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The Impact of Capital-Based Regulation on Bank Risk-Taking[1]

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In this paper we model the dynamic portfolio choice problem facing banks, calibrate the model using empirical data from the banking industry for 1984–1993, and assess quantitatively the impact of recent regulatory developments related to bank capital. The model implies a U-shaped relationship between capital and risk-taking: As a bank's capital increases it first takes less risk, then more risk. A deposit insurance premium surcharge on undercapitalized banks induces them to take more risk. An increased capital requirement, whether flat or risk-based, tends to induce more risk-taking by ex-ante well-capitalized banks that comply with the new standard. *Journal of Economic Literature* Classification Numbers: G20, G28.

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1. INTRODUCTION

In this study we consider the impact of recent developments in bank capital regulation on the risk-taking behavior of banks.

In recent years, in the wake of the savings and loan crisis in the United States, more stringent and complex capital regulation has been brought to bear upon federally-insured depository institutions. In 1988 the federal regulatory agencies adopted new capital rules, including standards for capital in relation to risk-weighted assets. As described in Avery and Berger (1991), a major effect of these rules was to raise the required ratios of capital to total assets and to risk-weighted assets.[2]

Another initiative, the Federal Deposit Insurance Corporation Improvement Act (FDICIA), was legislated in 1991. One important aspect of this initiative was its requirement that the FDIC implement "risk-related" pricing of deposit insurance. Thus, in 1993 fixed insurance premia were replaced by premia tied to capital ratios and supervisory risk-ratings. Thereby, banks with lower capital ratios were made to pay higher premia.

These regulatory reforms were aimed at discouraging bank risk-taking, preventing bank failures, and ensuring continued solvency of the deposit insurance fund. Excessive risk-taking—also called the "moral hazard" problem—arises because the government deposit-guarantee allows banks to make riskier loans without having to pay higher interest rates on deposits. As a result, banks may be prone to take on excessive risk.[3] Indeed, there is mounting evidence that excessive risk-taking has been a problem under the deposit insurance contract; see Berlin *et al.* (1991) and references therein.

The goal of this paper is to analyze and quantify the effects of capital-based regulations. More precisely, the paper addresses the following questions: (1) How does a bank's risk-taking behavior depend on its capital position (i.e., how does the behavior of an undercapitalized bank differ from the behavior of a well-capitalized bank)? And (2) how does a bank's risk-taking behavior depend on regulatory requirements? By addressing these questions we are able to assess the *differential* effect of capital-based regulations. In other words, we are able to account for the fact that banks with different capital positions will react differently to capital-based regulation.

Previous studies examined related questions, showing, in particular, that minimum capital standards may increase risk-taking, contrary to their intent. However,

[2] Bank capital shields the deposit-insurance fund from liability by absorbing bank losses and preventing bank insolvency. For this reason, capital regulation has long been a mainstay of banking supervision. Formal capital guidelines, including minimum required ratios of capital to total assets, were instituted by the federal regulatory agencies in 1981. Prior to that, federal regulators had supervised bank capital on a case-by-case basis. See Wall (1989) for further discussion.

[3] To policymakers and regulators, a potential social cost of bank risk-taking is the possibility that a major bank failure or a series of failures could impose external costs on financial markets. See Bhattacharya and Thakor (1993) and Berger *et al.* (1995) for further discussion.

most of these studies rely on a static, "representative bank" framework where a bank's ex-ante capital position is fixed and given and only the marginal effect of an increase in capital on the bank's portfolio choice is considered. Thus, in these studies, no link is established between a bank's capital position and its portfolio choice. Papers belonging to this category include Kahane (1977), Kareken and Wallace (1978), Koehn and Santomero (1980), Kim and Santomero (1988), Furlong and Keeley (1989), Keeley and Furlong (1990), Crouhy and Galai (1991), and Gennotte and Pyle (1991). The only study which we are aware of and which allows for variations in a bank's capital position is Ritchken *et al.* (1993). However, that study does not analyze the effects of capital-based regulations.

In contrast to this literature, we develop a model which stresses heterogeneity: Different banks have different capital positions. Our model considers a bank which chooses its portfolio composition, i.e., how to allocate investments between risky and safe assets. This choice is allowed to depend on the bank's capital position, and the outcome of the bank's choice is allowed to depend on random factors (e.g., the extent to which loans go into default). Hence, a bank's capital position and its choices vary over time as a result of past choices and the realization of past risky investments.

After formulating the general model, we calibrate it, using parameter values which come from data on the banking sector during the period 1984–1993. Then we solve the model numerically under alternative regulatory paramerizations and compare the results. The solution of the model generates predictions on the investment choices of banks with different capital positions and the sensitivity of these choices with respect to regulatory variables. Hence, we *quantify* the effect of capital-based regulation on a cross section of banks. Our main results are as follows.

First, we find a U-shaped relationship between capital position and risk-taking. Severely undercapitalized banks take maximum risk. Then, as a bank's capital rises, it takes less risk. Then, as capital continues to rise, it will take more risk again. Thus, risk-taking first decreases, then increases.[4] The implication that risk-taking can decrease or increase as banks increase their capital is also found in the previous literature. For example, in Furlong and Keeley (1989) and Keeley (1990), risk-taking declines with an increase in capital, while the opposite possibility is encountered in Koehn and Santomero (1980) and Gennote and Pyle (1991).[5] However, our result that risk-taking first declines and then increases (the overall

[4] Put differently, severely undercapitalized banks as well as well-capitalized banks take more risk than banks with "intermediate" capital position. The reasons for taking more risk, however, are different. The undercapitalized bank takes more risk because—in the event of bankruptcy—it shifts the cost to the FDIC (so its risky investments are "subsidized.") The well-capitalized bank, on the other hand, chooses the risky investment because of its higher profitability (on average) and because the probability of bankruptcy is small.

[5] Stanton (1998) shows that not only may risk-taking decline with an increase in bank capital, but also a binding regulatory capital requirement may cause a bank to "underinvest" in loans with positive net present value.

U-shape) with capital is novel, and helps tie together these two strands of the literature.

Moreover, this result highlights an important distinction between the moral hazard problem, in particular, and bank risk-taking, in general. Maximal risk-taking among severely undercapitalized banks is a reflection of the moral hazard problem, in that it represents an effort to exploit the risk-shifting benefits of deposit insurance. Incremental risk-taking at higher capital levels, however, occurs when the bank is sufficiently remote from insolvency and its portfolio choice ensures very low probability of insolvency; thus, it is distinct from the moral hazard problem.[6]

Second, we find that premium surcharges on undercapitalized banks have the effect of widening the range of capital levels at the lower end at which banks engage in maximal risk-taking. Thus, premium surcharges aggravate the moral hazard problem. The effect of premium surcharges has not been examined in previous studies.

Third, we find that with an increase in the required minimum capital standard, an ex-ante well-capitalized bank will take on additional portfolio risk as it adds capital. Fourth, we show that a risk-based capital rule functions much like a flat rule, in that a bank generally does not choose to reduce risk in order to achieve compliance. When a flat standard is replaced by an effectively more stringent, risk-based standard, an ex-ante well-capitalized bank tends to move in the direction of increasing both capital and risk in order to comply with the new rule.[7] The papers by Thakor (1996) and Li *et al.* (1996) examine issues related to risk-based capital requirements. However, they do not examine the comparative effects of a flat vs a risk-based capital requirement.[8]

Finally, we find that market pricing of uninsured liabilities (so-called “market discipline”) may deter excessive risk-taking by undercapitalized banks. However, curtailment of moral hazard via market discipline requires that risk be priced ex ante in response to changes in portfolio risk composition.

Our analysis has a number of policy implications. The results suggest that a minimum capital standard—whether or flat or risk-based—can, in principle, curtail the risk-shifting benefits of deposit insurance and the associated moral hazard (by requiring a bank to be located sufficiently outside the range of maximal risk-taking.) The analysis also demonstrates that it is difficult to regulate the risk-taking behavior

[6] Gorton and Rosen (1996) argue that excessive risk-taking among well-capitalized banks, to the extent that it occurs, reflects conditions that are exogenous to the bank’s portfolio decisions, such as managerial incompetence or a lack of lending opportunities. In their view, the moral hazard problem applies primarily to undercapitalized banks. The implications of our model are consistent with this view.

[7] This implication of the model is consistent with empirical studies that have examined banks’ response to the introduction of risk-based capital standards. These studies generally have not found evidence of a shift toward reduced risk-taking (Berger and Udell, 1994; Hancock and Wilcox, 1994).

