Financing Choices of Banks: The Role of Non-Binding Capital Requirements

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Abstract

This paper presents a model of the financing choices (debt v. equity) of banking institutions. It emphasizes the interplay of two well-known factors in corporate financing, namely risk-shifting incentives and growth opportunities. The model provides a new interpretation of the role of capital requirements, recognizing that banks may not operate at the maximal leverage levels allowed. Banks can invest both in real loans that have positive NPV but are in limited supply and in marketable securities that have zero NPV but are in infinite supply. This leads to the coexistence of a local optimum and a socially inefficient global optimum. The role of capital requirement lies in restricting the equilibrium selection. By cutting off the global optimum, capital requirements constrain the majority of banks to stay at their local optima. The macroeconomic implications are also discussed.

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This paper presents a model of the financing choices (debt v. equity) of banking institutions. It emphasizes the interplay of two well-known factors in corporate financing, namely, risk-shifting incentives and growth opportunities. On one hand, as first pointed out by Jensen and Meckling (1976), debt financing creates an agency problem in that stockholders have incentives to invest in risky assets because higher risk increases the "upside" of their payoffs while the firm's creditors absorb the downside. On the other hand, growth opportunities are vulnerable in financial distress and high-growth firms tend to have less debt. Banking firms can be viewed as an extreme case for which risk-shifting incentives are most severe because, with deposit insurance, bank debt is riskless and debt-holders do not have the same incentive to monitor as they do for non-financial firms[1]. In fact, as pointed out by Flannery and Rangan (2002), a general assumption or prediction in the banking regulation literature is that, given flat-premium deposit insurance, banks will operate at the minimum capital ratio allowed and the maximum risk achievable[2].

However, such an assumption or prediction is not wholly consistent with empirical observations. For example, in 1989, in the troubled savings and loan industry, the solvent institutions had an average core capital ratio of 6.4%, well above the 4% standard set by the Financial Institutions Reform, Recovery, and Enforcement Act (FIRREA). At the end of 1993, one year after FIRREA was fully implemented, the average core capital ratio of the savings and loan industry was about 9% and it has remained above this level. Of course, a simple explanation might be that violating capital standards has some costs and firms desire to have a cushion again potential losses. However, as will be discussed in more detail later, a cushion of 5% is too big to be explained by the data. Two questions naturally arise. First, why are capital

[1] Debt investors of non-financial firms typically use debt covenants and/or the maturity and priority structures to limit opportunistic behaviors of the firms (see e.g., Smith and Warner, 1977 and Barclay and Smith, 1995 and 1995a).

[2] For example, see Sharpe (1978), Merton (1977), Kareken and Wallace (1978), and Dothan and Williams (1980) in their analyses of the need for banking regulation and/or the effect of higher capital requirements on risk taking.

requirements not binding for most banks? Second, what do capital requirements do when they are not binding?

This paper provides a general model of banks' financing and risk choices. It shows that as for non-financial firms, profitability and growth opportunities provide disincentives for risk-taking. Banks can invest in both real loans and marketable securities. Real loans are special and essentially illiquid, allowing banks to earn rents on them.[3] The discounted stream of current and future rents on real loans is called, in the banking literature, franchise value or charter value. The supply of profitable lending opportunity is limited because the loan production process exhibits decreasing returns to scale. If banks can invest only in real loans, the trade-off between preserving rents (the franchise-value incentive) and exploiting government insurance value (the risk-shifting incentive) means that banks do not necessarily choose maximal levels of leverage and risk imposed by regulatory rules. However, the interior solution to the bank's maximization problem is only a local optimum. After exploiting all profitable investments in real loans, banks can invest in marketable securities or traded assets with zero NPV but in perfectly elastic supply. With marketable securities, banks can leverage up indefinitely to exploit the government's deposit insurance.[4] Therefore, a global optimum corresponding to maximal leverage and risk, from the banker's point of view, always dominates the local optimum. Because banks do not internalize any social costs of bank failures, the global optimum is not socially optimal. This underscores an interesting and probably unintended role that capital regulation plays. For a fixed amount of capital, capital requirements (both flat-rate and risk-based) limit the bank's ability to leverage and thus impose an upper limit on the maximal gain from leveraging and risk taking. When capital requirements are properly set at a level such that the gain from operating at the boundary is lower than that at the local optimum, the bank

[3] There is a sizable literature on how banks may improve efficiency by reducing agency costs. The bank first screens potential borrowers either based on collateral or loan size (Bester, 1985 and Freixas and Laffont, 1990). Later, by threatening to cut off credit or audit directly, it prevents the opportunistic behavior of the borrower both interim (moral hazard) and ex post (costly state verification) (Stiglitz and Weiss, 1983, Diamond, 1984, and Holmstrom and Tirole, 1997, etc.). As a result, the bank is in a position to provide cheap "informed" funds as opposed to costly "uninformed" or arm's length funds (Fama, 1985 and James, 1987). Finally, there is a positive externality of bank monitoring such that other fixed-payoff claims need not undertake a similar costly evaluation (Easterbrook, 1984 and Besanko and Kanatas, 1993). James (1987) and Cosimano and McDonald (1998) empirically find market power at the level of individual commercial banks.

[4] In banking history, we do observe banks using marketable securities as a way of gambling. For example, during the 1980s, U.S. savings and loans gambled with junk bonds (Barth, 1991). In Southeast Asian countries, banks in Korea and Thailand invested in forward markets, which resulted in huge losses before the financial crisis (Dornbusch, 1998).

chooses to stay at the local optimum. Hence, capital requirements serve as a necessary device that induces the majority of banks to settle at their local optima.

The unintended role of capital regulation is in sharp contrast with the popular view that capital regulation only prevents banks from going across the boundary. For example, regulators claim that "the primary function of capital at a bank ... is to absorb losses ... act as buffer shielding senior claimants" (Shadow Financial Regulatory Committee, March 2000). In other words, capital regulation is simply to prevent banks from choosing capital positions that are too low to comfortably absorb the risk exposure they pursue. This paper thus contributes to our understanding of bank financing choices and effects of capital requirements on bank behavior. On one hand, a small change in capital requirements may cause a large swing in bank's capital ratio if it induces the bank to switch between the interior optimum and the boundary. On the other hand, there is not one single optimal capital requirement as long as the requirements can send most banks to their local optima.

Although the model is designed to explain the financing choices of financial institutions, it has implications for non-financial firms as well. I model the trade-off between gains from risk shifting and losses of growth opportunities. This trade-off is relevant for non-financial firms as well. Governance mechanisms such as monitoring by debt-holders and restrictions of debt covenants serve a similar role to capital requirements for financial institutions. If unchecked, non-financial firms also have incentive to expand and invest in marketable securities or traded assets financed by arm-length debt investors.[5]

In an excellent paper by Flannery (1989), the author presents a model of banks' choice of individual loan default risk in which the value function has a similar shape to that in this paper.[6] As the focus of that paper is on individual loan risk and that the driving force of the coexistence of the two equilibria is different, the choice between these two equilibria is not analyzed. The focus of the current paper is on financing choices between debt and equity. Moreover, this paper analyzes the consequences of the coexistence of the two equilibria and highlights how regulation can change the choices between the local and global optimum. The role of franchise value in creating incentives for banks to choose conservative levels of leverage and risk have

[5]A recent case in point is Vivendi. The company took on an extremely high level of debt and engaged in a spree of unrelated acquisitions which are, at best, zero NPV projects.

[6]Flannery (1989) shows that bank examniation procedures and capital adequacy standards can also make the payoff to equity-holders concave in individaul assets and thus interior solutions are possible.

been extensively analyzed (e.g., Marcus, 1984; Keeley, 1990; Acharya, 1996; Marshall and Venkataraman, 1999; Hellmann, Murdock and Stiglitz, 2000; Bhattacharya, Plank, Strobl, and Zechner, 2000; and Pelizzon, 2001). These studies greatly improve our understanding of conditions under which insured banks would seek less than maximal risk. However, these studies produce corner solutions, that is, if banks do not choose the maximal leverage, they choose zero leverage. Moreover, the role of marketable securities is left unexplained.

The literature on the optimal design of regulations generally finds that it is advantageous to utilize a variety of regulatory instruments, including among others, capital requirement, deposit-rate ceiling, closure policy, access to a discount window, and preservation of bank rents (e.g., Kanatas, 1986; Craine, 1995; Sleet and Smith, 1999; Besanko and Kanatas, 1996; and Hellmann, Murdock, and Stiglitz, 2000). This paper offers a new, though complementary, interpretation of capital regulation. Financial liberalization in the past decade in the U.S. as well as in the emerging markets provide banks with more opportunities to hold marketable securities and to change their asset risks quickly and at low cost. The model's prediction that for banks investing in marketable securities, the risk-shifting incentive dominates any consideration of preservation of franchise value underscores the importance of restricting the equilibrium selection, which should therefore be taken into consideration in banking regulation design.

