THE BEHAVIOR OF BANKS UNDER THE DEPOSIT INSURANCE AND CAPITAL REQUIREMENTS

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1. Introduction

Compare to other firms, banks are special in three ways. First, most banks are insured by deposit insurance. Second, banking industry is highly regulated. Third, banks are financial intermediary. To attract deposits is one of a bank's main functions, and deposits compose the most part of a bank's debt. Among the various regulations, minimum capital requirements play an important role, which require banks to keep their capital-to-asset ratio above a certain amount. Usually the minimum capital requirements are considered as a remedy of the deposit insurance. In banking system, deposit insurance can be purchased from the governmental insurance agency–the Federal Deposit Insurance Corporation(FDIC). Although banks are not commanded to join the FDIC, most banks have the membership. In the beginning of the FDIC history, member banks obtained full coverage on deposit at a quite low premium. Later, the effective premium increased while coverage were cut down, however, the premium explicitly paid was still ignorable compared to the big amount of deposit coverage[1]. After risk-based premium system was originally established, 75% banks were in the best-rated category. This percentage of best-rated banks increased to 93% in 2000. These best-rated banks pay no premium for deposit insurance.

It should not be surprising if banks take advantage of this "generous" insurance system. According to moral hazard theory, an insurant tends to be less careful about their risky behavior since he can leave the loss to the insurer. This moral hazard behavior is often seen especially when insurance is not correctly priced. Under the protection of the FDIC, banks have incentive to take deposits as much as they can for some debt-favor reasons such as tax deduction on interest payment, and let the FDIC pay for the deposits if it turns out banks do not have enough capital to pay the deposits back. As a matter of fact, the average bank capital ratio had decreased from 13% to 6% during the first decade after deposit insurance became effective. However, the capital ratio had begun to fall steadily from more than 50% since 1840, long time before the FDIC was established. This casts some doubts on the criticism of the deposit insurance.

1970s witnessed another mild decrease in capital ratio of banks in the U.S. Meanwhile, the number of failed banks rose slightly. In 1981 the regulator, for the first time, implemented explicit capital requirements in hope of preventing bank crisis. They required all the

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[1]Before 1990, the nominal assessment rate was fixed at 8.3 basis points. Due to the refund system, the effective rate before 1983 was even lower. Before 1980 the effective rate had been less than 4.0 basis points for 30 years except 1974. From 1990 to 1995, this rate increased dramatically to more than 20 basis points. However, it dropped later to a very low level, i.e. less than 0.5 basis point.

commercial banks to keep their capital ratios above a one-for-all minimum ratio. The reasoning of these capital requirements is very simple. A bank's operation can be financed either by its creditors (mainly depositors) or equityholders (its owners). If funds from creditors are not paid when due, it can cause the bank to fail. In contrast, funds from equityholders are not obligations to the bank. Therefore, the greater the capital-to-asset ratio, "the more likely the bank will be able to continue to pay its obligations during periods of economic adversity"[2].

However, the number of failed banks increased dramatically from 1981, and reached the peak (280) in 1988. This may be taken as the support evidence for the main criticism. Many researchers assert that the fixed capital requirements will result in shift from low-risk assets to high-risk assets. A binding regulation will bring some distortion to a firm. Capital requirements might also distort a bank's financial decision. Since bank risk is not incorporated in the fixed capital requirements, a bank could have some compensation for the regulatory distortion from its investment by taking riskier portfolio. This argument implies higher probability of bank failure. Thus the increase in the number of failed banks after 1981 makes this argument sound plausible. However, the whole economy was not in good condition in 1970s to 1980s. "On the economic front, soaring interest rates and a spike in oil prices instigated a worldwide recession in 1981"[3]. The skyrocketing number of failed banks might be attributed to some other market factors.

In any case, improvements were called for later for these fixed capital requirements. Basel Accord I (1988) was brought into effect nation wide in 1992, which adopted risk-based capital requirements. Under the 1988 Accord, bank assets and off-balance-sheet items are "risk-weighted" based on their perceived credit risk using four broad categories[4]. Although this 1988 Accord also requires all banks to hold a one-for-all capital ratio (8%), the total amount of capital required is different across banks depending on their credit risks. The higher the credit risk, the more total amount of capital the bank has to hold. However, it "does not penalize them for holding less risky portfolios"[5]. Meanwhile, the Federal Deposit Insurance Corporation Improvement Act was enacted in 1991. Similarly, this act categorizes banks into "well capitalized" group and low capital group. Banks are undercapitalized "have restrictions or conditions on certain activities and may also be subject to mandatory or discretionary supervisory actions"[6].

The logic of adopting risk-based capital requirements is that a bank needs more capital to support its solvency if it incurs more risk. Compared to fixed capital requirements, these risk-based capital requirements are more risk sensitive. However, some researcher find that banks might shift priced risks to non-priced risks. In the 1988 risk-based capital

[2]Basel and the Evolution of Capital Regulation: Moving Forward, Looking Back, Story Archive of NuBank, FDIC Office of Public Affairs, Jan, 2003.

[3]Basel and the Evolution of Capital Regulation: Moving Forward, Looking Back, Story Archive of NuBank, FDIC Office of Public Affairs, Jan, 2003.

[4]Most claims are risk-weighted at 100%, although residential mortgages are weighted at 50%, claims on or guarantees provided by qualifying banks and other entities (in the U.S. this category includes most notably the government-sponsored enterprises such as Fannie Mae and Freddie Mac) are weighted at 20%, and very low risk assets, such as those guaranteed by qualifying governments, are weighted at 0%.

[5]Basel and the Evolution of Capital Regulation: Moving Forward, Looking Back, Story Archive of NuBank, FDIC Office of Public Affairs, Jan, 2003.

[6]Basel and the Evolution of Capital Regulation: Moving Forward, Looking Back, Story Archive of NuBank, FDIC Office of Public Affairs, Jan, 2003.

requirements, only credit risk is captured roughly. In this case, banks have incentives to move to assets with low credit risk but high other risks. Thus, actually this risk-based capital requirements will lead to higher total risk of banks, and hence the higher probability of bank failure. Nevertheless, these risk-based capital requirements are still effective today, and seem working well. The number of failed banks dropped quickly after 1992, when the risk-based capital requirements took full effect nation wide.