[8] Thakor (1996) shows that a more stringent risk-based standard may reduce banks’ willingness to screen risky borrowers and, as a result, may lead to increased credit rationing. Li *et al.* (1996) demonstrate that a more stringent risk-based standard may lead to increased risk-taking if the standard weighs only credit risk and banks face both credit and interest-rate risk.

of well-capitalized banks by means of a risk-based standard, which is a rather blunt instrument. The results call into question the effectiveness of capital-based deposit insurance premia, but offer a favorable evaluation of "prompt corrective action," the supervisory policy of progressively strict intervention as a bank's capital declines. Finally, the analysis suggests caution in evaluating the potential "market discipline" effects of a subordinated debt requirement.

We proceed as follows. The basic model is developed in Section 2. Section 3 deals with calibration of the model. In Section 4, we numerically solve the model under the assumption of no premium surcharge. In Section 5, we analyze the impact of a higher capital requirement and the effects of premium surcharges. In Section 6, we consider several extensions of the model. In Section 7 we discuss the policy implications of the model and how they relate to recent changes in the regulatory environment facing banks. Section 8 concludes.

2. THE BASIC MODEL

We consider the dynamics of bank portfolio choices in an infinite-horizon model. To simplify the model, and commensurate with the data we have, we allow banks to choose their portfolio composition only (as opposed to choosing their portfolio size). Accordingly, bank size is fixed and normalized at 1.

Banks are subject to a flat (not risk-based) minimum capital requirement—also called a "regulatory standard"—C^*. Assets are funded by capital C and deposits D; $C + D = 1$. At the beginning of each period, the bank chooses a portfolio composition consisting of R units of the risky asset and S units of the safe asset; $R + S = 1$.

The (gross) cost of deposits is given by the function $r(C)$,

$$r(C) = r_0 \text{ if } C \geq C^* \quad \text{and} \quad r(C) = r_0 + \pi \text{ if } C < C^*, \tag{2.1}$$

where $\pi \geq 0$ is a premium surcharge. Hence, when bank capital satisfies the regulatory standard, C^*, the cost of deposits is r_0, which incorporates both interest paid to depositors and the base deposit insurance-premium. If the regulatory standard is not met, $C < C^*$, a premium surcharge $\pi \geq 0$ is assessed.

Equation (2.1) can be interpreted in two ways. One is to view it as representing a bank having only insured deposits. The other is to view the bank as having some uninsured deposits but investors being able to observe only the bank's capital position, C, and not its portfolio allocation, (R, S). For the second interpretation, the additional deposit cost (surcharge), π, incurred by undercapitalized banks should be understood as including a market-assessed risk-premium.[9] A third possible

[9] Studies generally have found that lower capital levels or increased loan losses are associated with higher prices for uninsured liabilities; see, for example, Ellis and Flannery (1992) and Flannery and Sorescu (1996).

case—and one that Eq. (2.1) is not meant to represent—is where the market can observe (and quickly react to) a bank's portfolio choice. In that case the market-assessed risk premium is dependent on the bank's choice of R. We analyze this case in Section 6.

The safe asset earns a certain, end-of-period, return $x > 1$ per unit of investment, while the risky asset earns a random return y. Ex ante, the risky asset promises the return $y_0 > x$ per unit invested, but ex post, a fraction u of the investment in the risky asset yields a return of 0; i.e., this fraction is lost. The remaining fraction, $1-u$, yields the promised return y_0.[10] Thus, the realized return on the risky asset is $y(u) \equiv y_0(1-u)$. The fractional loss u is a random variable taking values between 0 and 1, drawn from a distribution with density function $g(u)$ and cumulative distribution function $G(u)$.

In any period, the bank's owners (stockholders) earn the residual return on the bank's investments after the bank has paid its depositors and its deposit insurance premium and met the minimum capital requirement. Formally, let $z(C, R, u)$ denote the return net of payments to depositors that is implied by a beginning-of-period capital level C, a portfolio choice R, and a loss realization u:

$$z(C, R, u) \equiv x(1-R) + y(u)R - r(C)(1-C). \tag{2.2}$$

If $z(C, R, u) \geq C^*$, stockholders earn $z(C, R, u) - C^*$. If $0 < z(C, R, u) < C^*$, stockholders earn zero, and the entire net return that period goes toward next period's capital.[11] If $z(C, R, u) \leq 0$, the bank ceases to exist and the FDIC pays off depositors after claiming the return on the bank's asset portfolio.

A potential limitation of this model is that the bank can recapitalize only through retained earnings. In reality, a bank might increase its capital-to-asset ratio by issuing new equity. This possibility is addressed in an extension of the model developed in Section 6. Alternatively, an undercapitalized bank might shed assets and shrink. We do not attempt to model this possibility because data for calibrating the costs of making such adjustments are difficult to come by, and because historical experience suggests that many undercapitalized banks do not attempt to recapitalize in this way. On the contrary, an important factor contributing to the savings and loan crisis was the *growth* of such troubled institutions.[12]

The set of fractional losses consistent with continued bank solvency is bounded above by u_A, where u_A satisfies $z(C, R, u) = 0$. Similarly, the set of fractional

[10] The returns x and y_0 are net of loan-production costs or other noninterest expenses associated with financial intermediation.

[11] This assumption is consistent with regulatory requirements mandated by FDICIA, whereby undercapitalized banks are prohibited from paying dividends or paying management fees to a parent holding company.

[12] Peek and Rosengren (1995a) present evidence on the connection between regulatory enforcement actions and shrinkage of bank loan portfolios. Our model can be viewed as an exploration of the effects of capital-based regulation in the absence of direct, supervisory intervention in banks' portfolio decisions.

losses consistent with positive stockholder earnings is bounded above by u_B, where u_B satisfies $z(C, R, u) = C^*$. Thus, using (2.2),

$$u_A = [x(1 - R) + y_0 R - r(C)(1 - C)]/y_0 R, \tag{2.3}$$

$$u_B = u_A - (C^*/y_0 R). \tag{2.4}$$

Note that u_A and u_B are functions of C and R.

The bank's optimal investment in the risky asset will depend only on C, the state variable. The optimal investment function, denoted $R(C)$, is determined along with the value function $V(C)$ as the solution to the dynamic programming problem

$$V(C) = \max_R \left\{ \int_0^{u_B} [z(C, R, u) - C^*] g(u)\, du + \delta V(C^*) \int_0^{u_B} g(u)\, du \right.$$
$$\left. + \delta \int_{u_B}^{u_A} V(z(C, R, u)) g(u)\, du \right\}, \tag{2.5}$$

where δ denotes the rate at which stockholders discount future earnings. The maximand in (2.5) is understood as follows. The first term represents expected current-period earnings, since stockholders earn $z(C, R, u) - C^*$ in the event of a favorable realization, $u \leq u_B$, and earn zero otherwise. The second term represents the continuation value when the bank meets the capital requirement at the end of the current period, weighted by the probability that this will be the case. The third term is the expected continuation value when the bank cannot meet the capital requirement (but is still solvent).

Since $z(C, R, u) - C^* = y_0 R(u_B - u)$, we can rewrite (2.5) in the more amenable form

$$V(C) = \max_R \left\{ u_B y_0 R G(u_B) - y_0 R \int_0^{u_B} u g(u)\, du + \delta V(C^*) G(u_B) \right.$$
$$\left. + \delta \int_{u_B}^{u_A} V(z(C, R, u)) g(u)\, du \right\}. \tag{2.6}$$

Since (2.6) is not analytically solvable, we generate a numerical solution. Toward that, we discretize the problem as follows. Define $n = C^*/0.002$ points along the range $[0, C^*]$:

$$C_1 = 0.002; \quad C_{i+1} = C_i + 0.002, \ i = 1, \ldots, n. \tag{2.7}$$

(The number n will vary, depending on the regulatory requirement, C^*.)

We also define 20 points R_j in [0, 1]:

$$R_1 = 0.05; \quad R_{j+1} = R_j + 0.05,\ j = 1, \ldots, 20. \tag{2.8}$$

To each C_i, R_j, we attribute n points u_k in $[u_B, u_A]$:

$$u_k = u_A - (0.002)k/(1 + y_0)R_j, \quad k = 1, \ldots, n. \tag{2.9}$$

u_k represents the fractional loss that would leave the bank with $(0.002)k$ units of capital at the end of the period, given that the bank began the period with C_i units of capital and a portfolio choice R_j. Note that $C_n = C^*$, $u_0 = u_A$, and $u_n = u_B$.