This paper also has macroeconomic implications. In an extension of the model, I find that the favorable equilibrium selection induced by capital regulation is not stable in the sense that, when hit by an exogenous (adverse) shock, banks adopt "bang-bang strategies." That is, they tend to be either extremely conservative in order to get out of trouble and realize future rents, or to be extremely aggressive to exploit the government guarantee. It is well known that exogenous shocks affect a borrower's net worth and therefore worsen the asymmetric information problems between lenders and borrowers, which could lead to economic fluctuations (Bernanke and Gertler, 1989; Calomiris and Hubbard, 1990). It, however, is less understood that the financial intermediary's response to the shock via its balance-sheet decisions can also be procyclical.

Regarding modeling strategies, I use the option-theoretic framework which has two advantages. First, it is more general than a simple two-state model. Second and more importantly, it allows me to capture the idea that current rents, which exhibit decreasing returns to scale, affect both the current asset price and the probability of defaulting in a relatively simple and general structure. The elegant option-pricing formulae actually make the model simpler than a two-state model without having to rely on strong assumptions.

The remainder of this paper is organized as follows. The first section introduces the model. Section 2 develops the main results. Section 3 extends the model to the situation when the bank is hit by an exogenous (adverse) shock. Section 4 presents an analysis of the Southeast Asian crisis in respect to the model. Section 5 concludes the paper.

1. The Model

In this paper, the institutional structure of commercial banks is exogenously imposed. In particular, I assume that banks finance their investments by issuing demand deposits and that the activities of taking deposits and making loans occur within the same entity.[7] The bank is initially endowed with a fixed amount of capital.[8] This assumption is consistent with the notion that it is costly for banks to raise equity capital (Stein, 1998) and with the way new institutions are formed.[9] Bank shareholders are risk neutral. Bank managers act on behalf of the shareholders. Although common in the literature, this assumption abstracts from the possible conflicts of interests between managers and shareholders (Gorton and Rosen, 1995). It will be discussed later that managerial career concerns do not alter the main results. The bank can invest in both non-traded real loans with positive NPVs but in limited supply and in marketable securities with zero NPV but in unlimited supply.

The bank exists at three given dates with no discounting. At $t = 0$, it decides its asset size, I, and the risk level, σ (defined as the asset volatility), of both real loans and marketable securities. Note that, with a fixed amount of capital, there is a one-to-one correspondence between size and leverage. At $t = 1$, there is a new investment opportunity that generates a positive NPV equal to π. π can also be interpreted as future rents. For simplicity, I treat π as being certain (not random). In a dynamic setting, π can be endogenized (see, e.g., Hellmann,

[7] Kashyap, Rajan, and Stein (1999) show that there are economic synergies for the two sides of the balance sheet to share the burden of holding liquid assets.

[8] Some earlier literature assumes that the bank has a fixed size and determines the division between debt and equity (e.g., Merton, 1977, Sharpe, 1978, and Koehn and Santomero, 1980). I find that, under this assumption, only corner solutions exist. To conserve space, I do not present these results.

[9] Historically, bank regulators required new institutions to have a minimum of initial capital stock depending on the population of the service area. For example, in the 1980s, the FHLBB, the regulatory agency of savings and loans required a minimum of $2 million in initial capital stock for institutions located in counties with a population greater than 100,000.

Murdock, and Stiglitz, 2000 and Pelizzon, 2001). Because this paper focuses on equilibrium choices regarding real loans and marketable securities, a static framework is sufficient to capture the basic ideas.

The bank faces periodic examinations. At the end of each period, the regulator reviews the bank based on accounting reports. If the regulator finds that the bank is insolvent, then he/she, rather than closing the bank immediately, would restrict the bank in a way that prevents it from investing in profitable projects. Therefore, the bank realizes π only if the bank is solvent in accounting terms at the end of the first period. To avoid the debt overhang problem, I assume that the bank debt issued at $t = 0$ matures at $t = 1$.[10] If the bank is solvent, it pays off its debt and proceeds with a new project with a NPV of π. For simplicity, I assume that the bank invests whatever remains in a risk-free asset. If it is insolvent, the bank is liquidated. At $t = 2$, the bank realizes π and is liquidated.

In modeling rents on bank loans, I follow the assumptions in Gennotte and Pyle (1991) that loan payoffs are characterized by both asset size, I, and risk, σ. I denote the net present value of a loan portfolio with size I (book value) and risk σ as $J(I, \sigma)$. The market value of the asset is:

$$v(I, \sigma) \equiv J(I, \sigma) + I. \tag{1}$$

Note that $v(I, \sigma)$ can be viewed as the bank's production function with leverage and risk as inputs. I assume that $v_{I\sigma} = 0$, i.e., the bank can increase size I and add risk σ independently. To capture the idea that the bank has a limited number of profitable projects and has diminishing returns to inputs, I assume that $v(I, \sigma)$ (and $J(I, \sigma)$) is a concave function of size and risk. Consider a bank situated in a geographical region where it has some competitive advantage in certain types of loans with certain level of risks. Compared with other banks, this local bank has lower loan initiation costs. If it continues to grow, however, it eventually extends beyond its expertise. The costs associated with information gathering, contracting, and monitoring would grow faster than the interest that the bank can charge borrowers. This is consistent with the empirical findings of Petersen and Rajan (1995) that in a sample of small firms, over half are located within two miles of their primary lending institution. Similarly, if the bank continues to increase its loan risk, it eventually extends beyond the loan market where it has expertise,

[10] Alternatively, one can assume that the debt is rolled over.

resulting in diminishing returns.[11]

The concavity of the loan production function implies that banks invest in real loans only up to the point where $J_I = 0$ and $J_\sigma = 0$. In the region where $J_I < 0$ or $J_\sigma < 0$, the bank is better off investing in assets which are in perfectly elastic supply at NPV of at least zero. Marketable securities or traded assets satisfy this condition. Beyond certain point, marketable securities dominate non-traded real loans.

This paper emphasizes bank rents on the asset side. Rents on current assets and future investment opportunities drive the interior solution. Banks, however, may also earn rents from insured deposits, the liability side of the balance sheet.[12] For simplicity, I choose not to model bank rents from deposits in the main model. I assume that with deposit insurance, the bank borrows at risk-free rate R_f. For simplicity, I normalize R_f to zero. I also assume that deposits are the bank's only liabilities and that bank deposits are insured at zero charge. I later discuss the implication of rents earned from deposits.

At time 0, the bank's balance sheet in market value appears as follows:

Assets in place	$v(I,\sigma)$	D
Insurance Put	$Put(v,D,\sigma)$	
Investment opportunity	G	E
Market value of the Firm	V	V

On the left-hand side of the balance sheet, $v(I,\sigma)$ is the market value of assets in place as described earlier; $Put(v,D,\sigma)$ is the value of the insurance put option on bank assets with a current value of v and an exercise price of D; G is the expected present value of investment opportunity π, which resembles a binary call option on bank assets with the same term as that of the insurance put option. On the right-hand side of the balance sheet, D is the market value of the bank's debt, which equals the face value because of the deposit insurance. Note that, for non-financial firms, if the debt is fairly priced according to the risk, D should equal the face value subtracted by the put value ($Put(v,D,\sigma)$). E is the market value of equity. The

[11] See Black et al. (1978) for a discussion of the administrative costs associated with high-risk loans. In reality, there is another cost associated with increasing risk: as deposit insurance guarantees only the principal of the deposits, insured depositors lose interest payments if the bank is insolvent. As a result, insured depositors will charge a premium for this interest-payment risk as the bank becomes riskier. Although my model assumes the cost of funds is 0, this element can be easily incorporated without altering the main results.

[12] Hannan and Berger (1991) and Neumark and Sharpe (1992) find empirically that consumer bank deposit interest rates exhibit greater asymmetric price rigidity in more concentrated markets. Hutchison and Pennacchi (1996) also find that banks have market power in setting retail deposit interest rates and the resulting rents contribute to bank charter value as 3.82% of total deposits.

manager's objective is to maximize total market value of equity E. For notational convenience, let us define c as the book value of equity and W as the total market value of equity in excess of the book value of equity. That is, $W = E - c$. As I assume that the bank is initially endowed with a fixed amount of capital (i.e., the book value of equity c), maximizing the total market value of equity E is then equivalent to maximizing W. W can be expressed as:

$$\begin{aligned} W &= v + Put(v, \sigma, D) + G - D - c \\ &\equiv J(I, \sigma) + G + Put(v, \sigma, D). \end{aligned} \tag{2}$$

Therefore, W has three components: the rent on assets in place $J(I, \sigma)$, the value of future investment opportunity, G, and the deposit insurance put option, $Put(v, \sigma, D)$. The sum of the first two can be interpreted as the franchise value, that is, franchise value consists of both current rents and future rents. Alternatively, by put-call parity, W can also be written as:

$$W \equiv Call(v, \sigma, D) + G - c.$$

This is the sum of the value of a call option on current assets, $Call(v, \sigma, D)$, and the value of a binary call option on future investment opportunities, G, less the owner's capital, c.