How on earth will capital requirements affect bank risk-taking behavior? How will banks change their capital structure and risk-taking behavior in an environment with both deposit insurance and capital requirements? What difference will the risk-based capital requirements make? Actually, before the formal capital requirements debuted in 1981, banks were closely monitored by their insurer–the FDIC. Banks did not run into any crisis like 1980s and early 1990s. Even during the first decade of the FDIC was established, the number of failed banks was no more than 75 each year. Under the deposit insurance, why banks stayed stable for almost 40 years without explicit capital regulation? Do we really need explicit capital requirements?

In this paper, I investigate how banks react to the fixed and risk-based capital requirements under deposit insurance. I adopt one factor option pricing model to evaluate bank equity in terms of asset-to-debt ratio. I find banks benefit from using more capital even there are no capital requirements. Moreover, banks tend to take lower risk instead of high risk no matter there are capital requirements or not, if they are solvent. However, for insolvent banks, they may take riskier investment. Under the risk-based capital requirements, banks would prefer lower capital requirements by taking lower risk. Lastly, capital requirements only have impact on banks with low capital. For those well capitalized banks, capital requirements will not affect their behavior too much.

The paper is organized as follows. In section 2, I review the existing literature on bank capital and risk-taking. In section 3, I set up the option pricing model for equity value and derive the closed form solutions. This section also presents comparative statics analysis and some numerical results. In concluding section 6, I discuss some implications of my model.

2. Literature Review

One of the most cited theory for bank behavior comes from moral hazard. As it is well known, moral hazard theory is often used in explaining the distorted behavior due to insurance. Under the protection of insurance, it sounds plausible that banks will tend to increase deposits and hence decrease capital ratio. However, this moral hazard explanation is based on the assumption that banks pay little or no cost when bankruptcy occurs due to overabundant debt. Thus debt is more favorable than equity under the deposit insurance.

Concerning the preference between equity and debt, immense capital structure studies have provided all sorts of explanations. The first work in capital structure was done by Modigliani and Miller in 1958(Modigliani and Miller 1958). They argue that firm value is irrelevant to how it is financed. However, their famous "irrelevant theorem" is derived in a highly simplified situation with a long list of restricted explicit and implicit assumptions. A great deal of studies have followed starting from relaxing those assumptions one by one. Most of them show that once these stringent assumptions are relaxed, capital structure is relevant to the value of firm. Basically, the key assumptions that change the M&M theorem are the following: 1) there are no taxes; 2) there are no bankruptcy costs; 3) there are no transaction costs; 4) market is complete and information is symmetric.

Generally speaking, tax deduction on interest payment makes debt more favorable, while bankruptcy costs make equity more attractive. The more the debt is used, the higher probability of bankruptcy, and the more bankruptcy costs. Tax deduction on the interest payment will prompt banks to use deposits as much as possible, and leave the possible bankruptcy burden to the FDIC. However, moral hazard explanation ignores the implicit bankruptcy costs. Some studies show that explicit bankruptcy costs are not of significant amount. However, bankruptcy event may incur some implicit costs, which are usually in the form of opportunity costs. If a bank goes to bankruptcy, even not considering the deposit repayment, equity at best has only zero value. To bank equityholders, the opportunity costs of bankruptcy involve two parts: possible earnings from continuous operation and the protection of the FDIC. A solvent bank may have great chance of future earnings. However, once an insolvent bank is claimed bankrupt, it will lose all the possible future earnings. This constitutes implicit bankruptcy cost to equityholders. Moreover, once a bank is claimed bankrupt, the FDIC will pay for the remaining deposits. However, this is one-time payment. Equityholders will lose the benefit from the deposit insurance permanently. The loss of deposit insurance also constitutes explicit bankruptcy cost to equityholders. After taking into consideration of these implicit bankruptcy costs, debt use is not as attractive as moral hazard theory predicts.

On the other hand, moral hazard is also employed to explain risk-taking behavior. The logic is similar. For an insured bank, deposit insurance provides a shelter for risk transfer. With the guarantee from the FDIC, shareholders could be less risk averse, and increase credit risk in hope of gaining higher return. Hence, moral hazard theory predicts that banks will take higher credit risk. Therefore, if moral hazard prevails, deposit insurance will lead to lower capital ratios and higher credit risk. This may constitute the base of the risk-based capital requirements debuted nation wide in 1992. One of the major criticisms of the 1981 fixed capital requirements is that they do not capture any risk elements.

Nevertheless, this moral hazard explanation for risk-taking is subject to some criticisms. As mentioned above, it ignore the implicit costs of bankruptcy. The shareholders would like to maximize the equity value as well as to avoid bankruptcy. Hence, under capital requirements, banks should not change risk-taking behavior too much in order to balance the bankruptcy risk that is borne by the bank equityholders. Moreover, some empirical studies show different results than the prediction by moral hazard on bank capital ratio and risk-taking. For instance, Keeley and Furlong (1990) use the data of 1970-1986 to show that risk-taking declines while capital increases.

The moral hazard theory without considering implicit bankruptcy costs does not provide a complete explanation for bank capital structure and risk-taking behavior. The implicit costs of bankruptcy will discourage risk-taking behavior and deposit taking. There are several ways to accomodate this factor. Portfolio analysis is one of them. This is a utility maximizing framework. A bank is assumed to behavior like a risk averse manager. Both return and risk are variables of the bank's objective function. Thus, an increase in bankruptcy risk leads to a decrease in utility. Rochet (1992) compares value maximizing approach and this utility maximizing approach. He finds that in the former framework, capital requirements cannot prevent banks from choosing very specialized and very risky portfolio. However, capital requirements may achieve the goal in the latter framework.