Let $S(u_B) \equiv \int_0^{u_B} ug(u)\,du$. The numerical solution to (2.6) will then be a set of portfolio positions $R_i^* = R^*(C_i)$ and a set of discounted present values $V_i^* \equiv V^*(C_i)$, $i = 1, \ldots, n$, such that R_i^* solves

$$\max_{R_j} \left\{ u_B y_0 R_j G(u_B) - y_0 R_j S(u_B) + \delta V_n^* G(u_B) \right.$$
$$\left. + \sum_{k=1}^{n-1} \delta[(V_k^* + V_{k+1}^*)/2)][G(u_{k+1}) - G(u_k)] \right\}, \tag{2.10}$$

and such that V_i^* satisfies (to close approximation):

$$V_i^* = u_B y_0 R_i^* G(u_B) - y_0 R_i^* S(u_B) + \delta V_n^* G(u_B)$$
$$+ \sum_{k=1}^{n-1} \delta[(V_k^* + V_{k+1}^*)/2)][G(u_{k+1}) - G(u_k)] \tag{2.11}$$

for each i. u_B, u_k, and u_{k+1} in (2.10) are evaluated at C_i and R_j, while u_B, u_k, and u_{k+1} in (2.11) are evaluated at C_i and R_i^*. Condition (2.10) states that for each i, R_i^* is the portfolio allocation that maximizes $V(C_i)$, the expected value of current and discounted future earnings. The corresponding maximum value of $V(C_i)$ is V_i^* as defined by (2.11).

3. CALIBRATION OF THE MODEL

We computed a numerical solution to (2.10) and (2.11), using a FORTRAN program.[13] To do this we first had to specify a probability distribution $G(u)$ and to assign parameter values. Parameters values to be assigned are the minimum

[13] The programs used to compute the solutions discussed below are available from the authors upon request.

capital requirement, C^*, the deposit interest rate, r_0, the return on the safe asset, x, the ex-ante promised return on the risky asset, y_0, the discount factor, δ, and the parameters of the specified probability distribution, $G(u)$. In this section, we assign values consistent with observed data from the banking industry. Later in the paper, we indicate the effects of varying these values.

3.1. *Parameter Values Other Than G*

We initially set $C^* = 0.06$, which was the regulatory standard prior to the reform. We calibrate r_0, the interest rate plus the base insurance premium per dollar of deposits, as follows. We draw on a panel data set consisting of end-of-year, Call Report data from the years 1984 through 1993. Every U.S. commercial bank having at least $300 million in assets and at least a 6% ratio of equity capital to assets as of year-end 1984 is included in the panel.[14] First, we compute the sample means, by year, of interest expense per dollar of-deposits.[15] To these, we add the mean effective insurance-premium payment (per dollar of deposits, by year.) Then, we compute the mean of these means across years, to obtain the empirical estimate $r_0 = 1.050$. (We employ this two-step procedure in order to avoid placing disproportionate weight on earlier years, since the number of banks in the panel was declining over time.)

The safe asset is represented by 6-month treasury bills. We set the safe asset's return x equal to 1.060, the average interest rate on 6-month treasury bills over the period 1984–1993.

Direct measurement of the return to banks' risky investments, y_0, is impractical. Hence, we selected values for y_0 that are consistent with the returns on publicly issued debt rated B or lower. The typical spreads between the return to these debts and 6-months treasury bills have ranged from 5% to 6%; see, for example, Carey and Luckner 1994. Accordingly, calibrations considered below include $y_0 = 1.1133$ and $y_0 = 1.1175$.

Our calibration of the discount factor is based on historical stock-market returns. During 1971–1990, the annual excess stock-market return over 6-month treasury bills averaged 0.037 (Campbell and Hamao (1992).) We add this to the average 6-month t-bill rate during 1984–1993, 1.060, and then take the reciprocal, to obtain $\delta = 0.91$.

3.2. *Simulation Procedure for Estimating the Loss Distribution, $G(u)$*

Following McAllister and Mingo (1996) and Jones (1995), a Monte Carlo implementation of a multifactor model is used to estimate the probability distribution

[14] Attention is confined to this period because modifications to the Call Reports that were instituted at the start of the period introduced certain inconsistencies with earlier years' data. Extreme values were deleted from this panel data set.

[15] Interest expense per dollar of deposits for year t is total deposit-interest expenses incurred during $[t - l, t)$, i.e., during the year prior to date t, divided by the average total deposits for the reporting dates $t - 1$ and t.

of losses on the risky asset. We do this following a two-step procedure. First we determine the probability distribution of defaults on individual risky projects. Then, conditional on default, we estimate the amount lost. Combining these two steps gives us the loss probability distribution, $G(u)$.

In more detail, we equate the risky asset with a portfolio of 100 loans, each of which is invested in a project that yields a random return. The return on the project associated with loan i, denoted r_i, is assumed to depend linearly on an economic, “market risk,” factor w and an idiosyncratic risk factor ε_i:

$$r_i = bw + \varepsilon_i. \tag{3.1}$$

The economic factor w is assumed to be a normal random variable with mean 0 and variance 1. The idiosyncratic factors ε_i are assumed to be normal random variables that are independent of each other and of w, having mean 0 and variance s^2. The correlation between individual project returns in the portfolio is b^2.

If the realized return on a project is below the cutoff point y_0, the loan goes into default. Therefore, the probability of default is $d = \Pr(r_i < y_0 \mid b^2, s^2)$. Note that once y_0, b^2, and s^2 are specified, the model implies a probability of default d on an individual loan. Alternatively, if d and b^2 are specified, then s^2 is determined by the model.

The fractional loss on a loan, conditional on default, is denoted L and is allowed to depend on general economic conditions. Specifically, we posit a piecewise linear relationship between L and w:

$$\begin{aligned} &L = L_0 \text{ if } w \geq 0, \quad L = L_0 + L_1(w - w_1) \text{ if } w_1 < w < 0, \\ &L = L_0 + L_1 + L_2(w - w_2) \text{ if } w_2 < w < w_1, \quad \text{and} \quad L = L_0 + L_1 + L_2 \\ &\qquad \text{if } w < w_2. \end{aligned} \tag{3.2}$$

Given this specification, we numerically calculate the (unconditional) probability distribution of total losses on a hypothetical loan portfolio, after assigning reasonable values to y_0 and the parameters b and d in (3.1) and L_0, L_1, L_2, w_1, and w_2 in (3.2). The calculations involve, first, randomly drawing realizations for the market and idiosyncratic risk factors to determine which loans default. The default rate is then multiplied by the rate of loss in the event of default to yield a loss rate on the portfolio. To calibrate the loss probability distribution in this way, 10,000 simulated portfolio loss rates are constructed.[16]

3.3. *Assignment of Numerical Values to Parameters Underlying G*

We mostly hold the correlation parameter constant at $b^2 = 0.25$, a value suggested as reasonable by Jones (1995) and McAllister and Mingo (1996) (as reported

[16] We adopted the particular approach employed by Jones (1995). We thank David Jones for supplying us with a copy of his simulation program.

below we have also experimented with other values, without appreciable effect on the results). With respect to the parameter d, the individual default probability for the loans comprising our model's risky asset, we assume that this is at least as great as the probability of default associated with B-rated bonds. According to Moody's (1994), default rates within one year of issue on B-rated bonds historically have averaged around 8%. We experimented thus with d's ranging from $d = 0.08$ to $d = 0.09$.

We set $L_0 = 0.30$, $L_1 = 0.40$, $L_2 = 0.10$, $w_1 = -1.50$, and $w_2 = -2.00$; i.e., the loss given default is 30% when the economy is strong, it increases up to a maximum of 80% when the economy weakens, and it has an expected value of 41%.[17]

This expected loss-given-default is corroborated by other, independent, data. For instance, a report by the Society of Actuaries (1993) finds an average of 44% loss severity (loss per unit of credit exposure) on defaulted private placement bonds for issuers rated BB or lower. Furthermore, drawing on the panel data-set introduced previously, we find that the dollar amount of commercial loans, past due 90 days or more or nonaccruing, as a proportion of total dollars loaned, averaged 0.009, while net losses per dollar loaned averaged 0.023.[18] The latter number divided by the former, which may be viewed as indicative of the typical loss per dollar of defaulted loans, is 0.38.