In this paper, I use the Black-Scholes formula and other standard option pricing formulae to value the call option and the binary call option.[13] The value function, W, at time 0 is,

$$W = vN(x) - DN(x - \sigma) + \pi N(x - \sigma) - (I - D), \tag{3}$$

where $x = 0.5\sigma + ln(v/D)/\sigma$. I choose to use the option-pricing framework for two reasons. First, it is more general than a simple two-state model. Second and more importantly, it allows me to capture the idea that current rents, which exhibit decreasing returns to scale, affect both the current asset price and the probability to default in a relatively simple and general structure. The elegant option-pricing formulae actually make the model simpler than a two-state model without strong assumptions.

2. Equilibrium Choices of Leverage and Risk

There are two building blocks in deriving my results. The first is the bank's behavior when it invests only in marketable securities with zero current rents. In this situation, only corner

[13] For that purpose, I adopt the standard assumption of a geometric Brownian motion with constant drift and volatility rate for the process of the underlying asset.

solutions can be obtained, that is, the bank always chooses maximal leverage and risk. The second building block is the bank's behavior when it invests only in non-traded assets. In this situation, an interior solution exists under regularity conditions. I begin by discussing these two situations separately. Then I combine the results to characterize the bank's behavior when it has a limited number of positive NPV lending projects, but can further expand with marketable securities.

2.1. When a Bank Invests Only In Marketable Securities

With a fixed amount of capital, the capital structure decision is equivalent to choosing the optimal bank size. Marketable securities earn zero rent, i.e., $J(I, \sigma) = 0$, and $v = I$. The future rents equal to π. The bank's problem can be written as,

$$\underset{I,\sigma}{Max}\ W(I, \sigma) = I \cdot N(x) - (I - c)N(x - \sigma) + \pi N(x - \sigma) - c, \tag{4}$$

where $x = 0.5\sigma + ln(I/(I - c))/\sigma$. Differentiating W with respect to I and simplifying, noting that $IN'(x) = (I - c)N'(x - \sigma)$, we have:

$$W_I = N(x) - N(x - \sigma) - \frac{\pi}{I(I - c)\sigma} N'(x - \sigma), \tag{5}$$

From an option pricing point of view, changing current asset value I changes both the strike price $(I - c)$ and the risk-neutral probabilities $N(x)$ and $N(x - \sigma)$. It is interesting to note that the effects of changes in risk-neutral probabilities $N(x)$ and $N(x - \sigma)$ cancel each other out (i.e., $IN'(x) = (I - c)N'(x - \sigma)$) which considerably simplifies the whole analysis. This relationship, however, is not easy to be captured by a discrete-time setting. This is, in addition to its generality, the reason why I choose to use an option-pricing framework.

The sum of the first two terms in Equation (5) is positive, meaning that an incremental increase in size increases the value of the call option on current assets. As marketable securities are zero-NPV investments, the call value comes purely from the deposit insurance. Meanwhile, a larger bank size and therefore higher leverage increases the probability of default and thus reduces the binary option value of the future investment opportunity. The equilibrium choice of the bank size, I, is thus a trade-off between the increased deposit-insurance value (the risk-shifting incentive) and the bigger chance of losing future investment opportunities (the franchise-value incentive). Let $\pi^0 = \frac{I(I-c)\sigma[N(x)-N(x-\sigma)]}{cN'(x-\sigma)}$. Equation (5) is reduced to:

$$W_I = \frac{c}{I(I - c)\sigma} N'(x - \sigma)(\pi^0 - \pi), \tag{6}$$

Similarly, the risk choice depends on:

$$W_\sigma = (I - c)N'(x - \sigma) + \pi N'(x - \sigma)\frac{\partial(x - \sigma)}{\partial\sigma}. \tag{7}$$

Note that $\partial(x-\sigma)/\partial\sigma = -0.5 + ln(d)/\sigma^2 = -x/\sigma$. Rearranging the terms allows us to rewrite the above equation as:

$$W_\sigma = \frac{x}{\sigma}N'(x - \sigma)(\pi^1 - \pi), \tag{8}$$

where $\pi^1 = (I - c)\sigma/x$. To understand the equilibrium choices of leverage (i.e., by choosing I) and risk, it is important to understand how π^0 and π^1 change with leverage and risk. Lemma 1, which is proved in the Appendix, states that π^0 and π^1 are increasing functions of I and σ, respectively.

Lemma 1. *$\partial\pi^0/\partial I > 0$ and $\partial\pi^1/\partial\sigma > 0$.*

From Equations (6) and (8), it follows that given its initial position, the bank wants to add or reduce leverage and risk depending on the magnitude of π in comparison with π^0 and π^1. Lemma 1 implies that after it adds or reduces leverage and risk, the bank has more incentive to do so further. As a result, the bank's problem has only corner solutions. This replicates and provides a formal proof to the results in Keeley (1990).[14] Among the two corner solutions, one actually dominates the other. This is because as $I \to +\infty$, the value of the call option on current assets goes to infinity and thus W goes to infinity. Therefore, the optimal bank size I in the global sense is always infinite. On the other hand, as $I \to +\infty$, $x \to 0.5\sigma$, we have $\pi^1 \to +\infty$ and $W_\sigma \to +\infty$ for any σ. Taken together, the bank always invests in the riskiest assets in an infinite amount. The intuition is that, given a fixed amount of capital, the gain from the deposit insurance through leveraging is unbounded. As a result, the incentive to increase the insurance put value (the risk-shifting incentive) always dominates the incentive to preserve the binary call option value of the investment opportunity (the franchise-value incentive). Formally, we have the following proposition:

Proposition 1. *In the absence of regulatory constraints, a bank with given initial capital c always chooses maximal leverage and risk if it is allowed to invest in marketable securities.*

[14]Keeley (1990) emphasizes one of the corner solutions, i.e., the bank may take low leverage and risk due to charter value.

In the presence of capital requirements, for a given amount of capital, the bank size cannot exceed a certain threshold, I^{reg}. It can be verified that, for the parameter values in banking (e.g., a leverage ratio greater than 80% and volatility greater than 5%), $\pi^0 < \pi^1$. Therefore, with regulatory constraints, the optimal risk level is the maximal amount achievable when the capital requirement is binding. After comparing the total values from the two extreme choices, $(I^{reg}, \sigma^{\max})$ and $(c, \sigma^{\min})$, the bank chooses the one that generates the higher value of W.

2.2. When a Bank Invests Only in Real Loans

The bank's problem now becomes,

$$\underset{I,\sigma}{Max}\ W(I,\sigma) = v(I,\sigma)N(x) - (I-c)N(x-\sigma) + \pi N(x-\sigma) - c, \tag{9}$$

where $x = 0.5\sigma + ln(v/(I-c))/\sigma$. In the absence of deposit insurance and future investment opportunities, banks seek to maximize the net present values of their asset portfolios, $J(I,\sigma)$. Thus, the value-maximization condition is $J_{I^*} = 0$ and $J_{\sigma^*} = 0$. Let us call this a benchmark condition.

Differentiating the objective function with respect to I, we have:

$$W_I = v_I N(x) + vN'(x)\frac{\partial x}{\partial I} - N(x-\sigma) - (I-c)N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I} + \pi N'(x-\sigma)\frac{\partial x}{\partial I}. \tag{10}$$

Note that $N'(x) = (I-c)N'(x-\sigma)/v$, we have:

$$W_I = v_I N(x) - N(x-\sigma) + \pi N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I} = 0. \tag{11}$$

Similarly, differentiating with respect to σ and simplifying gives,

$$W_\sigma = v_\sigma N(x) + (I-c)N'(x-\sigma) + \pi N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial \sigma} = 0. \tag{12}$$

It is easy to verify that when $\pi = 0$, $v_I < 0$ and $v_\sigma < 0$ are at the optimum. That is, compared with the benchmark condition, the bank overinvests in risky assets when there is not any future investment opportunity.

The bank solves the two equations (11) and (12) simultaneously for the optimal size and risk. Compared to the previous case of marketable securities, increasing size and risk affects both the value of the call option on current assets and the binary option value of future investment opportunity in a more complicated way. As the bank invests in real loans only up to the point where $J_I = 0$ and $J_\sigma = 0$, let us restrict our attention to the region where $J_I \geq 0$ and $J_\sigma \geq 0$. In this region, due to the economy of scale, increasing size and risk increases the value of current assets, which has a positive effect on the call option value. Meanwhile, it also increases the strike price (by increasing leverage), which has a negative effect on the call value. These two forces are in offsetting directions. The net effect is positive, because the sums of the first two terms in Equations (11) and (12) are positive. Alternatively, recall that the total value function can be written as $W = J(I, \sigma) + Put + G$. The increase in the call option value comes from both the insurance value and the rents on current assets. Compared with the previous case, the insurance value grows at a slower rate due to higher current asset values.