It is the induction of risk that induces the effectiveness of capital requirements. Similar studies include Kareken and Wallace (1978), Koehn and Santomero (1980), and Kim and Santomero (1988). Portfolio analysis is a general but complicated framework. To obtain the interpretable results, equity is assumed to be fixed. However, it is not a reasonable assumption for marketable equity. This simplification actually throws away some market factors that could significantly affect the capital structure and risk-taking.

Calem (1999) establishes a dynamic portfolio choice model for bank risk-taking study. He finds a U-shaped relationship between capital and risk-taking: As a bank's capital increases it first take less risk, then more risk. Hence, he argues that an increased fixed or risk-based capital requirement will induce more risk-taking by well-capitalized banks. Although Calem does not assume fixed equity, he assumes a fixed value for total assets, which is equal to the sum of equity and deposits. This may be a logical assumption for general firms, however, it is not an appropriate assumption to banks for two reasons. First of all, this assumption ignore the value of deposit insurance. Unlike other firms, deposit insurance is also a valuable asset to banks. In the case of bankruptcy, bank debtholders (mainly depositors) still can have their claims back. Hence the value of deposit insurance should be taken into account in the valuation of total assets. Secondly, the fixed sum of equity and deposits implies that a bank can only increase capital ratio by reducing deposits. This imposes a over-stringent constrain on bank capital structure.

Another risk-related approach is state preferences model, which has been developed by Sharpe (1978), Karekan and Wallace (1978), and Dothan and Williams (1980), etc. In a state preference model, there are several possible states in the future. A bank in this model is seeking to maximize its equity value, which is just the expected value of capital at current time when the bank is solvent. However, the equity value becomes the sum of the current capital value and current deposit insurance value when the bank is insolvent.

Using the similar framework, Furlong and Keeley (1989) reach the conclusion that a higher bank capital ratio does not lead a value-maximizing bank to increase asset risk. On the contrary, more stringent capital requirements reduce the gains of a bank from increasing the risk of its asset portfolio. This conclusion is opposite to the results from foregoing studies using portfolio framework, such as Kahane (1977), and Koehn and Santomero (1980). Keeley and Furlong (1990) point out it is because of one of the assumptions in portfolio framework. In portfolio framework, it is assumed that the returns follows a normal distribution. However, it cannot be true in the case of insolvency. Keeley and Furlong truncate the normal distribution, and show a similar result to their state preference framework. Keeley and Furlong (1989) also use a third approach–option pricing model–to reach the similar conclusion.

Option pricing model originates from an idea similar to state preference model: to evaluate the market price of equity. Since Black and Scholes (1971) first derive a closed form solution to call option, it has been spread widely in various issues. Capital liabilities might be its first major development (Merton 1998). However, this approach has not shed too much light on the analysis of risk-taking behavior. In this approach, debt is comparable to a put option, while equity is considered as a call option. Hence, both debt and equity can be evaluated using the option pricing model. Following Black and Scholes' methodology, Brennan and Schwartz (1978) show the non-monotonicity of capital structure with the presence of taxes through a numerical analysis of a stochastic differential equation. They show that even without bankruptcy costs, tax deduction on interest payment will yield an interior optimal capital ratio. This result is different than the classic conclusion that tax benefit will stimulate debt use as much as possible if there are no bankruptcy costs.

Leland (1994), enlightened by the same spirit, finds a closed form solution to the price of firm. He demonstrates the optimal capital structure under tax benefit and bankruptcy costs. Fisher, Heinkel and Zechner (1989)also use the option pricing framework to derive the price of debt and equity with tax benefit and bankruptcy costs under the assumption that recapitalization costs are not ignorable. However, they do not replicate Brennan and Schwartz's result. In my opinion, Brennan and Schwartz actually take into account implicit bankruptcy costs by allowing different tax rate at bankruptcy. They introduce a non-constant tax scheme, i.e. tax rates are conditional on the performance. In Brennan and Schwartz's model, tax rate is positive only when the value of total asset is greater the book value of debt. In this case, tax benefit is in fact affected by bankruptcy, although there are no explicit bankruptcy costs. We can also considered the tax benefit as a type of implicit bankruptcy costs.

To apply the Black-Scholes option pricing model on banks, however, we also need to take into account deposit insurance and capital requirements. With deposit insurance, depositors have the right to sell their claims to the FDIC at the contract price when asset value is less than deposit value. Therefore, we can consider deposit insurance as a put option to depositors.

Merton (1977) might be the first to apply the Black-Scholes put option formula directly on banks. He (1978) extends the previous deposit insurance model into a model with explicit surveillance costs occurring at random auditing times. He finds that the equity per unit of deposit is a monotonically increasing function of the asset-to-deposit ratio, and strictly concave when the ratio is over 1. Thus a bank under deposit insurance should benefit from taking more capital. Moreover, he argues that a solvent bank tend to take less risk due to the fear of losing valuable deposit insurance. This factor is an element of implicit bankruptcy costs.

Like state preference model, equityholders are supposed to "pay" for the put option of the deposit insurance in Merton's option pricing model. However, depositors instead of equityholders are the beneficiary of the deposit insurance: When the bank is bankrupt, depositors have the right to exercise the put option and get their claims paid. Why should equityholders pay for the deposit insurance? Merton does not provide a clear explanation. Moreover, to derive the closed form solution for the equity value per unit of deposits, Merton makes two assumptions, which seem unnecessary to me. The first is asset return dynamics satisfy the Capital Asset Pricing Model(CAPM). The second is the growth rate of deposits is just equal to the interest rate paid by the bank plus the rate paid in form of service.

Marcus and Shaked (1958) calibrate Merton's model to derive the fair premium for FDIC deposit insurance. They find the FDIC premium is actually greater than what is warranted by the ex ante default risk posed by the banks. This implies that the deposit insurance is overpriced rather than underpriced. Then why do banks voluntarily pay for the "overpriced" deposit insurance? From my point of view, this question and the previous question are closely related. The answer comes from implicit bankruptcy costs that are ignored in Marcus and Shaked's paper. Actually, there are two components in the explicit insurance premium paid by banks: the value of deposit insurance derived by Marcus and Shaked and the increase in equity value through an implicit protection of the FDIC. Although depositors rather than equityholders are the direct beneficiary of the FDIC when bankruptcy occurs, equity value is enhanced if a bank is insured. On one hand, depositors obtain the option of deposit insurance and pay for this right by receiving less interest. On the other hand, equityholders have higher value of their claim by being a member of the FDIC. Thus bank equity should be priced incorporating implicit protection of the FDIC. If a bank is claimed bankruptcy, the equityholders will lose this implicit benefit that can be counted as opportunity costs of bankruptcy. Hence, depositors and equityholders jointly pay for the deposit insurance. Marcus and Shaked do not consider the implicit costs of bankruptcy, therefore, they achieve an "overpriced" deposit insurance.