3.4. *Piecewise Linear Approximation to G(u)*

Loss distributions generated using the simulation procedure just described exhibit a characteristic shape. They exhibit a mass point at zero, corresponding to well-performing loans. Then the distributions exhibit a moderate rise through the median and a very sharp rise through the upper percentiles; losses exceeding 20% are confined to the extreme upper tail of the distribution.

Given this, we approximated G by means of a piecewise linear distribution. In other words, we utilized distributions of the form

$$\begin{aligned} G(u) &= [u/u^1]G(u^1) \quad \text{if } 0 \le u \le u^1, \\ G(u) &= G(u^i) + [(u - u^i)/(u^{i+1} - u^i)][G(u^{i+1}) - G(u^i)] \\ &\qquad \text{if } u^i \le u \le u^{i+1},\ i = 1, \dots, 7, \end{aligned} \tag{3.3}$$

where $u^1, \dots, u^8$ denote the 1st, 5th, 25th, 50th, 75th, 95th, 99th, and 100th percentiles, respectively. We chose these percentiles in accordance with the shape

[17] The dependence of loss-given-default on w has a modest effect on the shape of the loss distribution, similar to the effect of a small increase in the correlation parameter b^2. The results are robust to alternative specifications of loss-given-default.

[18] The proportion of loans in default is calculated annually as the end-of-year ratio of loans 90 days or more past due or nonaccruing to total loans. A bank's net loss rate is calculated annually as the ratio of net charge-offs (charge-offs minus recoveries) during the year divided by the average of beginning and end-of-year total loans. To obtain the average proportion of loans in default and the average net loss rate for the panel, we compute the mean across banks for each year and then compute the mean of these means across years.

TABLE I
Calibrations of the Loss-Distribution

Percentile	$G(u_i)$	(i) $d = 0.080$ $b^2 = 0.25$	(ii) $d = 0.080$ $b^2 = 0.28$	(iii) $d = 0.0875$ $b^2 = 0.25$
u_1	.01	0.0001	0.0001	0.0001
u_2	.05	0.0002	0.0002	0.0002
u_3	.25	0.007	0.007	0.007
u_4	.50	0.020	0.019	0.022
u_5	.75	0.056	0.056	0.062
u_6	.95	0.15	0.16	0.17
u_7	.99	0.21	0.23	0.23
u_8	1.00	0.83	0.62	0.70
$E(u)$		0.047	0.047	0.051

of the distributions as described above. We assigned values to u^6 and u^7 that were somewhat larger than the corresponding percentiles of the simulated distributions, to adjust for the strong concavity of the tails of the simulated loss distributions. We let u^8 be determined by the condition $G(u^8) = 1$.[19]

Values of u^1 through u^8 for three distributions utilized below are shown in Table I, along with the mean values $E[u]$. Loss distribution (i) in Table I is the piecewise linear approximation to the simulated distribution based on an 8% individual default probability ($d = 0.08$) and a 25% correlation between loan rates of return ($b^2 = 0.25$), and (ii) is based on $d = 0.08$ with a marginally higher correlation $b^2 = 0.28$. For both simulations we set $y_0 = 1.1133$. Distribution (iii) is based on a higher individual default probability $d = 0.0875$, with $b^2 = 0.25$ and $y_0 = 1.1175$. It is worth noting that we experimented with alternative values of y_0 for these simulations and found that on the margin, the value of y_0 has almost no effect on the simulated distribution.

To check for consistency, we computed the expected return on the risky asset for the simulated distributions G from Table I, given the values of y_0 specified above. The calculated expected returns $E[y(u)]$ ranged within a few basis points of 1.061. As one would expect, the implied expected returns exceed the risk-free return (1.06) by a small amount, reflecting specialized knowledge of banking firms.

4. SOLUTIONS TO THE MODEL ASSUMING A FIXED INSURANCE PREMIUM

4.1. *U-Shape of the Solution*

In this section, we focus on solutions obtained with $\pi = 0$, i.e., where no premium surcharge is assessed when bank capital falls below the regulatory standard

[19] For instance, we set u^6 equal to the mean value of u between the 90th and 99th percentiles of the simulated distribution.

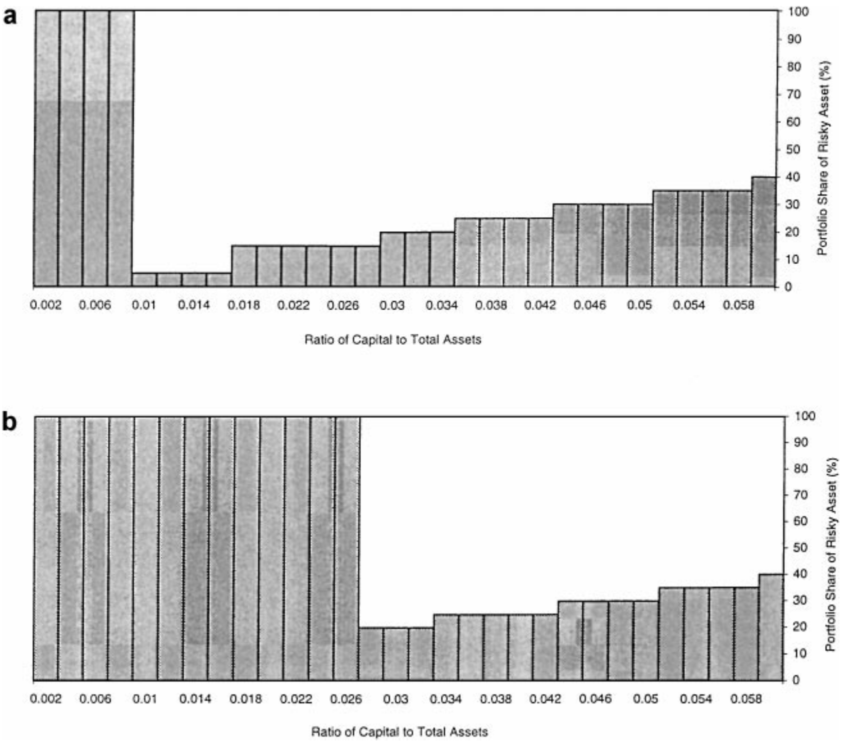

FIG. 1. Characteristic shape of the solution: (a) with no premium surcharge on undercapitalized banks; (b) with a 5-basis-point (0.0005) premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.06$; unit cost of deposits $r_0 = 1.05$ interest rate on safe assets $x = 1.06$; promised return on risky asset $y_0 = 1.1133$; risky asset individual default probability $d = 0.08$; correlation parameter $b^2 = 0.25$; expected loss on risky asset $E[\mu] = 0.047$; expected return on risky asset $E[y(\mu)] = 1.061$.

C^*. We also hold C^* constant at 0.06, which was the regulatory standard prior to the introduction of risk-based standards.

In Fig. 1a, we depict the solution obtained when the risky asset is calibrated with $y_0 = 1.1133$ and with the loan-loss distribution (i) of Table I. This solution exhibits a characteristic, U-shaped relationship between the amount of risk a bank takes and the bank's current capital position. A severely undercapitalized bank takes maximal risk. Then, as capital rises beyond a certain level, the solution jumps to a much lower level of risk-taking. Subsequently, as capital rises further the bank takes on more risk. Therefore, risk-taking first decreases and then increases.

The U-shaped pattern can be given an intuitive interpretation as follows. To begin with, the cost of investing in the risky asset is the loss of future profits in the event of insolvency. This is counterbalanced by the benefit of shifting the current period's payment obligations (paying depositors and the insurance premium) to the FDIC, and by the more attractive return on the risky asset ($E[y(u)] > x$). At low capital levels, this trade-off yields a corner solution (maximal risk-taking), since undercapitalized banks have little to lose in the event of insolvency, and since risk-taking may be their best way to recapitalize. Earlier papers also have demonstrated that the risk-shifting benefits of deposit insurance lead to extreme risk-taking when banks hold little capital (Furlong and Keeley (1989), Keeley and Furlong (1990).)

At higher capital levels, an additional factor affecting the marginal return to risk-taking comes into play—the possibility that the bank will experience a loss of capital without becoming insolvent. In this event, the bank does not get the cost-shifting benefit (at least not in the present period) while delaying its recapitalization. This outcome reduces the bank's incentive to invest in the risky asset. The bank then switches from maximal risk-taking to much more limited risk-taking.[20] This yields an interior solution (intermediate level of risk-taking), as in the model of DeGennaro *et al.* (1995).

Then, at still higher capital levels, incremental investment in the risky asset is associated with smaller incremental risk of becoming insolvent—the bank has a bigger "cushion." In addition, the expected return to the risky asset is higher than the return to the safe asset. Therefore, the incentive to invest in the risky asset rises again. This generates a positive relationship between capital and risk at high levels of capital.