Similarly, the effect of increasing size and risk on the binary call option is also two fold: it increases both the current asset value and the strike price of the binary option. Lemma 2 states that the net effect is negative (the proof is given in the Appendix).

Lemma 2. $\frac{\partial(x-\sigma)}{\partial I} < 0$, $\frac{\partial(x-\sigma)}{\partial \sigma} < 0$.

Again, the equilibrium choice of leverage and risk is a trade-off between enhanced value of the call option on current assets and the larger chance of losing future investment opportunities. Because the loan production function $v(I, \sigma)$, (or equivalently $J(I, \sigma)$) is concave, the value of the call option on current assets would at some point grow at a slower rate than the value of the binary option on future investment opportunity declines. Under the regularity condition that $W(I, \sigma)$ is globally concave in I and σ,[15] there is a unique solution (I^*, σ^*).

The bank's probability of failure is:

$$q = 1 - N(x - \sigma), \tag{13}$$

where $x = 0.5\sigma + ln(v/(I - c))/\sigma$. It immediately follows that the bank's default probability depends not only on leverage and risk as suggested by Merton (1977) among others, but also on its production technology, $v(I, \sigma)$. Banks that generate larger rents (higher $v(I, \sigma)$ for given I and σ) are often those with superior monitoring and screening technologies, a larger branch network, and better client relationships. Compared with other banks, these banks can invest in riskier assets without necessarily incurring higher default risk. This has important policy implications on risk-based capital supervision, which will be discussed in the next section.

Directly from Lemma 2, for a fixed risk level, the more valuable the future investment opportunities are, the lower the leverage the bank chooses. Similarly, given the leverage, the optimal risk level decreases with the value of future investment opportunities. It is formally

[15] This condition requires that the $v(I, \sigma)$ function is sufficiently concave point-wise.

proved in the Appendix that under the condition that $v_{II}v - v_I^2 + k^2 < 0$, we have $dI^*/d\pi < 0$, and $d\sigma^*/d\pi < 0$. This condition can be interpreted as v is concave enough in I. The comparative statics results tell that the optimal choices of size and risk are negatively related to the value of future investment opportunities.

To examine the impact of investment opportunities on the probability of failure, we have,

$$\frac{dq^*}{d\pi} = \frac{\partial q}{\partial I}\frac{dI^*}{d\pi} + \frac{\partial q}{\partial \sigma}\frac{d\sigma^*}{d\pi}. \tag{14}$$

Note that $\partial q/\partial I = -N'(x-\sigma)\partial(x-\sigma)/\partial I > 0$ and $\partial q/\partial\sigma = -N'(x-\sigma)\partial(x-\sigma)/\partial\sigma > 0$. Combining with Lemma 2, we have $dq^*/d\pi < 0$. Hence, the larger the value of future investment opportunities, the smaller the default probability for the bank as it becomes more conservative. These results are summarized in the following proposition.

Proposition 2. *For given initial capital c, when the bank invests in non-traded real loans with concave enough net present value function in I and σ, the optimal choices of leverage and risk and the resulting default risk decrease with future investment opportunities. That is, $dI^*/d\pi < 0$, $d\sigma^*/d\pi < 0$, and $dq^*/d\pi < 0$.*

2.3. When a Bank Invests in Real Loans and Can Expand with Marketable Securities

When the bank can expand with marketable securities, the interior solution in the previous section is not sustainable. Consider a bank operating at its local optimum (I^*, σ^*). The interior optimum has two possible locations: it is either in a region where $J_I > 0$ or in a region where $J_I \leq 0$. The latter case is trivial: the bank switches to traded assets before it even reaches an interior optimum. It is easy to verify that there does not exist an interior optimum and the capital requirements are always binding.

Now let us consider the case in which $J_I > 0$. If the bank further increases its loan size beyond I^*, it will reduce shareholder value as it moves away from the optimum. Intuitively, although increasing loan sizes increases the call value on current assets (a size effect), it also increases the probability of default and thus in losing both current and future rents (a leverage effect). The latter effect dominates. However, if it continues to expand, after the point when $J_I = 0$, it will be investing in marketable securities and eventually the results in Section 2.1 will be in effect.

Denote the bank size at the switching point between the real loans (i.e., positive NPV projects) and marketable securities as I_s, where $J_I(I_s, \sigma^*) = 0$. Then for $I > I_s$, the $W(I, \sigma)$ function becomes:

$$W(I, \sigma) = (I + \overline{J})N(x) - (I + \overline{J} - c)N(x - \sigma) + \pi N(x - \sigma) - c, \tag{15}$$

where $x = 0.5\sigma + ln((I + \overline{J})/(I - c))/\sigma$, $\overline{J} = J(I_s, \sigma^*)$, which is the maximal NPV achieved at the switching point. Similar to the earlier section on traded assets, we have:

$$W_I = \frac{c}{I(I - c)\sigma} N'(x - \sigma)(\pi^s - \pi), \tag{16}$$

where $\pi^s = \frac{(I+\overline{J})(I-c)\sigma[N(x)-N(x-\sigma)]}{(\overline{J}+c)N'(x-\sigma)}$. From equation (11) and the fact that $W(I, \sigma)$ is concave,

$$\pi > \frac{v_I N(x) - N(x - \sigma)}{N'(x - \sigma)\frac{\partial(x-\sigma)}{\partial I}}\Big|_{I=I^s} = \pi^s \Big|_{I=I^s} . \tag{17}$$

This is to say, immediately after the switching point I^s, the value function $W(I, \sigma)$ is downward sloping. However, if the bank continues to expand, the decision rules in Section 2.1 on marketable securities apply: the gain from the deposit insurance eventually dominates the loss of current assets and future investment opportunities. The bank would like to leverage up indefinitely. Thus the interior solution characterized in Section 2.2 is only a local optimum. There always exists a global optimum where the bank invests in the riskiest traded assets in an infinite amount. The coexistence of a local interior optimum and a global one is illustrated in Figure 1. It is interesting to note that in Flannery (1989), the value function has a very similar shape to that in Figure 1. In that paper, the choice between these two equilibria is not analyzed, because the focus is on individual loan risk and the driving force of the coexistence of the two equilibria is different. The focus of my paper is on financing choices between debt and equity. And I will highlight later how regulation can change the choices between the local and global optimum.

As investing in zero-NPV marketable securities does not create any value, they serve purely as a device to pursue risk and thus to exploit the government's insurance. With the social costs of bank default, the global optimum is inefficient. This discussion is summarized in the following proposition.

Proposition 3. *For given initial capital, c, when the bank invests in both non-traded real loans and marketable securities, a global optimum corresponding to the maximal leverage and risk using marketable securities dominates the local optimum in real loans.*

This suggests a role for government intervention using capital regulation. In the presence of capital requirements, the bank size cannot exceed a certain limit. This effectively imposes an upper limit on the maximal gain from leveraging and risk taking. The bank then compares the maximal gain achieved by operating at the boundary with the value at the interior optimum. As illustrated in Figure 1, if the total value, B, derived from maximal leverage (corresponding to a size I^1_{reg}) is lower than that achieved at the local optimum A, it will stay at its local optimum. However, if the capital requirement is too lenient, e.g., set at I^2_{reg}, because the resulting value, C, is higher than A, the bank will operate at the boundary I^2_{reg}. Therefore, capital requirements not only prevent a few banks from going across the boundary, but, more importantly, also cut off the global optimum, which induces most of the banks to choose their local optima.

Another interesting point is that there is not one single optimal capital requirement. Rather, there is a range of capital requirement that does the job of sending banks to their local optima. Again, it is useful to look at Figure 1. The upper bound of the optimal capital requirement is I^3_{reg}, the point at which gambling with marketable securities achieves the same value as the local optimum does. Any requirements between the local optimum, I^*, and I^3_{reg} can induce the bank to stay at its local optimum. Obviously, if the capital requirement is set at a point to the left of the interior optimum, I^*, the bank hits the boundary even before it achieves the interior optimum, which results in inefficiency. With the heterogenous bank production function, there is a dispersion of interior optima. Therefore, the optimal choice of capital requirements reflects a trade-off between ensuring that more banks choose their local optima and minimizing the inefficiencies arising from some banks not being able to achieve their local optima. In a healthy banking industry with significant franchise value, banks achieve higher value at their local optima. Thus, even lenient capital requirements can induce most banks to operate at their local optima. However, in a banking system with eroded rents (for example, due to financial liberalization)[16] and thus with lower values achieved at the local optima, risk-shifting incentives tend to prevail and tighter capital requirements are critical in containing wide-spread risk taking.

