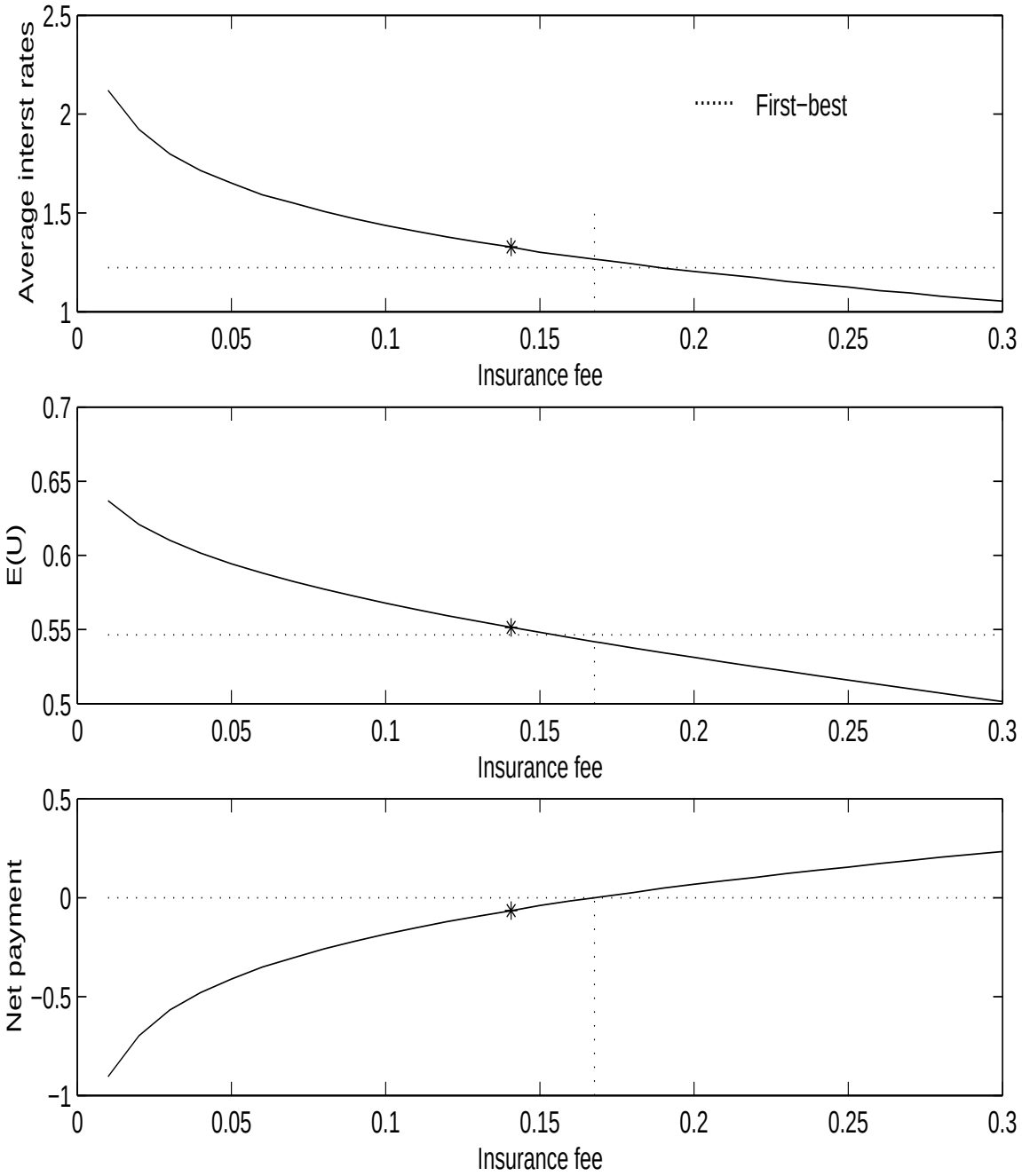
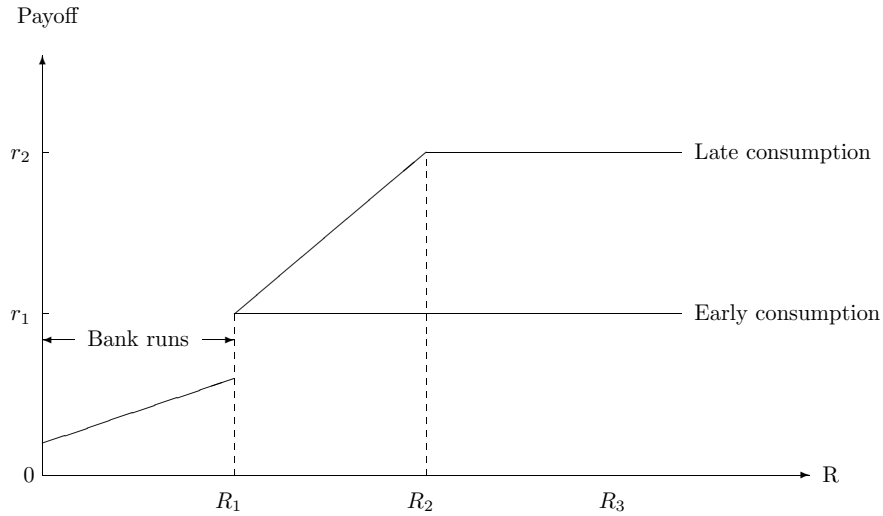