Marcus (1984) modifies Merton (1978)'s model of banks with deposit insurance. He takes into account a non-negative charter value in his model. The model shows that if there is a valuable charter, a value maximizing bank will show extreme risk-taking behavior: take either very low risk or very high risk. In my opinion, the charter value also constitutes implicit costs of bankruptcy. In my model, I show that even there is no valuable charter, a value maximizing bank will not exploit deposit insurance by taking high risk. It is because there are other types of implicit bankruptcy costs.

The last approach is dynamic programming, which is rarely used so far. Milne and Whalley (2001) are one the few who use this approach. The advantage to use dynamic programming is that it allows endogeny of risk-taking and capital ratio. Moreover, dynamic framework allows the representative bank to set up a different long-run goal. This matches our intuition very well. However, it is more technic involved. Actually, the essential difference between option pricing model and dynamic programming model is that the former assume a general equilibrium environment, while the latter is set to reach a partial equilibrium. This will not affect the result too much. Hence, I opt for option pricing model.

In my paper, I withdraw some elements from Merton's model. However, I relax these two assumptions in Merton's model. I have also derived a closed form solution. Furthermore, I assume a bank is seeking to maximize its total value of equity, instead of the equity per unit of deposits. Merton uses equity per unit of deposits for simplicity reason, however, the total value maximizing is more reasonable assumption.

3. Model

As mentioned above, like debt and equity of many other firms, debt and equity of banks can also be viewed as options. In general firms, debt is risky since it is subject to default. If firm value is less than debt value at maturity, then the creditors have the first priority of being paid. Due to the limited liability, however, creditors are only paid up to the current value of the firm. Hence, with the limited liability policy, levered firms actually short a put option worth the difference between debt value and the firm value. If firm value exceeds the debt value at maturity, then the firm pay the creditors the full amount and the option is worth nothing. Hence, the risky debt can be taken as default-free debt plus a short position of a put option. On the other hand, equity is the residual claims. As a result of the limited liability, the value of equity is either zero or the excess of the firm value over the debt value at maturity. Thus equity can be taken as a call option. Hereby,the firm value at maturity is always equal to the default-free debt value less a put option and plus equity value. If we use V to represent the value of the whole firm, B to represent the value default-free debt, P to represent the value of the put option, and S to represent the value of equity, then the above argument can be expressed as $V = (B - P) + S$.

Generally speaking, risk-free debt is not achievable for firms. However, banks are an exceptional case. In order to keep the stability of the society, a government will not allow default on deposits to occur. Although not all deposits are insured, and the FDIC does not claim 100% coverage of the deposits now, deposits in banks are usually considered backed by the government and hence are considered default-free. In this case, deposit insurance can be viewed as the put option, since the deposit insurance give the equityholders an option to sell the deposits to the FDIC at price B. Hence, deposit insurance replaces limited liability policy in the equation above. As mentioned earlier, equity value is boosted by deposit insurance, and the value of deposit insurance includes the increase of equity value and explicit insurance premium. Therefore, the put option value $P = IP - \Delta S$, where IP represents insurance premium, and ΔS represents the increase of equity value due to the deposit insurance. Thus, the equation above can be rewritten as $V = (B - IP) + (S + \Delta S)$. This equation shows that depositors obtain default-free claim at the cost of insurance premium; while what equityholders pay is implicit costs that already reflect in $S + \Delta S$. For a value-maximizing bank, equityholders maximize their equity value, $S + \Delta S$.

3.1. **Assumptions of the Model.** To develop a option pricing model, I make some assumptions as follows.

Assumption 1: *There exists a complete and competitive market. Investors can borrow and lend at the same risk-free interest rate r.*

Assumption 2: *All securities can be traded continuously in time.*

Assumption 3: *All deposits are paid at interest rate i. This interest rate includes pecuniary interest payment and services provided by the bank. To avoid arbitrage, $r \geq i$. Otherwise, no investors will make transaction in the market. The difference between r and i can be considered as some uncharged convenience provided by banks.*

Assumption 4: *The deposits of the bank follow a deterministic growth path $dD/dt = gD$.*

Assumption 5: *Deposits are the only type of debt in the bank.*

Assumption 6: *The value of the bank, V, follows a stochastic process of the form*

$$dV = (\mu V - iD)dt + dD + \sigma V dw = \begin{cases} (\mu V - (i-g)D)dt + \sigma V dw & V > 0 \\ 0 & V = 0 \end{cases} \tag{3.1}$$

where $E[dw] = 0$, $E[(dw)^2] = dt$; μ is the instantaneous expected rate of return on the assets; and σ is the instantaneous standard deviation of the return on the assets.

Assumption 7: *The FDIC charges the bank a one-time premium to insure all the deposits. If the bank is solvent at audit time, i.e. $V > D$, then the bank continues its normal business. Otherwise, the bank is liquidated by the regulator.*

Assumption 8: *The FDIC premium is fairly priced.*

Assumption 9: *The regulator audits the bank discretely in time following Poisson distribution with parameter λ, which means that the mean of the number of audits per time period is λ. All audit events occur independently and identically distributed*[7].

Assumption 10: *The bank does not pay any dividends.*

Assumption 11: *The objective of the bank is to maximize the value of equity for the current equityholders.*

3.2. **The Evaluation of Bank Equity under the Capital Requirements.** As mentioned above, equity can be viewed as a call option. Hence I start with a standard call option pricing model by creating a hedge portfolio.