The U-shaped relationship between capital and risk-taking is a novel implication of our model. This result helps reconcile conflicting views found in the literature on capital regulation. One strand of the literature argues that minimum capital requirements mitigate the risk-taking incentives arising from deposit insurance; see Furlong and Keeley (1989), Keeley (1990), and Campbell *et al.* (1992). Others argue that minimum capital requirements may lead to increased portfolio risk because of ways in which a binding capital constraint may affect a bank's lending or investment opportunities or its marginal return to risk-taking; see Koehn and Santomero (1981), Kim and Santomero (1988), Gennotte and Pyle (1991), Besanko and Kanatas (1996). Our model demonstrates that these two—apparently opposing—views are consistent. Once a bank's portfolio choice is allowed to depend on its ex-ante capital position, the bank may either decrease or increase its portfolio risk as it moves toward compliance with a minimum capital requirement. The reason the above studies generate opposing results is that they are based on static, "representative bank" models. No link is established between a bank's capital position and its portfolio choice, and only the marginal effect of an increase in capital on the bank's portfolio choice is considered. Consequently, such studies are unable ("by construction") to deliver increased *and* decreased risk-taking within the same framework.

[20] Insolvency risk is the only aspect of risk that is relevant at lower capital levels because the risky asset is characterized by a loss distribution that is highly skewed and has a long tail (it is *leptokurtic*). Thus, losses only rarely occur but tend to be large when they do occur.

It is worth emphasizing that in our model, incremental risk-taking at higher capital levels does *not* represent an effort to exploit the risk-shifting benefits of deposit insurance; to the contrary, it occurs when the bank is sufficiently remote from insolvency and its portfolio choice ensures very low probability of insolvency. Thus, incremental risk-taking among such banks is distinct from the moral hazard problem facing undercapitalized banks.

4.2. Results under Alternative Calibrations

To verify the robustness of this finding, we experimented with various other parameterizations. Across alternative calibrations, the U-shaped pattern is generally preserved. We typically observe marginal or no changes in risk-taking by a well-capitalized bank, but we often observe substantial changes in the range of maximal risk-taking among undercapitalized banks. We summarize the results as follows.

(a) Different banks may face different risk-taking opportunities, where some banks may have the opportunity to obtain a relatively high promised return on a class of loans in exchange for a relatively high risk of default. To assess how banks risk-taking behavior may vary with such differing opportunities, we examined the effect of increasing the individual default probability d and the promised return y_0 associated with the risky asset, holding its expected return, $E[y(u)]$, and b^2 (correlation with the market risk factor) constant.

An increase in d and y_0 generally results in a wider range of maximal risk-taking among undercapitalized banks and may yield a marginal reduction in risk-taking by a well-capitalized bank. This is illustrated by the solution depicted in Fig. 2a, where we calibrated the risky asset with $y_0 = 1.1175$ and the loan-loss distribution (iii) of Table I.

In comparison to Fig. 1a, the range of maximal risk-taking is substantially wider and risk-taking by well-capitalized banks declines marginally (from 40% to 35% of the portfolio). The characteristic U-shaped pattern is still seen.

These effects are a consequence of the increased risk of large losses associated with the loss distribution of column (iii) of Table I in comparison to the loss distribution of column (i). On the one hand, because the largest potential losses occur with increased probability, risk-taking by well-capitalized banks is discouraged. On the other hand, because the risk of insolvency is greater, the cost-shifting benefit from investing in the risky asset increases. Also, the present value of future profits is reduced, although (by assumption) the single-period expected return on the risky asset has been held constant. These two effects promote riskier portfolio choices on the part of undercapitalized banks.

(b) Holding other parameters constant, an increase in the promised return y_0 on the risky asset entails an expansion of the range of maximal risk-taking. This is due, naturally, to the greater attractiveness of the risky asset. For example, holding $d = 0.08$ and $b^2 = 0.25$ constant, when we increase y_0 from $y_0 = 1.1133$ to $y_0 = 1.1150$, the range of maximal risk-taking expands from 0.008 (Fig. 1a) to 0.026 at the upper end.

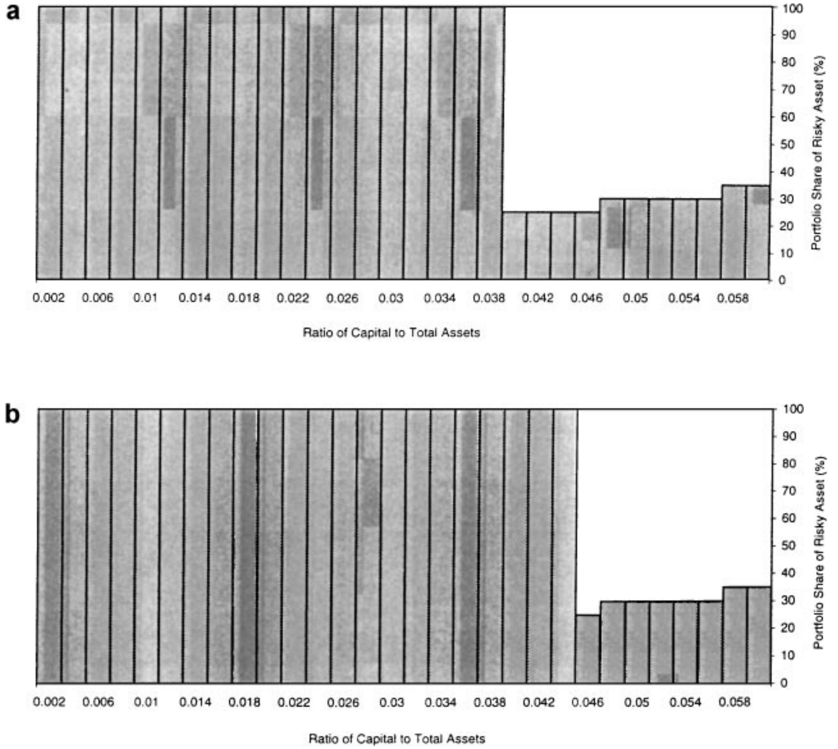

FIG. 2. Solution under alternative calibration of risk parameters (increased individual default probability and higher promised return): (a) with no premium surcharge on undercapitalized banks; (b) with a 5-basis-point (0.0005) premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.06$; unit cost of deposits $r_0 = 1.05$ interest rate on safe asset $x = 1.06$; promised return on risky asset $y_0 = 1.1175$; risky asset individual default probability $d = 0.0875$; correlation parameter $b^2 = 0.25$; expected loss on risky asset $E[\mu] = 0.051$; expected return on risky asset $E[y(\mu)] = 1.061$.

(c) The range of maximal risk-taking tends to be quite responsive to r_0, or equivalently, to the spread between the cost of deposits r_0 and the return x on the safe asset: A larger rate spread implies a smaller range of maximal risk-taking. For example, the solution depicted in Fig. 2a is replaced by that depicted in Fig. 3 when we reduce r_0 by 5 basis points, to 1.0495.[21] In particular, the range of maximal risk-taking contracts from 0.038 to 0.018 at the upper end. When r_0 is further reduced to 1.0490, the range of maximal risk-taking disappears entirely (and is replaced by minimal risk-taking). The logic behind this is that as the spread between r_0 and x increases, banks become more profitable and, accordingly, will try to remain in business by taking less risk.

[21] Likewise, when we increase r_0 by 5 basis points, the range of maximal risk-taking expands up to capital level 0.048.

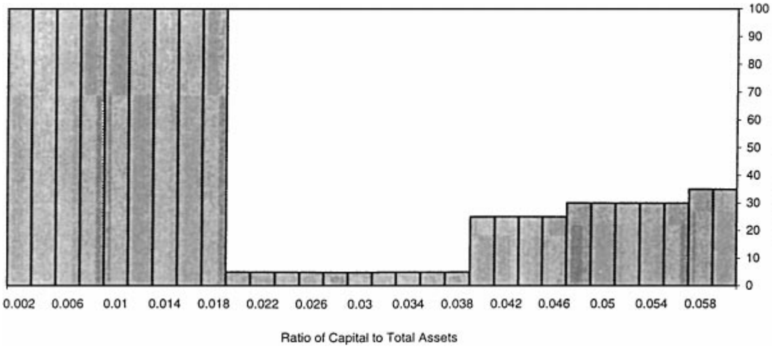

FIG. 3. Solution under alternative calibration of the unit cost of deposits with no premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.06$; unit cost of deposits $r_0 = 1.0495$; interest rate on safe asset $x = 1.06$; promised return on risky asset $y_0 = 1.1175$; risky asset individual default probability $d = 0.0875$; correlation parameter $b^2 = 0.25$; expected loss on risky asset $E[\mu] = 0.051$; expected return on risky asset $E[y(\mu)] = 1.061$.