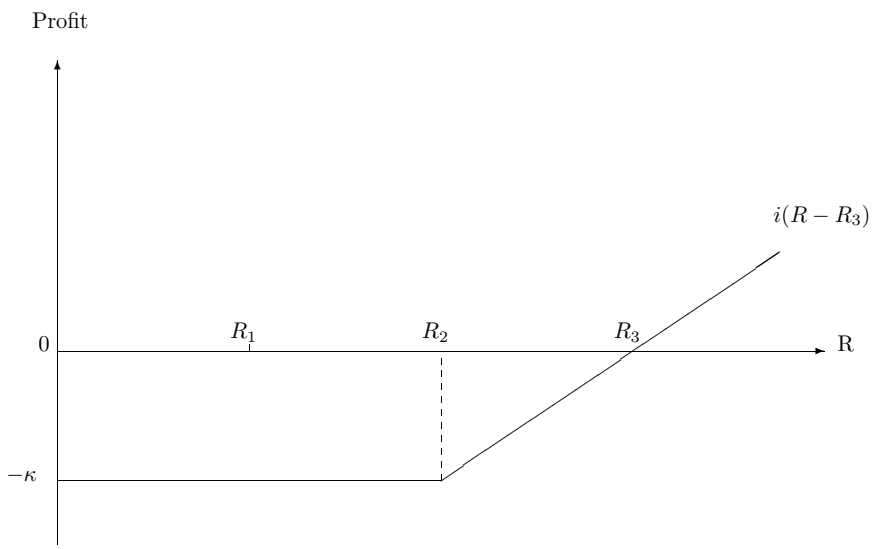