Construct a portfolio worth P dollars by investing N_1 shares of the bank assets $V(D,t)$, N_2 shares of the bank equity denoted as F, and lent the remaining dollars denoted as Q at the market rate r. Then

$$P = N_1 V(D,t) + N_2 F(V,D,t) + Q(t). \tag{3.2}$$

Since F is a function of V, D and t, by Ito's lemma,

$$dF = \{F_t + F_V[\mu V - (i-g)D] + \frac{1}{2}\sigma^2 V^2 F_{VV} + gDF_D\}dt + F_V \sigma V dw \tag{3.3}$$

Adjust N_1 and N_2 slowly relative to the change in V, D and t so that $dN_1 = dN_2 = 0$. Hence,

$$\begin{aligned} dP &= N_1(dV) + N_2(dF) + dQ \\ &= N_1(\mu V - (i-g)D)dt + \sigma V dw) \\ &\quad + N_2(\{F_t + F_V[\mu V - (i-g)D] + \frac{1}{2}\sigma^2 V^2 F_{VV} + gDF_D\}dt + F_V \sigma V dw) + rQdt. \end{aligned} \tag{3.4}$$

Then divide both sides by P to obtain the return rate of the portfolio.

$$\begin{aligned} \frac{dP}{P} &= \frac{N_1}{P}(dV) + \frac{N_2}{P}(dF) + \frac{dQ}{P} \\ &= \frac{N_1}{P}(\mu V - (i-g)D)dt + \sigma V dw) \\ &\quad + \frac{N_2}{P}(\{F_t + F_V[\mu V - (i-g)D] + \frac{1}{2}\sigma^2 V^2 F_{VV} + gDF_D\}dt + F_V \sigma V dw) + r\frac{Q}{P}dt. \end{aligned} \tag{3.5}$$

Choose N_1 and N_2 such that there is no risk for all t[8].

$$Var_t(\frac{dP}{P}) = Var_t(\frac{N_1}{P}\sigma V dw + \frac{N_2}{P} F_V \sigma V dw) = 0. \tag{3.6}$$

[7] In reality, regulators usually provides random audits on banks. Merton (1978)assumes a Poisson distribution for audit procedure. Here I follow his assumption.

[8] Since the value of bank assets V has a stochastic element, it is difficult to eliminate the risk completely. However, this process can be performed carefully to achieve appropriate approximation.

To achieve this risk-free portfolio, I have to eliminate the items producing risks. Thus,

$$\frac{N_1}{P}\sigma V + \frac{N_2}{P}F_V\sigma V = 0, \tag{3.7}$$

which is equivalent to

$$N_1 = -N_2 F_V. \tag{3.8}$$

Then it becomes a risk-free portfolio yielding a risk-free market interest rate.

$$\begin{aligned} E(\frac{dP}{P}) &= \frac{N_1}{P}(\mu V - (i-g)D)dt \\ &+\frac{N_2}{P}\{F_t + F_V[\mu V - (i-g)D] + \frac{1}{2}\sigma^2 V^2 F_{VV} + gDF_D\}dt + r\frac{Q}{P}dt = rdt. \end{aligned} \tag{3.9}$$

Substitute equation (3.8) into equation (3.9) and rearrange the equation, I obtain the fundamental partial differential equation as follows, of which the equity value must a solution.

$$\frac{1}{2}\sigma^2 V^2 F_{VV} + rVF_V + gDF_D + F_t - rF = 0. \tag{3.10}$$

Assume equity is independent of time, then $F_t = 0$. The fundamental equation is simplified to

$$\frac{1}{2}\sigma^2 V^2 F_{VV} + rVF_V + gDF_D - rF = 0. \tag{3.11}$$

To derive this PDE, I actually assume the bank is solvent at the auditing time, i.e. $V > D$. In this case, an audit does not affect the return on the no-arbitrage portfolio. However, if the bank is insolvent at auditing time, the return of the portfolio will be affected. The total change is the sum of decrease in the return of the bank assets and decrease in the return of the bank equity. After taking expectation of the loss and follow the same procedure above, equation (3.9) becomes

$$\begin{aligned} E(\frac{dP}{P}) &= \frac{N_1}{P}(\mu V - (i-g)D - \lambda V)dt \\ &+\frac{N_2}{P}\{F_t + F_V[\mu V - (i-g)D - \lambda V] + \frac{1}{2}\sigma^2 V^2 F_{VV} + gDF_D\}dt \qquad (3.12) \\ &-\frac{N_2}{P}\lambda F dt + r\frac{Q}{P}dt = rdt. \qquad (3.13) \end{aligned}$$

Simplify this equation using the no-arbitrage condition equation (3.8), the fundamental PDE becomes when the bank is insolvent at auditing time,

$$\frac{1}{2}\sigma^2 V^2 F_{VV} + rVF_V + gDF_D - (r+\lambda)F = 0. \tag{3.14}$$

for $V < D$.

Compare to the fundamental PDE for solvent bank, this equation can be interpreted as follows: If the bank is insolvent during auditing time, it may be requested for bankruptcy. As a result, the bank has to pay at higher required return rate: $r + \lambda$. However, if the bank is solvent, the required return rate is only r. The higher required return rate, the low the value. Hence, bank equity value is depressed when the bank is insolvent. Since there is difference λ between required returns when the bank is solvent and insolvent, the implicit bankruptcy costs can be considered as a monotonically increasing function of λ.