My model contributes to our understanding of bank financing behavior and the debate on

[16]Hellman, Murdock, and Stiglitz (2000) and Allen and Gale (2000) model how competition, as a result of financial liberalization, might induce banks to bid up deposit rates and hence reduce franchise values. Besanko and Thakor (1993) model the impact of competition on the asset side and the value of relationship banking in particular.

the effect of tightening capital requirements on bank risk.[17] First, a small change in capital requirements can cause a large swing in the bank capital ratio if it moves from the boundary to the interior optimum and vise versa. This is consistent with the findings in Flannery and Rangan (2002) that within five years of the introduction of Basle According in 1989, the average capital ratio increased about 4% for the largest 100 banks in the U.S.[18] Moreover, as illustrated in Figure 1, a tightened capital requirement has different impacts on banks depending on their initial positions. Those that are already at the interior optimum will not be affected at all unless the leverage at the interior optimum does not meet the capital requirement. For those banks that are at the boundary, tightened capital requirements may or may not send them to the interior optimum depending on how much "tighter" the requirements are. If the bank goes to its interior optimum due to tighter requirements, its risk level will be lower. This is consistent with the findings of Dahl and Shrieves (1990) that banks altered their asset composition towards less risky assets when they faced a binding (flat-rate) regulatory capital constraint in 1985-1986.

The above results are in contrast with those presented by Hellmann, Murdock, and Stiglitz (2000). They find that capital requirements are Pareto inferior to deposit-rate ceilings. Their results, however, are derived in a setting where bank capital is costly and banks choose the maximal leverage levels allowed. Another element in their model is that deposit-market competition can drive away any rents on assets. A deposit rate ceiling helps preserve bank rents and accentuates risk-shifting incentives. Although this paper does not model rents on deposits, it is conceivable that even if banks do not have any market power, as long as they earn some quasi-rents, the interior solution can be sustained. A deposit rate ceiling would limit the bank's ability to take on more debt and, for a fixed amount of capital, to grow bigger.[19] Thus, a deposit ceiling can also play the role of cutting off the global optimum and sending banks back to their local optima. In this sense, it is equivalent to a flat-rate capital requirement. Capital regulation has one advantage over the deposit-rate ceiling: through risk-based capital

[17] Despite the popularity of using solvency regulations to control bank risk, some researchers argue that capital requirements may induce banks to shift towards risky assets and therefore result in higher probability of failure (e.g., Kareken and Wallace, 1978, Koehn and Santomero, 1980, Rochet, 1992, and Gennotte and Pyle, 1991).

[18] Flannery and Rangan (2002) is the first paper that that explicitly study the capital buildup (in market value) above the regulatory requirements in the 1990s. They focus on the market value of capital. They find that higher market value of capital ratio reflects portfolio risk. Although my model's main predictions are on book value of capital ratio, their results are consistent with my model. For banks operating at their local optima, it is likely that, all else equal, banks with higher portfolio risk earn higher rents and thus have higher market capital ratio.

[19] In a different setting, Matutes and Vives (2000) and Besanko and Thakor (1992) also make this point.

requirements, capital regulation can be adjusted to take bank risk into account.

2.4. Discussion

The model makes some simplifying assumptions. First, it assumes that managers' incentives are fully aligned with shareholders' interests. As pointed out by Gorton and Rosen (1995), management entrenchment can be important in explaining risk-taking behavior under certain circumstances. Managerial career concerns, however, do not alter the main results in this paper. In my model, without regulatory intervention, the incentive to take risks is very strong: it corresponds to infinite value to shareholders. In this case, shareholders do not care whether the manager is of a good or a bad type because the financial institution has become solely a device to leverage and thus to exploit the government's deposit insurance. From the point of view of managers, as long as they own a fraction of the bank, they behave as if their interests are fully aligned with those of the shareholders and choose to operate at the global optimum. The manager's self-interest may only affect the location of the local optimum.

Although I assume the amount of capital is fixed, the model has implication on how the optimal capital level is determined. When bank capital is fixed, the maximal gain from leverage is limited by the capital requirement. If the bank can raise capital costlessly, it always has the incentive to put up more capital to take advantage of the additional ability to leverage.[20] That is, the bank always has incentive to push the global optimum towards the right. In reality, it has to trade off between the gain from additional leverage and the cost of issuing equity.

I have restricted my analysis to fixed-rate capital requirements. The model, however, is also applicable to risk-based capital requirements. Risk-based requirements assign risk weights to different types of assets based on perceived credit risks and banks need to hold different amounts of capital against assets with different risk weights. The way that the maximal possible leverage is calculated does not alter the fact that the capital requirements impose an upper limit on bank size and thus the gain from leverage. To the extent that under risk-based capital requirements banks have to hold more capital (8%) against the assets with the highest risk (the maximal risk weight is 100%), these requirements are most effective for banks that are operating at the boundary because those at the boundary also take lots of risks. Risk-based capital requirements, however, are not without costs. For banks with heterogenous loan production functions, risk-

[20] The proof is similar to that of Proposition 1.

based capital requirements can impose excessive restrictions. An underlying assumption of risk-based capital requirements is that banks have the same production technologies, i.e., the default risk of a bank depends solely on its asset risk and leverage. However, as Equation (13) suggests, the probability of default also depends on its production technology as represented by $v(I, \sigma)$. Consider two banks with different technologies. Even if they choose the same leverage and asset risk, their default risks are different, with the more profitable one having lower default probabilities. Consequently, they should be regulated differently. When a bank operates at its interior optimum, where self-discipline is at work, risk-based capital requirements may impose excessive restrictions on the banks' investment decisions and therefore lead to inefficiency.[21] Nevertheless, if the primary concern is to control bank defaults, capital requirements dominates deposit-rate ceilings.

An important feature of the model is that banks can invest in marketable securities or other traded assets, which are in perfectly elastic supply with zero NPV. In reality, we do observe banks using marketable securities as a way of gambling. For example, during the 1980s, U.S. savings and loans gambled with junk bonds (Barth, 1991). In Asian countries, banks in Korea and Thailand invested in forward markets which resulted in huge losses before the Asian financial crisis (Dornbusch, 1998). Moreover, the model predicts that if unchecked, non-financial firms also have incentives to take on high leverage and engage in zero-NPV projects at the expense of debt-holders. A recent case in point is Vivendi. The company used its cash to buy back shares and borrowed to invested in a chain of unrelated acquisitions, which were at best zero NPV projects. Vivendi recently found itself on the verge of bankruptcy filings due to its extremely high leverage.

There is one remaining issue: could there be some alternative, and simpler explanation of the empirical facts that banks hold capital well above the minimal requirements? The answer is that the cushion seems higher than what can be justified by the data. Take the example again of the savings and loan industry. In 1993, it has an average core capital ratio of 9%, 5% higher than the minimal requirements of 4%.[22] At the end of 1992, the average return on assets was

[21] Inefficiency arises as banks become less willing to screen potential borrowers, which leads to higher incidence of credit rationing in equilibrium (Thakor, 1996), or as banks become less willing to renegotiate troubled loans, which forces more borrowers to shift to capital markets and impare capital allocation (Thakor and Wilson, 1995).

[22] Core capital requirements are the most binding one among the three tiers of standards.

0.77%, with an average quarterly variability of 0.87% within the past 20 quarters. Assuming ROA has a normal distribution, in order to be 99.99% sure that the capital ratio does not fall below the requirement because of the variability in returns, the firms only needed to keep a cushion of 2.4%, which is less than half of the actual cushion. Therefore, a simple "cushion" story is not enough to explain the excess capital held by banks.

3. The Stability of the Equilibrium

So far, I have characterized bank behavior at the equilibrium under capital regulation with most banks operating at their interior optima while others are operating at the boundary. In this section, I ask if such a pattern is stable. In particular, I discuss a special case in which the bank is hit by an exogenous (adverse) shock. I show that the above pattern is not stable in the sense that when hit by an exogenous shock, the bank's problem has only corner solutions.

I define the shock as a sudden decline in asset value (e.g., due to an increase in long-term interest rate, or a drop in asset prices). To the extent that the shock is temporary, the bank loses its immediate profits, but not necessarily its future investment opportunities. On the other side of the balance sheet, the value of deposit liability remains unchanged. For simplicity, I assume that $J = 0$, or, equivalently, $v = I$.[23] The bank's future investment opportunity is π. Although I use the same notation, this π does not have to be the same as the pre-shock π. The problem then becomes for a fixed level of bank debt D, how does the bank decide on its size and risk when it does not earn any current rents, i.e., $J = 0$. This setup is similar to that in Marcus (1984). The bank's value function can be written as,

$$W = I \cdot N(x) - D \cdot N(x - \sigma) + \pi N(x - \sigma) - (I - D) \tag{18}$$

where $x = 0.5\sigma + ln(I/D)/\sigma$. The first-order conditions are:

$$W_I = \frac{N'(x - \sigma)}{\sigma I}(\pi - H^0), \tag{19}$$

$$W_\sigma = \frac{x}{\sigma} N'(x - \sigma)(H^1 - \pi), \tag{20}$$

where $H^0 = \frac{[(1-N(x)]\sigma I}{N'(x-\sigma)}$, $H^1 = \sigma D/x$. I prove in the appendix that $\partial H^0/\partial I < 0$ and $\partial H^1/\partial \sigma > 0$. Similar to the arguments in Section 2.1, the bank's problem has only two corner solutions.