Figure 3

Payoff functions under capital requirements



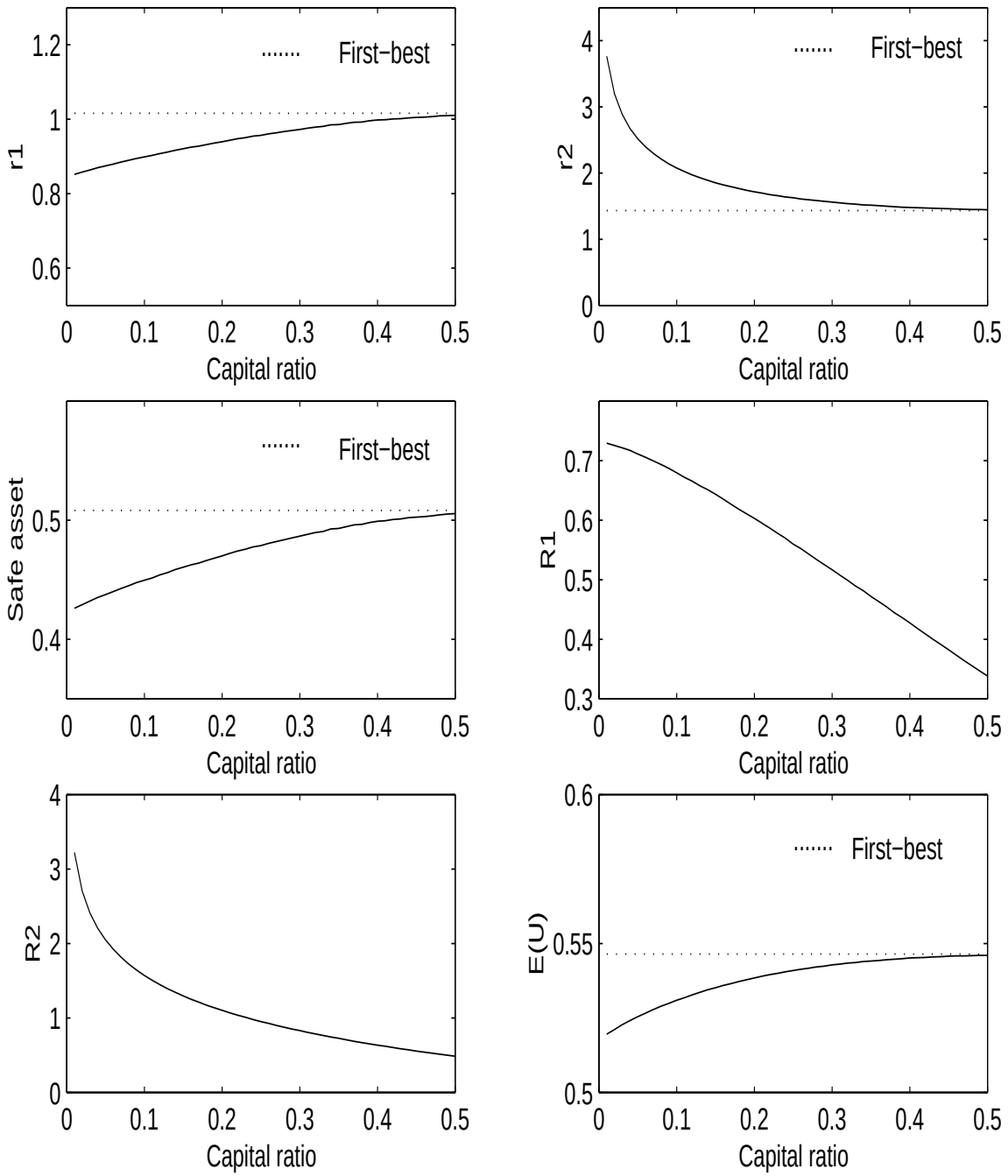
Agent's payoff function



Bank's profit function

Figure 4

Optimal contracts under capital requirements



Appendix

A Proof of Lemma 1

Rewrite the social planner's problem as

$$\max_{r_1}\max_{i\leq 1-r_1\alpha} \quad U \equiv \alpha u(r_1) + (1-\alpha)u(\frac{1-i+i\cdot E(R)-r_1\alpha}{1-\alpha})$$

For a given r_1, banks will choose to maximize their holdings of risky assets because:

$$\frac{dU}{di} = u'(r_2)\cdot[E(R)-1] > 0$$

Hence $i = 1 - r_1\alpha$. Plug it into the above problem, it is straightforward that $r_2 = \frac{(1-r_1\alpha)\cdot E(R)}{1-\alpha}$, and the first-order condition is $u'(r_1) = E(R)\cdot u'(r_2)$.

B Proof of Proposition 1

I prove the proposition in two steps.

- The first-best allocation is superior to the A-G optimum.

  Suppose the A-G optimum is characterized by r_1^{AG} and i^{AG}. By using the same r_1 and i, a representative agent obtains an expected utility of $\alpha u(r_1^{AG}) + (1-\alpha)u[E(r_2^{AG})]$ under a first-best contract. Due to concavity of the utility function, a representative agent is better off in the first-best contract environment. And from the definition of first-best allocation, $\alpha u(r_1^f) + (1-\alpha)u(r_2^f) \geq \alpha u(r_1^{AG}) + (1-\alpha)u[E(r_2^{AG})]$. Therefore, the first-best optimum is superior to the A-G optimum.