Therefore, at the equilibrium, the equity value $F(V, D)$ must satisfy either of these two PDEs (3.11 and (3.14). Note the equity value F is a function of asset value V, and deposit value D. It can be converted into a function only with asset-to-debt, denoted as $x = V/D$. Define $E(x) = F(V, D)$. Then

$$F_V = \frac{E_x}{V_x} = \frac{E_x}{D} \tag{3.15}$$

$$F_{VV} = \frac{\partial F_V}{\partial V} = \frac{1}{D}\frac{\partial E_x}{\partial V} = \frac{1}{D}\frac{\partial E_x/\partial x}{\partial V/\partial x} = \frac{1}{D^2}E_{xx} \tag{3.16}$$

$$F_D = \frac{E_x}{D_x} = \frac{E_x}{-V/x^2} = -\frac{x}{D}E_x \tag{3.17}$$

Substitute equations (3.15), (3.16) and (3.17) into equations (3.11) and (3.14), then the PDEs become ordinary differential equations. If there are no minimum capital requirements, $x = V/D \in (0, \infty)$. When $x \geq 1$, $V \geq D$, the bank is solvent; while when $0 < x < 1$, $V < D$, the bank is insolvent.

$$\frac{1}{2}\sigma^2 x^2 E_{xx} + (r - g)xE_x - rE = 0. \tag{3.18}$$

for $x \geq 1$.

$$\frac{1}{2}\sigma^2 x^2 E_{xx} + (r - g)xE_x - (r + \lambda)E = 0. \tag{3.19}$$

for $x \leq 1$.

These two ODEs are homogeneous Cauchy-Euler differential equations. The general solution is

$$E(x) = C_1 x^{m_1} + C_2 x^{m_2} \tag{3.20}$$

where C_1 and C_2 are determined by boundary conditions; and

$$m_1 = \frac{a_2 - a_1 + \sqrt{a_2^2 - 2a_2a_1 + a_1^2 - 4a_2a_0}}{2a_2} \tag{3.21}$$

and

$$m_2 = \frac{a_2 - a_1 - \sqrt{a_2^2 - 2a_2a_1 + a_1^2 - 4a_2a_0}}{2a_2}. \tag{3.22}$$

a's are coefficients of the three items in the Cauchy-Euler differential equations. Here

$$a_2 = \frac{1}{2}\sigma^2 \tag{3.23}$$
$$a_1 = r - g \tag{3.24}$$
$$a_0 = -r \tag{3.25}$$

for $x \geq 1$;

$$a_2 = \frac{1}{2}\sigma^2 \tag{3.26}$$
$$a_1 = r - g \tag{3.27}$$
$$a_0 = -(r + \lambda) \tag{3.28}$$

for $x \leq 1$

3.2.1. *Without Capital Requirements.* Solve the Cauchy-Euler differential equations with the boundary conditions:

$$E_2(0) = 0 \tag{3.29}$$
$$\lim_{x\to\infty} [E_1(x)] \leq E_m, \tag{3.30}$$

where E_1 represents the solution for the solvent bank, E_2 represents the solution for the insolvent bank. When $x = 0$, the bank total asset is worth nothing, hereby the equity has zero value. The second condition follows the assumption that the value of equity is bounded. Moreover, to meet the continuity requirements, I impose another two conditions.

$$E_1(1) = E_2(1) \tag{3.31}$$
$$E_1'(1) = E_2'(1) \tag{3.32}$$

Thus I obtain the explicit solution for the value of bank equity when there are no capital requirements.

$$E_1(x) = x^{A+B_1} - \frac{B_2 - B_1}{B_1 + B_2} x^{A-B_1} \tag{3.33}$$

$$E_2(x) = \frac{2B_1}{B_1 + B_2} x^{A+B_2} \tag{3.34}$$

where

$$A = \frac{\frac{\sigma^2}{2} - (r-g)}{\sigma^2} \tag{3.35}$$

$$B_1 = \frac{\sqrt{\frac{\sigma^4}{4} + \sigma^2(r+g) + (r-g)^2}}{\sigma^2} > 0 \tag{3.36}$$

$$B_2 = \frac{\sqrt{\frac{\sigma^4}{4} + \sigma^2(r+g+2\lambda) + (r-g)^2}}{\sigma^2} > B_1 > 0. \tag{3.37}$$

3.2.2. *Fixed Capital Requirements.* In the case of fixed capital requirements, each bank faces a constant lower boundary on the capital ratio, denoted as $\underline{c}$. In reality, capital ratios are measured by book values. The book value of bank equity is the difference between V and D. Thus $\underline{c} = E_b/V$, while $x = V/D = \frac{1}{D/V} = \frac{1}{1-E_b/V}$. Obviously, asset-to-debt ratio x is positively related to capital-to-asset ratio. Define $\underline{x} = \frac{1}{1-\underline{c}}$. Then the boundary for x becomes $x \geq \underline{x}$. Since $0 < \underline{c} < 1$, $\underline{x} > 1$, it means that the bank cannot be insolvent. I only need to solve equation (3.18) with the boundary condition

$$E[\underline{x}] = 0 \tag{3.38}$$

Here I assume that a bank is liquidated once the bank does not meet the requirements when audit is performed. This assumption is a little strict, but it shows the idea how implicit costs are involved. In the case without capital requirements, bank equity value is positive unless the asset-to-debt is zero. When fixed capital requirements are imposed, the bank loses positive value of equity even when the asset-to-debt is positive. Thus the bank has to bear the some implicit opportunity costs if it wants to take lower capital ratio than the required. In reality, a violating bank may not be liquidated. However, it will have to face some punishments. For instance, it will be restricted to some loans. For simplicity, I make this strict assumption.

Again use the general solution to homogeneous Cauchy-Euler differential equation with different boundary condition, the value of bank equity under a fixed minimum capital ratio is

$$E(x) = x^{A+B_1} - \underline{x}^{2B_1} x^{A-B_1}, \tag{3.39}$$

where A and B_1 are defined in equations (3.35) and (3.36).