(d) An increase in b^2 yields a wider range of maximal risk-taking among undercapitalized banks and is associated with marginally reduced risk-taking by well-capitalized banks. This is illustrated by the solution depicted in Fig. 4, where we calibrated the risky asset with $y_0 = 1.1133$ and the loan-loss distribution (ii) of Table I. In comparison to Fig. 1a, the range of maximal risk-taking is substantially broader and risk-taking by a well-capitalized bank is marginally reduced (from 40% to 35% of the portfolio).

These effects of changing the correlation parameter can be explained as follows. With an increase in b^2, large losses occur with increased probability. This tends to discourage risk-taking by well-capitalized banks, but it increases the cost-shifting subsidy and promotes risk-taking by undercapitalized banks.

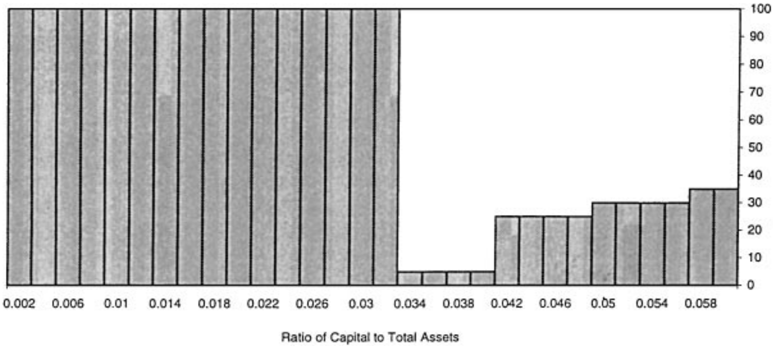

FIG. 4. Solution under alternative calibration of the risk parameters (increased market risk) with no premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.06$; unit cost of deposits $r_0 = 1.05$; interest rate on safe asset $x = 1.06$; promised return on risky asset $y_0 = 1.1133$; risky asset individual default probability $d = 0.08$; correlation parameter $b^2 = 0.28$ expected loss on risky asset $E[\mu] = 0.047$; expected return on risky asset $E[y(\mu)] = 1.061$.

5. SOLUTIONS TO THE MODEL UNDER VARYING REGULATORY PARAMETERS

We now present solutions for alternative values of the regulatory parameters, reflecting the effects of regulatory reforms.

5.1. Varying the Insurance Premium

We begin the analysis with the impact of capital-based deposit insurance premia. As noted, in 1993 the FDIC implemented "risk-related" pricing of deposit insurance, whereby banks with lower capital ratios and those assessed by examiners to be more risky pay higher premia.[22] When first introduced, the premium differential between the lowest and highest risk-categories was 8 basis points, with an average differential of about 5 basis points.[23]

The solution depicted in Fig. 1b assumes a premium differential of 5 basis points ($\pi = 0.0005$), where the calibration is otherwise identical to that in Fig. 1a. A comparison of Figs. 1a and 1b indicates that the primary effect of an insurance premium differential is to *aggravate* the moral hazard problem among severely undercapitalized banks: Banks at capital levels 0.010 through 0.026 switch from very limited risk-taking ($R^* \leq 0.15$) to holding only risky assets ($R^* = 1.0$). The premium differential π has no impact, however, on the behavior of a well-capitalized bank (capital level 0.06). In other words, contrary to what one might expect, an insurance premium differential exhibits no deterrent effect on risk-taking among well-capitalized banks.

Moreover, the premium differential has a substantial impact on failure probabilities among undercapitalized banks, which are computed from (2.3) given the solution to the model. For instance, in the case depicted in Figs. 1a and 1b, when banks at capital level 0.010 switch to maximal risk-taking as a result of the premium surcharge, their probability of failing after one period increases from 0.0067 to 0.2291. For banks at capital level 0.026, the probability of failing after one period increases from 0.0090 to 0.1969.

An insurance premium surcharge on undercapitalized banks is associated with an expanded range of maximal risk-taking because it boosts their risk-taking incentive: it increases the bank's payment due per dollar of deposits (and, therefore, increases the cost-shifting "subsidy"). Further, the premium surcharge reduces the expected present value of future profits, thus lowering the opportunity cost of risk-taking.

Although capital-based premia were intended to be a deterrent to risk-taking, in our model they fail to do so for well-capitalized banks. This result can be understood

[22] The FDIC bases insurance premia on bank capital-ratios and on supervisory risk-ratings that reflect examiner evaluations of bank earnings, asset quality, liquidity, and management. Essentially, our analysis assumes that premium assessments are based primarily on ex-post indicators, whereby banks undertaking increased risk are assessed higher premia only in the event that their risk-taking results in losses.

[23] There is now a wider differential as a result of reductions in insurance premia for institutions in the lowest risk-category.

TABLE II
Risk-Taking and Probability of Failure for Well-Capitalized Banks

Required capital level C*	Portfolio risk $R^*(C^*)$	Probability of end-of-period failure
0.060	0.40	0.0100
0.064	0.40	0.0098
0.068	0.45	0.0100
0.072	0.45	0.0099
0.076	0.50	0.0105
0.080	0.50	0.0099

Note. Calibration: $r_0 = 1.050$, $x = 1.1133$, $d = 0.080$, $b^2 = 0.25$, $E[u] = 0.047$, $E[y(u)] = 1.061$.

as follows. The insurance-premium surcharge reduces the net present value of an undercapitalized bank relative to that of a well-capitalized bank and this, *in principle*, should deter a well-capitalized bank from risk-taking. However, the premium surcharge also causes a reduction in the net present value of a well-capitalized bank, and this encourages risk-taking. Given the values of the parameters in our data set neither effect dominates, implying no change in the behavior of well-capitalized banks.

5.2. *The Impact of a Higher Capital Requirement*

Now consider the effect of increases in the regulatory standard on a bank's risk-taking and its probability of failing after one period. First, consider the effects on well-capitalized banks (banks that maintain compliance with the capital standard as it changes.) Table II depicts the results obtained when parameters other than the capital standard are calibrated as in Fig. 1a. A small increase in the capital standard above 0.06 (up to 0.064) does not lead to increased risk-taking among well-capitalized banks, and thus their probability of failure is reduced. Further increases in the capital requirement, however, lead to increased risk-taking, which mostly offsets the favorable effect of higher capital on the probability of failure.[24] For instance, a bank complying with an increase in the regulatory capital requirement from $C^* = 0.06$ to $C^* = 0.068$ increases its investment in the risky asset from 0.40 to 0.45, which leaves its probability of failure unchanged at 0.010. Therefore, more-than-marginal changes in the capital requirement affect the behavior of well-capitalized banks (in the direction of more risk-taking), but have little effect on the probability of failing after one period.

Similarly, reductions in the capital standard below 0.06 would be accompanied by reduced risk-taking with little change in the probability of failing after one period (not shown in the table). With a reduction in the capital standard, however, a well-capitalized bank becomes less distant from the range of maximal risk-taking,

[24] Deleted in proof.