[23] The results do not change as long as the bank has significantly fewer positive NPV opportunities such that it has to switch to marketable securities when it further increases its size, i.e., $I^0 \leq D$.

Proposition 4. *When an exogenous shock eliminates a bank's current rents but not its future investment opportunities, the bank chooses to between two corner solutions. Without regulatory constraints, the bank either chooses maximal leverage and risk or zero leverage and risk.*

Proposition 4 states that the behavior of banks in response to an exogenous shock is characterized by a "bang-bang" strategy. Banks either choose a safe strategy in order to get out of trouble and to realize the future rents or choose the riskiest strategy to exploit the government's insurance. These results are consistent with the empirical findings by Gan (2001) in a study of the savings and loans during the Texas real estate crisis in the 1980s. The study shows that the dispersion of asset risks increased after the crisis and that institutions in more concentrated markets were more likely to adopt safe strategies whereas those in less concentrated markets tended to gamble.

These results have important implications on macroeconomic fluctuations. There is a sizable literature on financial fragility that emphasizes how exogenous shocks might affect the interactions between borrowers and lenders by changing borrowers' net worth (Bernanke and Gertler, 1989; Calomiris and Hubbard, 1990) or how a weak bank balance sheet could induce panic and contagion, (Mishkin, 1999 and 1997). The results in this section suggest that the banks' responses to shocks can also generate instability. To the extent that banks' future investment opportunities are correlated, when the majority of banks are conservative, the industry as a whole shifts into safe assets by cutting down lending. Hence there is a "credit crunch." In the case when most banks are prone to risk taking, moral hazard may lead to widespread bank failure, thus amplifying a downturn. This highlights the built-in fragility of the banking system: exogenous shocks affect banks' balance sheet decisions, which can be pro-cyclical and contribute to macroeconomic fluctuations.

4. An Application: the Asian Financial Crisis

There are many theories for what may have caused the Asian financial crisis.[24] My model sheds light on one specific issue: why banks took on excessive risk before the crisis but not earlier. The central features of banks in my model include debt financing, government insurance, current

[24] A partial list includes panic among foreign investors (e.g., Radelet and Sachs, 1998), conspiracy of hedge funds, corrupted corporate governance (Johnson, Boone, Breach, and Friedman, 1999), and bank moral hazard (Krugman, 1998a).

rents and future investment opportunities, and the ability to invest in marketable securities. Thus, my model applies not only to commercial banks, but also to any institution that has the above features.

Financial institutions in the Asian countries, as part of the countries' industrial policies, historically played an important role in industrialization by funding selected infant industries (Amsden, 1989; The World Bank, 1993). Firms benefited from such control at an early stage because it induced them to commit to taking the right kinds of projects and thus lowered the cost of capital. Valuable bank-firm relationships meant significant bank franchise value. High franchise value alone, however, is not sufficient to ensure that banks would pursue prudent investment strategies. With (implicit) government guarantees[25] and weak financial regulations and supervision, my model shows that banks want to go to the global optimum and to take on excess leverage and risks, regardless of bank rents. There existed another important condition that induced banks to stay prudent: due to the limited scope or even the non-existence of capital markets, the institutions did not have many outside opportunities besides industrial loans. That is, in the language of my model, the banks could not expand indefinitely with zero-NPV marketable securities. Limited outside opportunities combined with higher franchise value induced the banks to stay at their interior optima.

Financial liberalization and capital-market development provided banks both competition and access to public markets. As suggested by Petersen and Rajan (1995), credit-market competition makes bank-firm long-term relationships less valuable because competition constrains the banks' abilities to charge low initial rates that are compensated by higher rates later on. Meanwhile, as the infant industries became mature, bank control became excessive either because the banks may inefficiently liquidate too many viable projects (Diamond, 1991), or because the banks, by using their information monopoly to extract surplus, distorted the firm's investment incentives (Rajan, 1992).[26] The net effect is a combination of eroded market power and the ability to take large positions in traded assets. In this situation, weak government supervision induced wide-spread moral hazard problems in the financial system.

[25] Although creditors of the financial institutions did not explicitly receive guarantees from the governments, press reports did suggest that most of those who provided funds believed that they would be protected from risk, given the strong political connection of the owners of these institutions or the historical bank-government relationship.

[26] Evidence supporting these arguments is found in U.S. See, for example, Houston and James (1996).

Another notable phenomenon is that, in all the afflicted countries, there was a boom-bust cycle in the asset markets that preceded the financial crisis: stock and land prices soared and then plunged. This is consistent with the risk-taking behaviors of banks. When banks overinvested in risky assets, to the extent that these assets were in limited supply, the overinvestment led to price inflations in the asset markets. When the asset prices were raised above their natural levels, financial intermediaries acquired a false appearance of solvency and therefore continued operating. However, drops in asset prices could also be self-validating: they made the intermediaries visibly insolvent and force them to liquidate their positions, which caused prices to drop further. Although it is a familiar point that moral hazard distorts investments, that the under-regulated intermediaries can lead to excessive investments and bubbles in the macro-economy has not received much attention. Krugman (1998b) and Allen and Gale (2000) are steps towards this direction. The results of this paper provide a micro-foundation to this line of research. The fact that under regulated institutions have incentives to take extremely large positions in risky assets despite of their franchise value or career concerns enables researchers to focus on the mechanism through which the moral hazard leads to bubbles and macro-level overinvestment and eventually to financial crisis.

5. Conclusion

This paper provides a general model about the interplay of risk shifting and growth opportunities, two well-known factors in corporate financing decisions. Designed to understand the financial decisions of banks, it emphasizes a simple but previously overlooked point: with banks investing in both real loans and marketable securities, the coexistence of a local optimum and a socially inefficient global optimum highlights the role of externally imposed capital requirements in restricting the equilibrium selection. Capital regulation is not just to prevent a few banks from going across the boundary, as we used to think, but rather, it is a necessary device to constrain the majority of banks to stay at their local optima.

The strong results in this paper have implications for macroeconomic theory or asset pricing. Recent work by Krugman (1998b) and Allen and Gale (2000a) suggests that under regulated intermediaries can lead to bubbles in the economy. Both studies assume away bank rents, a factor that might mitigate the risk-shifting incentives. This paper suggests that if unregulated, banks always have incentive to take the largest position in risky marketable securities despite franchise value or the career concerns of bank managers. Therefore, this paper provides a micro foundation for this line of research and allows researchers to focus on the mechanism through which moral hazard leads to macro-level overinvestment and eventually financial crisis.

This paper also speaks to the stability of the banking system. With an exogenous adverse shock wiping out the rents on current assets, banks tend to adopt "bang-bang" strategies and, depending on the value of future investment opportunities, become either extremely conservative or aggressive. This naturally leads to the conclusion that a banking system with low expected future rents is intrinsically vulnerable to exogenous shocks.

The model not only has implications for banks, but also applies to any institutions that are debt financed, have either explicit or implicit government guarantees, and can pursue risk with marketable securities. Moreover, by focusing on an extreme case of risk-shifting incentives, the model improves our understanding of the risk-shifting behavior of non-financial firms, especially when governance mechanisms, such as monitoring by debt-holders, are weak.

A. Appendix

Proof of Lemma 1 By simple calculus and manipulation, we have:

$$\frac{\partial \pi^0}{\partial I} = \frac{-\frac{c}{\sigma}[N'(x) - N'(y)] + (2I - c)[N(x) - N(y)] - \frac{yc}{\sigma}[N(x) - N(y)}{N'(y)} \cdot \frac{\sigma}{c}. \tag{A.1}$$

Note that $N'(x) = (I - c)N'(y)/I$ and let $d = (I - c)/I$, (A.1) can be reduced to:

$$\frac{\partial \pi^0}{\partial I} = \frac{c}{N'(y)} \left[\frac{1-d}{\sigma} N'(y) + [N(x) - N(y)](\frac{1+d}{1-d} - \frac{y}{\sigma}) \right] \cdot \frac{\sigma}{c}. \tag{A.2}$$

Let $A = \frac{1-d}{\sigma} N'(y) + [N(x) - N(y)] \left(\frac{1+d}{1-d} - \frac{y}{\sigma} \right)$. Then,

$$A_d = \frac{N'(y)}{\sigma d} + [N(x) - N(y)] \left[\frac{2}{(1-d)^2} + \frac{1}{\sigma^2 d} \right] > 0. \tag{A.3}$$

Note that $A_{\min} = \lim_{d \to 0} A = \lim_{y \to +\infty} \frac{y}{\sigma}[N(x) - N(y)] = 0$. We have $A > A_{\min} = 0$.