3.2.3. *Risk-Based Capital requirements.* In the case of risk-Based capital requirements, suppose the regulator sets a link between portfolio risk and minimum capital ratio. Banks are categorized into a number of groups according to their portfolio risks. Each group has a corresponding minimum capital ratio. The higher the portfolio risk is, the higher the minimum capital ratio is required. Without loss of generality, I assume that there are only two risk categories. A bank can choose either $(\sigma_h^2, \underline{x}_h; \underline{c}_h)$ or $(\sigma_l^2, \underline{x}_l; \underline{c}_l)$. h means higher portfolio risk or higher capital requirements, while l means lower portfolio risk or lower capital requirements. Then the corresponding equity values are

$$E_h(x) = x_h^{A_h+B_h} - \underline{x}_h^{2B_h} x^{A_h-B_h}, \tag{3.40}$$

$$E_l(x) = x_l^{A_l+B_l} - \underline{x}_l^{2B_l} x^{A_l-B_l}, \tag{3.41}$$

where

$$A_h = \frac{\frac{\sigma_h^2}{2} - (r-g)}{\sigma_h^2} \tag{3.42}$$

$$A_l = \frac{\frac{\sigma_l^2}{2} - (r-g)}{\sigma_l^2} \tag{3.43}$$

$$B_h = \frac{\sqrt{\frac{\sigma_h^4}{4} + \sigma_h^2(r+g) + (r-g)^2}}{\sigma_h^2} \tag{3.44}$$

$$B_l = \frac{\sqrt{\frac{\sigma_l^4}{4} + \sigma_l^2(r+g+2\lambda) + (r-g)^2}}{\sigma_l^2}. \tag{3.45}$$

A bank will choose the higher of $E_h(x)$ or $E_l(x)$.

3.3. **Comparative Statics Analysis and Numerical Analysis.**

3.3.1. *Capital Structure.* With the explicit form solution of the equity value, I use comparative statics analysis to find the impact of capital requirements in this section. First of all, I investigate the case without capital requirements. The equity value comes from equations (3.33) and (3.34). Take the first order derivative of equity value as follows:

$$\frac{dE_1(x)}{dx} = (A+B_1)x^{A+B_1-1} - (A-B_1)\frac{B_2-B_1}{B_1+B_2}x^{A-B_1-1} \tag{3.46}$$

$$\frac{dE_2(x)}{dx} = (A+B_2)\frac{2B_1}{B_1+B_2}x^{A+B_2-1}. \tag{3.47}$$

It is easily to see that the equity is a monotonically increasing function of asset-to-debt ratio x, since $B_2 > B_1 > 0, |B_2| > |B_1| > |A|$. It implies that the bank intends to take higher capital ratio under the deposit insurance even there are no capital requirements. This conclusion is subject to the criticism that some debt-favor factors have not been taken into this model, such as tax deduction. I will discuss this tax issue in the extension part. However, actually taking into account tax will not change this result too much, especially when capital ratio is low. The reason is that the implicit bankruptcy costs are more than enough to offset the tax benefit from using debt. Hence, a bank will finance from their own funds as much as possible, then turn to other means of finance. This implication is different from Myers and Majluf's "pecking order" (1984).

To bank equityholders, the difference between the "protection" of deposit insurance and limited liability is that equity value will rise with deposit insurance. However, when bankruptcy occurs, equityholders cannot benefit more from deposit insurance than limited liability. Equityholders still have zero value equity. Similar to other uninsured firms, reluctance of losing possible earnings plus fear of losing advantage of deposit insurance drive a bank stay away from any risk of bankruptcy, such as immoderate debt use and taking high risk investment portfolio. I will probe into risk-taking behavior in the next section.

Fixed capital requirements do not change this association too much. The first order derivative of the solution for the equity value under fixed capital requirements shows that the equity value is still monotonically positively related to asset-to-debt ratio x.

$$\frac{dE(x)}{dx} = (A + B_1)x^{A+B_1-1} - (A - B_1)\underline{x}^{2B_1}x^{A-B_1-1} \tag{3.48}$$

Figure 1 (insert figure 1) shows that equity value with fixed capital requirements are always below that without capital requirements. The difference between them is the regulation costs due to the distorted behavior under capital requirements, provided other factors hold constant. However,as x (positively related to capital ratio c) increases, the equity values with and without capital requirements converge. This implies that risk capital requirements only have impact on those undercapitalized banks.

Moreover, the second order derivatives also provide some interesting outcomes.

$$\frac{dE_1^2(x)}{dx^2} = (A + B_1)(A + B_1 - 1)x^{A+B_1-2} - (A - B_1)(A - B_1 - 1)\frac{B_2 - B_1}{B_1 + B_2}x^{A-B_1-2} \tag{3.49}$$

$$\frac{dE_2^2(x)}{dx^2} = (A + B_2)(A + B_2 - 1)\frac{2B_1}{B_1 + B_2}x^{A+B_2-2}. \tag{3.50}$$

First, the second order derivatives in the case without capital requirements show that the equity value is convex function of x when the bank is insolvent. However, it loses this convexity for some intervals when $x > 1$. That means, when a bank is insolvent, the marginal benefit from capital increases at an ascending speed. Therefore, the bank is more likely to take more capital to stay away from bankruptcy. Once it is solvent, however, the marginal benefit from capital ceases to increase at the ascending speed. Hence, the equity value becomes concave for some x. Merton (1978) suggests that the concavity might result from the positive spread of competitive market interest rate over the interest rate paid by the bank. However, it is not obvious in my model. In my model, the convexity is regained beyond some x. This pattern of transition also holds in the case of fixed capital requirements. This can be seen from the second order derivative of the equity value under fixed capital requirements as follows:

$$\frac{dE^2(x)}{dx^2} = (A + B_1)(A + B_1 - 1)x^{A+B_1-2} - (A - B_1)(A - B_1 - 1)\underline{x}^{2B_1}x^{A-B_1-2} \tag{3.51}$$

Figure 2 shows a numerical example when risk-based capital requirements are imposed. This figure illustrates that higher minimum capital requirements yield lower equity value if portfolio risk is the same. Moreover, the convergence of equity value between different combinations of portfolio risk and capital requirements confirms the conclusion above: risk capital requirements only have impact on those undercapitalized banks. This figure will be revisited in the next section.