- The A-G optimum is superior to the equilibrium allocation in the market economy.

  Suppose that the equilibrium contract in the market economy is characterized by r_1 and i (r_2 is state-contingent). The expected utility for a representative agent is

  $$U(r_1) = \int_0^{R^*} u(1-i+iR(1-\tau))f(R)dR + \int_{R^*}^{\infty}[\alpha u(r_1) + (1-\alpha)u(r_2^e(R))]f(R)dR$$

  where $R^* = \frac{r_1-1+i}{i}$ and $r_2^e = \frac{1-i+iR-r_1\alpha}{1-\alpha}$.

Now consider that the social planner adopts the same contract in the A-G environment. The expected utility for a representative agent is

$$U^{AG}(r_1^d) = \int_0^{R^*} u(1-i+iR)f(R)dR + \int_{R^*}^{\infty} [\alpha u(r_1) + (1-\alpha)u(r_2^e(R))]f(R)dR$$

Obviously, the A-G outcome is better off due to the absence of liquidation costs. Since the A-G optimum is the best outcome among A-G contracts, the A-G optimum must be superior to the market equilibrium.

C Proof of Lemma 3

- Denote $E(\Pi) = \int_{R^*}^{\infty} i(R-R^*) \cdot f(R)dR$,

$$\begin{aligned} \frac{d[E(\Pi)]}{di} &= \int_{R^*}^{\infty} (R-1)f(R)dR - i(R^*-R^*)\frac{\partial R^*}{\partial i} f(R^*) \\ &= \int_{R^*}^{\infty} (R-1)f(R)dR \\ &> 0 \end{aligned}$$

  Therefore, i must be chosen at its maximum value, $1-r_1\alpha$, in the equilibrium contract.

- The constraint (14) should be binding, too. Otherwise the banks can offer a better contract to depositors and attract more deposits by bidding up the interest rates. This process continues until the net profit is driven down to zero.

- Plug the two binding constraints into problem (12), it is straightforward to derive the first-order condition as in Eq. (17).

D Proof of Proposition 5

When $\overline{r} = r_2^f$ and $\delta^f = \int_{E(R)}^{\infty} i^f[R-E(R)] \cdot f(R)dR$, the banks can choose from two types of contracts.

- $r_2 \leq r_2^f = \overline{r}$, in which the ICDI is actually an FCDI scheme.

$$\begin{aligned} \max_{r_1,r_2} \quad & \alpha u(r_1) + (1-\alpha)u(r_2) \\ \text{s.t.} \quad & 1-i \geq r_1\alpha \\ & R^* = \tfrac{r_1\alpha + r_2(1-\alpha) - 1 + i}{i} \\ & \textstyle\int_{R^*}^{\infty} i(R-R^*) \cdot f(R)dR \geq \delta \\ & i = argmax \ \textstyle\int_{R^*}^{\infty} i(R-R^*) \cdot f(R)dR \end{aligned}$$

Following Appendix C, both restrictions are binding. Therefore $i = 1 - r_1\alpha$ and $\int_{R^*}^{\infty}(1-r_1\alpha)(R-R^*)\cdot f(R)dR = \delta$. This suggests that both i and r_1 can be determined once r_2 is chosen, because

$$\begin{aligned}
\frac{dU}{dr_2} &= \frac{\partial U}{\partial r_2} + \frac{\partial U}{\partial r_1}\cdot\frac{dr_1}{dr_2} \\
&= (1-\alpha)u'(r_2) + \alpha u'(r_1)\frac{-\int_{R^*}^{\infty}(1-\alpha)f(R)dR}{\int_{R^*}^{\infty}\alpha R f(R)dR} \\
&\geq [u'(r_2^f)\cdot E(R|R\geq R^*) - u'(r_1^f)]\cdot\frac{1-\alpha}{E(R|R\geq R^*)} \\
&= u'(r_2^f)[E(R|R\geq R^*) - E(R)]\cdot\frac{1-\alpha}{E(R|R\geq R^*)} \\
&> 0
\end{aligned}$$

The first inequality comes from the fact that $r_2 \leq r_2^f$ and $r_1 \geq r_1^f$. As a result, banks will choose the first-best contract $r_1 = r_1^f$, $r_2 = r_2^f$ among contracts of this type.