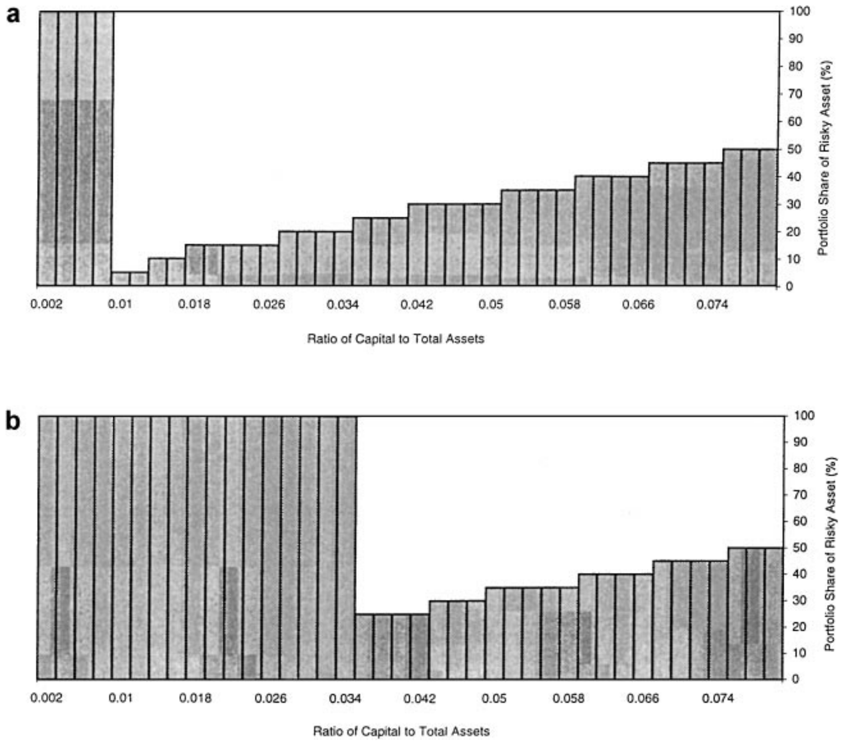

FIG. 5. Effect of a higher capital requirement: (a) with no premium surcharge on undercapitalized bank; (b) with a 5 basis point (0.0005) premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.06$; unit cost of deposits $r_0 = 1.05$; interest rate on safe asset $x = 1.06$; promised return on risky asset $y_0 = 1.1133$; risky asset individual default probability $d = 0.08$; correlation parameter $b^2 = 0.25$; expected loss on risky asset $E[\mu] = 0.047$; expected return on risky asset $E[y(\mu)] = 1.061$.

and as this occurs, the bank's overall probability of failure (over a multiple-period horizon) will begin to increase substantially.

We can conclude from this analysis that a minimum capital standard has a favorable effect on risk of failure to the extent that banks are required to be well-removed from the range of maximal risk-taking. However, once a bank has sufficient capital to be well above the range where maximal risk-taking occurs, a significant reduction in the bank's probability of insolvency cannot be achieved by requiring the bank to add yet more capital.[25]

The effect of an increase in the capital standard on the entire solution is illustrated in Fig. 5a. This solution replaces that depicted in Fig. 1a when the capital standard is raised to $C^* = 0.08$ (with other parameters held constant.) Note that the increase in

[25] This analysis presumes that the incentive contracts of bank managers do not reward them for safety; i.e., they are not positively linked to operating performance variables that are enhanced by low risk-taking.

risk-taking that occurs when a bank moves from the ex-ante well-capitalized level ($C^* = 0.06$ in Fig. 1a) to the ex-post well-capitalized level ($C^* = 0.08$ in Fig. 5a) is consistent with the overall U-shape pattern of the solutions, whereby risk-taking increases with capitalization. Further, introduction of a premium surcharge has the same effect under an 8% standard as under a 6% standard—it expands the range of maximal risk-taking, as shown in Fig. 5b.

5.3. *Results under Alternative Calibrations*

Experimentation with alternative calibrations indicates that these qualitative effects of a premium differential or a higher capital standard are robust. The impact of a premium differential on the size of the range of maximal risk-taking is comparatively small, however, when the range of maximal risk-taking is relatively wide ex-ante. This is illustrated by Fig. 2b in comparison to 2a. The solution depicted in Fig. 2b assumes a premium differential of 5 basis points ($\pi = 0.0005$), where the calibration is otherwise identical to that in Fig. 2a (which assumes $\pi = 0$.) The range of maximal risk-taking widens as a result of the premium differential, but by a relatively small amount (from 0.038 to 0.044 at the upper end.)

6. EXTENSIONS OF THE BASIC MODEL

6.1. *Endogenizing the Bank's Capital Target*

Thus far, we have assumed that the bank will hold no more capital than is required by regulation. We now relax this assumption. Suppose that each period, the bank chooses a target level of capital K for the subsequent period, subject to the regulatory standard C^*. If the bank desires to begin the next period with a capital "cushion" above the regulatory standard, it will choose $K > C^*$. In that case, K serves as a self-imposed capital requirement, replacing C^*. Thus, when $z(C, R, u) \geq \max[K, C^*]$, stockholders earn $z(C, R, u) - \max[K, C^*]$. When $0 < z(C, R, u) < \max[K, C^*]$, stockholders earn zero, and the entire net return that period goes toward next period's capital.

To represent this scenario, we replace C^* with K in (2.4) and on the right-hand side of (2.5). The bank now makes two choices, optimal investment in the risky asset, R^*, and optimal capital target, K^*, both of which depend on the state variable C. They are determined along with the value function $V(C)$ as the solution to the dynamic programming problem

$$V(C) = \max_{R,K} \left\{ \int_0^{u_B} [z(C, R, u) - K] g(u)\, du + \delta V(K) \int_0^{u_B} g(u)\, du \right.$$
$$\left. + \delta \int_{u_B}^{u_B} V(z(C, R, u)) g(u)\, du \right\} \tag{6.1}$$

subject to the constraint

$$K \geq C^*, \tag{6.2}$$

where u_B is now defined by

$$u_B = u_A - K/y_0 R. \tag{6.3}$$

Implicitly, our analysis thus far has assumed that the regulatory capital requirement is binding. We can evaluate the validity of this assumption by solving the above model with $C^* = 0$. If we find that for some calibrations the solution with $C^* = 0$ yields capital targets exceeding 0.06, then this would suggest that the regulatory minimum requirement assumed earlier is not binding under those calibrations. For each of the calibrations used earlier, however, we find that the bank would choose to hold very little capital. For example, with $C^* = 0$ and otherwise using the calibration from Fig. 2a, we find that the bank will maintain a capital target $K^*(C) = 0.004$ for any C. This confirms our implicit assumption that the regulatory requirement is binding.

Despite the fact that in our model the regulatory requirement is binding, a bank may desire to maintain more than the required amount of capital. This follows from the fact that the bank's objective function may be nonconcave (the marginal cost of holding capital above the required level may decline as the capital requirement is raised.) To evaluate banks' incentive to hold more capital, and whether our previous results depend on the presumed absence of such an incentive, we (re-) solved the above model for each of the calibrations used earlier. Essentially the same results are obtained. We find that the optimal capital target $K^*(C)$ generally coincides with C^*, and when it does not, it only exceeds C^* by a small amount.[26] For example, solving the model with the calibration from Fig. 1a shows that the bank will maintain a capital target $K^*(C) = 0.062$, implying a small cushion over the capital standard $C^* = 0.060$. At capital level 0.062, the bank invests 0.40 in the risky asset, identical to its investment without the possibility of capital cushion. Hence, our net conclusion is that the results remain relatively unchanged when the banks' capital target is endogenous.

6.2. *Risk-Based Capital Requirements*

In 1988, federal regulatory agencies adopted "risk-based" capital standards that, for many banks, were more stringent than the prior standards (Avery and Berger 1991). Under the prior standards, *primary capital* had to be at least 6% of total

[26] It should be noted that our model abstracts from various considerations that may propel banks to hold more than the regulatory minimum required capital. For instance, in our model there are no regulatory penalties for violating the standard other than the prohibition on dividends payments, whereas in reality, banks may be subject to further costly supervisory actions. We also abstract from the possibility that a bank's subordinated debt holders may require additional capital as protection against losses.

balance-sheet assets or the bank would face supervisory action.[27] Under the risk-based standards, differing weights are assigned to various categories of bank assets (e.g., home mortgage loans, treasury bills, commercial loans) prior to summing the assets, to reflect differences in credit risk. The regulations adopted in 1988 required that *total capital* be at least 8% of *risk-weighted* assets (where loan-loss reserves were no longer to be fully included as a component of measured capital).[28] In addition, these regulations set standards for *tier-one capital* (a more restrictive definition of capital) in relation to risk-weighted assets and for *tier-one capital* in relation to total assets.[29, 30]

The above extension of the basic model provides a ready framework for examining the effects of a risk-based capital standard: a risk-based standard may be represented by a constraint on permissible combinations of K and R in place of (6.2). We shall assume that this constraint takes the form

$$K \geq \mathrm{Max}[C^* + c(R - R_0)(0.002/0.05), C^*], \tag{6.4}$$

where C^*, R_0, and c are parameters determining the stringency of the requirement. (We multiply by 0.002/0.05 because 0.002 is one unit of capital and 0.05 is one unit of the risky asset in the discretized version of the model.)