On the other hand, it is easy to verify that,

$$\frac{\partial \pi^1}{\partial \sigma} = (I - c) \frac{x - \frac{\partial (x - \sigma)}{\partial \sigma}}{x^2} > 0. \tag{A.4}$$

A.1. Proof of Lemma 2

$$\frac{\partial (x - \sigma)}{\partial I} = \frac{v_I (I - c) - v}{\sigma v (I - c)}. \tag{A.5}$$

Let $A = v_I (I - c) - v$. Then $A_I = v_{II}(I - c) < 0$. Therefore, $A \leq A_{\max} = A|_{I=c} = -v < 0$. On the other hand,

$$\frac{\partial (x - \sigma)}{\partial \sigma} = -0.5 - \frac{\ln \left(\frac{v}{dI} \right)}{\sigma^2} + \frac{v_\sigma}{\sigma v} = \frac{-0.5\sigma^2 v - v \ln \left(\frac{v}{dI} \right) + \sigma v_\sigma}{\sigma^2 v}. \tag{A.6}$$

It is obvious that if $v_\sigma \leq 0$, $\partial (x - \sigma)/\partial \sigma < 0$. Denote the numerator as B. We only need to show that $B < 0$ as $v_\sigma > 0$. It is easy to verify that,

$$B_\sigma = -\sigma v - 0.5\sigma^2 v_\sigma - v_\sigma \ln \left(\frac{v}{dI} \right) + \sigma v_{\sigma\sigma}. \tag{A.7}$$

Obviously, $B_\sigma < 0$ as $v_{\sigma\sigma} < 0$ and $ln(v/dI) > 0$. It follows that, $B < B_{\max} = B|_{\sigma=0} < 0$.

A.2. Proof of Proposition 2

Differentiating the first-order conditions with respect to π, we have:

$$W_{\sigma\sigma} \frac{\partial \sigma^*}{\partial \pi} + W_{\sigma I} \frac{\partial I^*}{\partial \pi} + W_{\sigma \pi} = 0, \tag{A.8}$$

$$W_{I\sigma} \frac{\partial \sigma^*}{\partial \pi} + W_{II} \frac{\partial I^*}{\partial \pi} + W_{I\pi} = 0. \tag{A.9}$$

Then,

$$\theta\frac{\partial\sigma^*}{\partial\pi} = -W_{\sigma\pi}W_{II} + W_{I\pi}W_{\sigma I}, \tag{A.10}$$

$$\theta\frac{\partial I^*}{\partial\pi} = -W_{I\pi}W_{\sigma\sigma} + W_{\sigma\pi}W_{\sigma I}, \tag{A.11}$$

where $\theta = W_{II}W_{\sigma\sigma} - W_{\sigma I}^2$. For the maximization problem to have solutions, we assume that W is concave in I and σ, i.e., $W_{II} < 0, W_{\sigma\sigma} < 0$, and $\theta > 0$. It is easy to verify that:

$$W_{I\pi} = N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I}, \tag{A.12}$$

$$W_{\sigma\pi} = N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma}, \tag{A.13}$$

$$\begin{aligned} W_{II} &= v_{II}N(x) + \frac{v_I(I-c)-v}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I} + \pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial I^2} \\ &\quad + \pi N'(x-\sigma)(\sigma-x)\left(\frac{\partial x}{\partial I}\right)^2, \end{aligned} \tag{A.14}$$

$$\begin{aligned} W_{\sigma\sigma} &= v_{\sigma\sigma}N(x) + v_\sigma\frac{I-c}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma} + v_\sigma\frac{I-c}{v}N'(x-\sigma) \\ &\quad + (I-c)N'(x-\sigma)(\sigma-x)\frac{\partial(x-\sigma)}{\partial\sigma} + \pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial\sigma^2} \\ &\quad + \pi N'(x-\sigma)(\sigma-x)\left(\frac{\partial(x-\sigma)}{\partial\sigma}\right)^2, \end{aligned} \tag{A.15}$$

$$\begin{aligned} W_{I\sigma} &= \frac{v_I(I-c)-v}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma} + \frac{v_I(I-c)}{v}N'(x-\sigma) + \\ &\quad \pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial I\partial\sigma} + \pi N'(x-\sigma)(\sigma-x)\frac{\partial(x-\sigma)}{\partial I}\frac{\partial(x-\sigma)}{\partial\sigma}. \end{aligned} \tag{A.16}$$

We need to prove that $\partial I^*/\partial\pi < 0$ and $\partial\sigma^*/\partial\pi < 0$.

First, I prove the claim below.

Claim 1. *The following inequality holds:* $\frac{\partial^2(x-\sigma)}{\partial I\partial\sigma} > 0$.

Proof:

$$\frac{\partial^2(x-\sigma)}{\partial I\partial\sigma} = \frac{v[v-(I-c)v_I] - \sigma v_I v_\sigma}{v^2(I-c)\sigma^2} = \frac{A}{v^2(I-c)\sigma^2}. \tag{A.17}$$

It is obvious that $A > 0$ if $v_\sigma \leq 0$. We show that $A > 0$ still hold when $v_\sigma > 0$. Note that $A_I = vv_I - v_I^2(I-c) - v(I-c)v_{II} - \sigma v_{II}v_\sigma$. From Lemma 2 and $v_{II} < 0$, we have $A_I > 0$. $A_{\min} = A|_{I=c} = v^2 - \sigma v_I v_\sigma = f(\sigma)$. Then $f(0) > 0$, and $df/d\sigma = v_\sigma(2v - v_I) - \sigma v_I v_{\sigma\sigma} > 0$ as $B = 2v - v_I > 0$ (because $B_\sigma > 0$ and $B|_{\sigma=0} > 0$). Thus $A > A_{\min} > 0$.

From equations (A.10) and (A.11), $\partial I^*/\partial\pi < 0$ and $\partial\sigma^*/\partial\pi < 0$ hold if $W_{I\sigma} > 0$. Obviously, if $y = x - \sigma < 0$, combining Lemma 2 and Claim 1, we have $W_{I\sigma} > 0$.

Now, I only need to prove that when $y > 0$, $\partial I^*/\partial\pi < 0$ and $\partial\sigma^*/\partial\pi < 0$ still hold. Substituting $W_{I\sigma}, W_{II}$, and $W_{I\pi}$ into (A.10) and simplifying, we have:

$$\begin{aligned}\theta\frac{\partial\sigma^*}{\partial\pi} &= -N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma}\left[v_{II}N(x)+\pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial I^2}\right]\\ &\quad +N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I}\left[\frac{v_{_I}(I-c)}{v}N'(x-\sigma)+\pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial I\partial\sigma}\right]. \quad \text{(A.18)}\end{aligned}$$

By Lemma 2, Claim 1, and $v_{II} < 0$, we have $\frac{\partial\sigma^*}{\partial\pi} < 0$ as long as $\frac{\partial^2(x-\sigma)}{\partial I^2} < 0$. $\frac{\partial^2(x-\sigma)}{\partial I^2} < 0$ is easy to satisfy.

$$\frac{\partial^2(x-\sigma)}{\partial I^2} = \frac{1}{\sigma}\cdot\left[\frac{v_{II}}{v}-\frac{v_I^2}{v^2}+\frac{1}{(I-c)^2}\right]. \quad \text{(A.19)}$$

Let $k = v/(I-c)$. Then $k_{\max}$ is achieved at $I = c$. Note that for a bank to be called a bank, it has to have a certain amount of debt (deposit), i.e., $I \geq \lambda c$, where λ is in the teens. Therefore, for a given technology, $v(I,\sigma)$ and c, $k_{\max}$ is a bounded constant. Therefore, as long as $v_{II}v - v_I^2 + k^2 < 0$ holds, we have $\partial^2(x-\sigma)/\partial I^2 < 0$ and $d\sigma^*/d\pi < 0$.

In the following, I show that $\frac{\partial I^*}{\partial\pi} < 0$ as $y > 0$. Equation (A.11) can be expanded as,

$$\begin{aligned}\theta\frac{\partial I^*}{\partial\pi} =& -N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I}[v_{\sigma\sigma}N(x)+v_\sigma\frac{I-c}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma}\\ &+v_\sigma\frac{I-c}{v}N'(x-\sigma)+(I-c)N'(x-\sigma)(\sigma-x)\frac{\partial(x-\sigma)}{\partial\sigma}\\ &+\pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial\sigma^2}]+N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma}[\frac{v_I(I-c)-v}{v}N'(x)\frac{\partial(x-\sigma)}{\partial\sigma}\\ &+\frac{v_{_I}(I-c)}{v}N'(x-\sigma)+\pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial I\partial\sigma}]. \quad \text{(A.20)}\end{aligned}$$

Recall that the value function can be written as $W(I,\sigma) = u(I,\sigma) + \pi N(x-\sigma)$, where $u(I,\sigma)$ is a call option. As $u_{\sigma I} = u_{I\sigma}$, we have:

$$\begin{aligned}& v_\sigma\frac{I-c}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I}+(I-c)N'(x-\sigma)(\sigma-x)\frac{\partial(x-\sigma)}{\partial I}+N'(x-\sigma)\\ =& \frac{v_I(I-c)-v}{v}N'(x)\frac{\partial(x-\sigma)}{\partial\sigma}+\frac{v_{_I}(I-c)}{v}N'(x-\sigma). \quad \text{(A.21)}\end{aligned}$$

Substitute into (A.20), we have:

$$\begin{aligned}\theta\frac{\partial I^*}{\partial\pi} &= N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma}-v_\sigma\frac{I-c}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I}-\pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial\sigma^2}\\ &\quad\cdot\frac{\partial(x-\sigma)}{\partial I}+\pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial I\partial\sigma}\cdot\frac{\partial(x-\sigma)}{\partial\sigma}-v_{\sigma\sigma}N(x)\frac{\partial(x-\sigma)}{\partial I}. \quad \text{(A.22)}\end{aligned}$$

Note that the last two terms are all negative. I shall show that the sum of the first three terms are negative.