- $r_2 \geq r_2^f = \overline{r}$.

  The optimization problem for the banks is:

$$\begin{aligned}
\max_{r_2} \quad & \int_0^{R_1^*}[\alpha u(r_1) + (1-\alpha)u(\overline{r})]f(R)dR \\
& + \int_{R_1^*}^{R^*}[\alpha u(r_1) + (1-\alpha)u(\tfrac{1-i+iR-r_1\alpha}{1-\alpha})]f(R)dR \\
& + \int_{R^*}^{\infty}[\alpha u(r_1) + (1-\alpha)u(r_2)]f(R)dR \\
\text{s.t.} \quad & 1 - i = r_1\alpha \\
& R_1^* = \tfrac{r_1\alpha + \overline{r}(1-\alpha) - 1 + i}{i} \\
& R^* = \tfrac{r_1\alpha + r_2(1-\alpha) - 1 + i}{i} \\
& \int_{R^*}^{\infty} i(R-R^*)\cdot f(R)dR = \delta
\end{aligned}$$

The objective function reflects the fact that the maximum amount of payment a depositor can receive is $\overline{r}$ when the bank is insolvent. And similarly, both the budget constraint and the incentive compatibility constraint are binding; therefore the only choice variable is r_2. After some algebra, it is shown that

$$\begin{aligned}
\frac{dU}{dr_2} &= \frac{\partial U}{\partial r_2} + \frac{\partial U}{\partial r_1}\cdot\frac{dr_1}{dr_2} \\
&= \frac{\int_{R^*}^{\infty}(1-\alpha)f(R)dR}{\int_{R^*}^{\infty}\alpha R f(R)dR}\cdot[u'(r_2)\int_{R^*}^{\infty}\alpha R f(R)dR
\end{aligned}$$

$$
\begin{aligned}
& + \int_{R_1^*}^{R^*} \alpha R u'(\frac{(1-r_1\alpha)R}{1-\alpha}) f(R)dR - \alpha u'(r_1)] \\
< \quad & \frac{1-\alpha}{E(R|R \geq R^*)} \cdot [u'(\overline{r}) \int_{R_1^*}^{\infty} Rf(R)dR - u'(r_1)] \\
< \quad & \frac{1-\alpha}{E(R|R \geq R^*)} \cdot [u'(r_2^f)E(R) - u'(r_1^f)] \\
= \quad & 0
\end{aligned}
$$

where the first inequality comes from the fact that $r_2 \geq \overline{r}$ and $\frac{(1-r_1\alpha)R}{1-\alpha} > \overline{r}$ for $R \in [R_1^*, R^*]$, and the second inequality uses the fact that $r_1 \leq r_1^f$ when $r_2 \geq r_2^f$. Therefore, the first-best contract is also chosen.

Combining the results, under the ICDC with $\overline{r} = r_2^f$ and $\delta^f = \int_{E(R)}^{\infty} i^f[R - E(R)] \cdot f(R)dR$, the banks will choose the first-best contract and the economy achieves the first-best social optimum.

E Proof of Proposition 6

The proof is divided into the following steps.

- Step 1: $i = 1 + \kappa - r_1\alpha$.