3.3.2. *Risk-Taking Behavior.* With regard to risk-taking behavior, comparative statics analysis is also feasible. However, it is much easier to investigate it graphically. Figure 3 shows a zoom-in picture of the equity value as a function of asset-to-debt ratio at different risk levels σ^2 with and without capital requirements. When there are no capital requirements and the bank equity is more than solvent ($x > 1$), the equity value is greater at lower risk level. This is distinct from implication from standard option pricing model. If contingent claim price is derived from the Black-Scholes's model, the higher the volatility of the underlying assets is, the higher the value is. However, here the underlying asset–bank assets–is faced with some implicit bankruptcy costs. The possibility of losing the benefit from the FDIC and possible future earnings will rise, if the bank takes excessive portfolio risk and hence increase the possibility of bankruptcy. It is the implicit bankruptcy costs that change cause bank equity value to behave different than other contingent claims. That means bank equity value is depressed by the implicit bankruptcy costs.

However, it is interesting to note that in figure 3 bank equity value rises as portfolio risk increases when the bank is far apart from solvency ($x << 1$), then falls as portfolio risk increases when the bank approaches solvency from below, if there are no capital requirements. Mathematically, it is because the mean of the number of audits per time period λ is added to the fundamental PDE when the bank is insolvent without capital requirements. It is the the implicit bankruptcy costs as a monotonically increasing function of λ that make a bank twist its attitude towards risk when it collapses from solvency to insolvency. The twisting point is not at $x = 1$, but a little lower than $x = 1$.

The intuitive explanation for why the bank will take more risk when it is insolvent is the following. When it is actually deep insolvent, taking extremely risky portfolio can either result in bankruptcy or extremely high return. Since the bank is already found insolvent, why not take the chance to recover. Thus, the bank tends to take riskier position when it is far from solvency in hope of achieving higher return. As the bank gets closer and closer to solvent position, it becomes more and more risk-averse. On one hand, it is because the bank is about to recover, it does not need to take risky position. On the other hand, the bank needs to be more prudential to prepare for the solvent situation and stay away from bankruptcy.

These results partly confirm Merton's (1978) conclusion that a solvent bank is risk-averse but a insolvent bank is aggressive in risk-taking. He explains this as follows: A bank pays less than competitive market risk-free interest rate due to deposit insurance if the bank is solvent. However, if the bank is insolvent, it also lose this valuable asset. An increase of risk σ^2 leads to higher probability of becoming insolvent. Therefore, to keep this valuable deposit insurance, the bank should not take too much risk when it is solvent. Nevertheless, when the bank becomes insolvent, it will take more risk in hope of getting over the deficit by taking high risk-high return investments.

Increase in λ moves the twisting point closer to $x = 1$. This implies that the higher implicit bankruptcy costs have more incentive for risk-taking behavior when the bank is insolvent, since a bank wants get rid of bankruptcy more exigently. Nevertheless, changing λ does not have significant influence on the twisting asset-to-debt ratio x.

When fixed capital requirements are imposed, the bank behaves similar to when it is solvent without capital requirements. Since capital requirements must be set above the insolvent level, a bank under capital requirements intends to take lower risk in order to achieve higher equity value.

Moreover, the convergence between the equity values with and without capital requirements indicates that risk-taking behavior is not affected by risk-based capital requirements as capital ratio increases.

It is not easy to see from the analytic solution which combination of risk and minimum capital requirements yields the higher equity value. A numerical example in figure 2 illustrates how a bank chooses between high risk-high minimum capital requirements and low risk-low minimum capital requirements. There are four combination of risk and minimum capital requirements: low risk-low capital requirements, low risk-high capital requirements, high risk-high capital requirements, and high risk-high capital requirements. Under the same capital requirements, the higher the risk is the lower the equity value is. Hence, a value-maximizing bank should take lower risk for the same capital requirements. On the other hand, the higher the capital requirements are the lower the equity value is. This implies that a bank should choose lower capital requirements for the same risk if it can. As assumed above, a bank is faced with two combinations of risk and capital requirements, either low risk-low capital requirements, or high risk-high capital requirements. From figure 2, the combination of low risk and low capital requirements combination yields the highest equity value among four combinations, while the combination of high risk and high capital requirements yields the lowest equity value. Therefore, a bank will definitely choose low risk-low capital requirements rather than high risk-high capital requirements.

Figure 2 also shows that the combination of high risk and low capital requirements yields higher equity value than the combination of low risk and high capital requirements when asset-to-debt ratio is low. As asset-to-debt ratio increases, the equity value from the combination of low risk and high capital requirements increases faster then the equity value from the combination of high risk and low capital requirements. Eventually, the combination of low risk and high capital requirements yields higher equity value than the combination of high risk and low capital requirements. Hence, a well capitalized bank will take lower risk portfolio even it has to keep higher capital ratio. Actually both of these two combinations converge to the other two combinations based on their risk level respectively. It confirms that capital requirements do not affect risk-taking behavior of a well-capitalized bank. In short, these results imply that risk-based capital requirements will not lead to more risk-taking.

4. Conclusion

Deposit insurance and capital requirements are two focuses in banking literature. Many researchers criticize these two important schemes using moral hazard theory: Under the protection of the deposit insurance, banks have incentive to take deposits as much as they can for some debt-favor reasons such as tax deduction on interest payment, and let the FDIC pay for the deposits if it turns out banks do not have enough capital to pay the deposits back. One the other hand, banks also have incentive to take riskier investment in hope of having higher returns. When capital requirements are imposed, insured banks may shift priced risks to unpriced risks. Therefore, capital requirements actually will lead banks to take more risks, and hence lead to higher probability of bank failure. However, this criticism does not consider the implicit costs of bankruptcy. If a bank is bankrupt, it will lose the benefit of deposit insurance. Moreover, it will lose the possible future earnings.

In this paper, I take into account the implicit costs of bankruptcy, and investigate how banks react to the fixed and risk-based capital requirements under deposit insurance. In my basic model, I adopt one factor option pricing model and find a closed-form solution for bank equity in terms of asset-to-debt ratio. The results show that banks actually prefer to use more capital even there are no capital requirements. Moreover, banks tend to take lower risk instead of high risk no matter there are capital requirements or not, if they are solvent. However, for insolvent banks, they may take riskier investment. Under the risk-based capital requirements, banks would prefer lower capital requirements by taking lower risk. Lastly, capital requirements only have impact on banks with low capital. For those well capitalized banks, capital requirements will not affect their behavior too much.

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