Note that at the optimum, the following holds:

$$\pi N'(x-\sigma) = \frac{N(x-\sigma) - v_I N(x)}{\frac{\partial(x-\sigma)}{\partial I}} = \frac{-v_\sigma N(x) - (I-c)N'(x-\sigma)}{\frac{\partial(x-\sigma)}{\partial \sigma}}. \tag{A.23}$$

By Lemma 2, it can be verified that,

$$v_\sigma \frac{\partial(x-\sigma)}{\partial I} > v_I \frac{\partial(x-\sigma)}{\partial \sigma}.$$

Therefore, (A.22) can be reduced to:

$$\theta\frac{\partial I^*}{\partial \pi} < \frac{v - v_I(I-c)}{v} N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial\sigma} - \pi N'(x-\sigma)\frac{\partial^2(x-\sigma)}{\partial\sigma^2}\cdot\frac{\partial(x-\sigma)}{\partial I}. \tag{A.24}$$

It can also be verified that,

$$\frac{\partial^2(x-\sigma)}{\partial\sigma^2} = -\frac{2}{\sigma}\cdot\frac{\partial(x-\sigma)}{\partial\sigma} + \frac{\sigma v v_{\sigma\sigma} - \sigma v_\sigma^2 - \sigma v^2}{\sigma^2 v^2}. \tag{A.25}$$

Note that the second term is negative. We obtain that,

$$\theta\frac{\partial I^*}{\partial \pi} < \left[\frac{v - v_I(I-c)}{v} N'(x-\sigma) + \pi N'(x-\sigma)\frac{2}{\sigma}\frac{\partial(x-\sigma)}{\partial I}\right]\frac{\partial(x-\sigma)}{\partial\sigma}. \tag{A.26}$$

Denote the terms in the square brackets as A. It is easy to verify that $\lim_{I\to c} A = 0$. At the optimum, A can be written as:

$$\begin{aligned} A &= -(I-c)\frac{\partial(x-\sigma)}{\partial I}N'(x-\sigma) - \frac{2}{\sigma}\left[v_I N(x) - N(x-\sigma)\right] && \text{(A.27)} \\ A_I &= \left[-\frac{\partial(x-\sigma)}{\partial I} - \frac{\partial^2(x-\sigma)}{\partial I^2}(I-c)\right]N'(x-\sigma) \\ &\quad -(I-c)\frac{\partial(x-\sigma)}{\partial I}N'(x-\sigma)(\sigma - x)\frac{\partial(x-\sigma)}{\partial I} \\ &\quad -\frac{2}{\sigma}\left[v_{II}N(x) + \frac{v_I(I-c) - v}{v}N'(x-\sigma)\frac{\partial(x-\sigma)}{\partial I}\right]. && \text{(A.28)} \end{aligned}$$

We know that $\frac{\partial^2(x-\sigma)}{\partial I^2} < 0$ and that the term in the second square bracket is also negative. Therefore, $A_I > 0$, $A > A_{min} = \lim_{I\to c} A = 0$. Hence, $\partial I^*/\partial\pi < 0$.

A.3. Proof of $\partial H^0/\partial I < 0$

$$\partial H^0/\partial I = \frac{-N'(x) + x[1 - N(x)]}{N'(x-\sigma)}. \tag{A.29}$$

Denote the numerator as A. $A_x = 1 - N(x) > 0$. Note that when $I \to +\infty, x \to +\infty$. Then $A < A_{\max} = \lim_{x\to+\infty} A = 0$.

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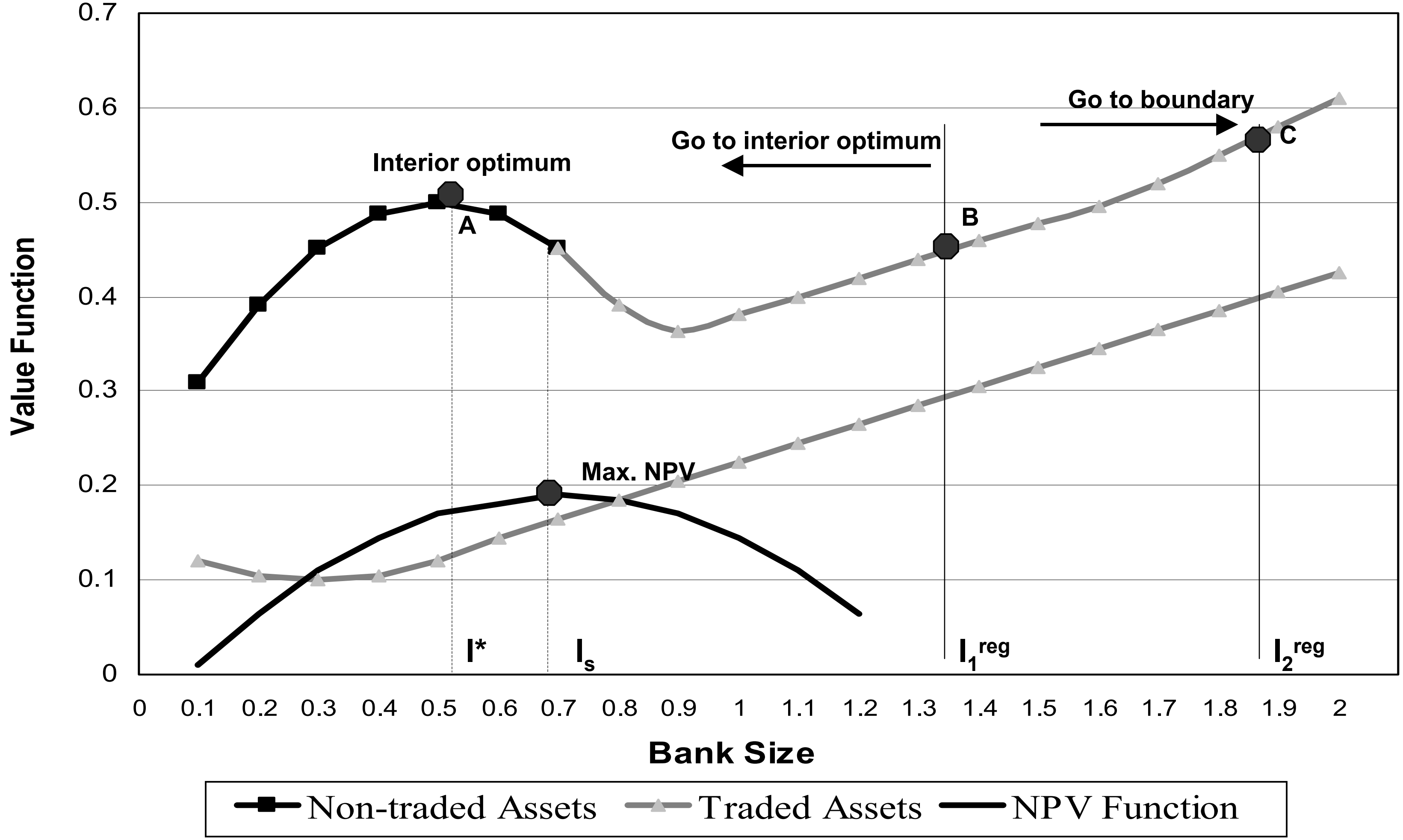

Figure 1. The Role of Capital Regulation. The bank decides its optimal size for fixed capital and a given σ. The gray line with triangle markers is the total value function if the bank invests in traded assets, i.e., NPV = 0 with unlimited quantity. The black line with square markers is the total value function if the bank invests in non-traded assets, i.e., NPV > 0 and with limited quantity. It achieves its maximum at I^*. The dashed line is the net present value function J(.), which reaches the maximum at I_s. The bank switches to traded assets at I_s. A, B, and C are the value achieved at the interior optimum and at the boundary imposed by capital requirement I_1^{reg} and I_2^{reg}, respectively. If the capital requirement is I_1^{reg} , as A is higher than B, the bank's optimal size is the interior optimum I^*. If the capital requirement is I_2^{reg}, as A is lower than C, the optimal size is I_2^{reg}.