  Define $E(\Pi)$ as the expected profit for the banks as specified in Eq. (19). It is easy to show that

$$
\frac{\partial E(\Pi)}{\partial i} = \int_{R_2}^{\infty} (R-1)f(R)dR \quad > 0
$$

  Therefore, Eq. (19) is binding. Besides, the incentive compatibility constraint (Eq. 20) is also binding following the same argument as in Appendix C. Accordingly, it could be rewritten as:

$$
\int_{R_2}^{\infty} (1+\kappa-r_1\alpha)(R-R_2)f(R)dR - \kappa \cdot E(R) = 0 \tag{22}
$$

  The Lagrange equation for the problem is:

$$
\begin{aligned}
\text{MAXU}(\kappa) \quad = \quad & \max_{r_1,r_2} \int_0^{R_1} u[r_1\alpha + (1+\kappa-r_1\alpha)R(1-\tau)] \cdot f(R)dR \\
+ \quad & \int_{R_1}^{R_2} [\alpha u(r_1) + (1-\alpha)u(\frac{(1+\kappa-r_1\alpha)R}{1-\alpha})] \cdot f(R)dR \\
+ \quad & \int_{R_2}^{\infty} [\alpha u(r_1) + (1-\alpha)u(r_2)] \cdot f(R)dR \\
+ \quad & \lambda\{\int_{R_2}^{\infty} (1+\kappa-r_1\alpha)(R-R_2)f(R)dR - \kappa \cdot E(R)\}
\end{aligned}
$$

where $R_1 = \frac{r_1(1-\alpha)}{1+\kappa-r_1\alpha}$, $R_2 = \frac{r_2(1-\alpha)}{1+\kappa-r_1\alpha}$, and λ is the Lagrange multiplier. $MAXU(\kappa)$ is the indirect utility function.

- Step 2: The first-order conditions for the above problem are:

$$\begin{aligned}
\frac{\partial \text{MAXU}(\kappa)}{\partial r_1} &= \int_0^{R_1} u'[r_1\alpha + (1+\kappa-r_1\alpha)R(1-\tau)] \cdot [\alpha - \alpha R(1-\tau)] \cdot f(R)dR \\
&\quad + \int_{R_1}^{\infty} \alpha u'(r_1) f(R)dR - \int_{R_1}^{R_2} \alpha R u'[\frac{(1+\kappa-r_1\alpha)R}{1-\alpha}] f(R)dR \\
&\quad + [u(r_1(1-\tau+\alpha\tau)) - u(r_1)] f(R_1) \frac{(1-\alpha)(1+\kappa)}{(1+\kappa-r_1\alpha)^2} - \lambda\alpha \int_{R_2}^{\infty} R f(R)dR \\
&= 0 \qquad (23) \\
\frac{\partial \text{MAXU}(\kappa)}{\partial r_2} &= \int_{R_2}^{\infty} (1-\alpha)[u'(r_2) - \lambda] f(R)dR \\
&= 0 \\
\Rightarrow \quad & u'(r_2) = \lambda \qquad (24)
\end{aligned}$$

- Step 3: As $\kappa \to \infty$, the equilibrium converges to the first-best allocation.

  When $\kappa \to \infty$, by using $R_1 \to 0$, $R_2 \to 0$, and $R_3 \to 1$, Eq. (23) can be written as

$$\begin{aligned}
\alpha u'(r_1) - \lambda\alpha E[R] &= 0 \\
\Rightarrow u'(r_1) &= \lambda E[R]
\end{aligned}$$

  Combined with Eq. (24), we obtain the familiar Euler equation $u'(r_1) = E[R] \cdot u'(r_2)$. Furthermore, I show that $r_2 = \frac{(1-r_1\alpha)E[R]}{1-\alpha}$ satisfies the incentive compatibility constraint (Eq. 22) as $\kappa \to \infty$. As $i = 1+\kappa-r_1\alpha$, $r_2 = \frac{(1-r_1\alpha)\cdot E(R)}{1-\alpha}$, when $\kappa \to \infty$,

$$\begin{aligned}
& \int_{R_2}^{\infty} (1+\kappa-r_1\alpha)(R-R_2) f(R)dR - \kappa E(R) \\
\to \quad & \int_0^{\infty} (1+\kappa-r_1\alpha) R f(R)dR - r_2(1-\alpha) - \kappa E(R) \\
= \quad & (1-r_1\alpha)E(R) - r_2(1-\alpha) = 0
\end{aligned}$$

  Comparing with the properties of the first-best optimum, it is safe to conclude that the market equilibrium converges to the first-best allocation as the capital requirement increases.