R_0 is the threshold level of risk-taking beyond which required capital increases with the proportion invested in the risky asset, and c is the rate at which required capital increases with the proportion invested in the risky asset once this threshold is exceeded. At levels of risk-taking at or below R_0, the capital requirement is fixed at C^*. The capital requirement becomes more stringent with an increase in C^* or c, or with a smaller R_0.

We examine the effect of a risk-based standard by solving the dynamic programming problem (6.1) subject to the constraint (6.4). The solution generally yields a unique capital level C^0 such that $K^*(C^0) = C^0$; i.e., at C^0, the bank converges to its capital target (and, *a fortiori*, meets the regulatory standard). The bank seeks to maintain this level of capitalization over the long run—it is analogous to the well-capitalized level in the original model. We shall refer to C^0 as the bank's "long-run capital target."

[27] *Primary capital* was defined to include equity, loan loss reserves, preferred stock, and various kinds of debentures; see Wall (1989) for details.

[28] The 8% risk-based standard adopted in 1988 was a *minimum* capital standard for banks. The regulations provided and continue to provide substantial leeway for regulators to set more stringent standards for all but the strongest institutions (Peek and Rosengren 1995a, 1995b).

[29] In addition, the 1988 regulation required banks to hold some capital against off-balance-sheet activities. Banks were directed to comply with the new standards by 1992. See Wall (1989) for details.

[30] The FDICIA also introduced a distinction between *well capitalized* and *adequately capitalized* (along with three distinct categories of undercapitalized), whereby the latter are subject to closer regulatory scrutiny. Thus, for instance, under current regulations, *total capital* has to be at least 8% of risk-weighted assets for a bank to be considered adequately capitalized, and at least 10% of risk-weighted assets for a bank to be considered well capitalized. In addition, there are tests for *well capitalized vs adequately capitalized* that are based on *tier-one capital* in relation to risk-weighted assets and *tier-one capital* in relation to total assets, respectively.

The solutions for various calibrations of the model suggest that a risk-based capital standard may have a restraining effect on risk-taking among well-capitalized banks, but only if the standard is sufficiently stringent. Otherwise, a risk-based standard is essentially no different from a flat standard: a marginally undercapitalized bank moves in the direction of increasing both its capital and its risk as it moves toward compliance (toward its long-run capital target.) In other words, unless the standard is comparatively stringent, banks do not choose to achieve compliance by taking on less portfolio risk than they otherwise would prefer at their long-run target capital level.

For example, consider the impact of alternative capital standards using the calibration from Fig. 1a. Table III shows, for various flat and risk-based standards, the bank's long-run capital target as implied by the solution to the model. The corresponding portfolio choice also is indicated. The first row of the table shows that, given a flat capital requirement, $C^* = 0.06$, the bank's long-run capital target is $C = 0.062$ (it will hold a "capital cushion," as noted previously), at which point it will invest 0.40 in the risky asset. In most cases the risk-based standards entail the same or higher capital and equal or greater risk compared to the flat standard $C^* = 0.06$. Moreover, in most cases, there is an equivalent flat standard for each risk-based standard. The exceptional cases ($c = 4$) are where the standard dictates a steep trade-off between capital and risk.

Moreover, the solutions given a risk-based standard exhibit the same overall U-shape as those depicted earlier. Also, under a risk-based standard as under a flat

TABLE III
The Impact of a Risk-Based Capital Requirement

Capital standard	Long-run capital target C^0	Portfolio risk $R^*(C^0)$
flat: $C^* = 0.060$	0.062	0.40
flat: $C^* = 0.062$	0.062	0.40
flat: $C^* = 0.064$	0.064	0.40
flat: $C^* = 0.066$	0.070	0.40
flat: $C^* = 0.070$	0.070	0.45
flat: $C^* = 0.072$	0.072	0.45
flat: $C^* = 0.080$	0.080	0.50
risk-based: $C^* = 0.06; c = 1; R_0 = 0.20$	0.070	0.45
risk-based: $C^* = 0.06; c = 1; R_0 = 0.30$	0.064	0.40
risk-based: $C^* = 0.06; c = 1; R_0 = 0.35$	0.062	0.40
risk-based: $C^* = 0.06; c = 2; R_0 = 0.25$	0.080	0.50
risk-based: $C^* = 0.06; c = 2; R_0 = 0.30$	0.072	0.45
risk-based: $C^* = 0.06; c = 2; R_0 = 0.35$	0.064	0.40
risk-based: $C^* = 0.06; c = 3; R_0 = 0.35$	0.066	0.40
risk-based: $C^* = 0.06; c = 4; R_0 = 0.35$	0.060	0.35
risk-based: $C^* = 0.06; c = 4; R_0 = 0.30$	0.060	0.30

Note. Calibration: $r_0 = 1.050$, $x = 1060$, $y_0 = 1.113$, $d = 0.080$, $b^2 = 0.25$, $E[u] = 0.047$, $E[y(u)] = 1.062$, $\pi = .0005$.

standard, the primary effect of an insurance-premium surcharge on undercapitalized banks is a widening of the range of maximal risk-taking.[31]

In sum, we find that if a risk-based standard is calibrated to be sufficiently stringent, then it has a restraining effect on risk-taking among well-capitalized banks. Otherwise, the impact of a risk-based standard is essentially no different from that of a flat capital requirement. The following intuition underlies this result. On the one hand, a severely undercapitalized bank can achieve compliance only by increasing its capital (not by reducing its portfolio risk), so that for this bank, the distinction between a risk-based and a flat capital requirement has little bearing on its portfolio risk decision. On the other hand, a bank with more capital faces a choice between raising additional capital (through retained earnings) and moderating its risk-taking to achieve compliance. When the amount of additional capital necessary to achieve compliance is small, the cost of raising capital (dividends foregone in the current period) will be exceeded by the opportunity cost of reducing the portfolio share of the risky asset, because the risky asset yields a higher return and because bankruptcy is a remote possibility.[32]

6.3. *Access to External Capital*

Next, we generalize the basic model by granting the bank access to external capital. Specifically, we assume that, in any period, the bank chooses a capital-infusion policy I as well as a portfolio allocation R. The capital-infusion policy determines the source of funds for next period's capital. If $I = 1$, the bank's owners provide a capital infusion. If $I = 0$, the bank uses internal financing as in the basic model. Any capital infusion, however, is conditional on the bank remaining solvent during the period.

For simplicity, we assume that the amount of any infusion brings the bank's capital back to the minimum capital requirement, C^*.[33] A capital infusion is treated as a negative dividend; that is, it is subtracted from current period earnings. Thus, in the case $I = 1$, the current period dividend equals $z(C, R, u) - C^*$ and the bank begins the next period with capital C^*, provided the bank remains solvent. Hence, we replace C^* with $(1 - I)C^*$ in (2.4). The bank's optimal investment in the risky asset and the optimal capital-policy both depend on the state variable C and are

[31] The solution under a risk-based standard does not necessarily coincide with the solution under a comparable flat standard, but differences are minor. (By "comparable," we mean a flat standard that coincides with the long-run target capital level under the risk-based standard.) For instance, to maintain compliance with a risk-based standard and avoid paying a premium surcharge when its capital has fallen to just below the long-run target level, a bank may take on less risk than it would when subject to a comparable flat standard.

[32] Regardless of their impact on the portfolio decisions of individual banks, regulatory capital requirements impose a cost on banks and, hence, can have industry equilibrium effects. For instance, if potential entrants into the industry are heterogeneous, then a more stringent, risk-based, capital standard may lead to a reduction in the proportion of those entrants having riskier lending opportunities.

[33] There is no loss of generality here. When this assumption is relaxed to allow smaller capital infusions, we find that optimal capital policies involve either an infusion of the entire amount to C^* or no capital infusion.

determined along with the value function $V(C)$ as the solution to the dynamic programming problem (2.6), where u_B is now defined by[34]

$$u_B = u_A - (1 - I)C^*/y_0 R. \tag{6.5}$$

Solving this model for each of the calibrations used earlier, we find that the portfolio risk-choices R_i^* implied by the solutions are identical or nearly identical to those of the original model. Thus, the ability to raise capital externally has little impact on decisions pertaining to portfolio risk.

On the other hand, this model yields new implications regarding the impact of the regulatory parameters on a bank's capital policy. First, a premium surcharge on undercapitalized banks provides an added incentive for those banks to raise capital externally. This is not altogether surprising, since the premium surcharge represents a cost of remaining undercapitalized. This effect is illustrated in Figs. 6a and 6b, which depict the solutions obtained using the calibrations from Figs. 2a and 2b. The presence of an asterisk indicates that the optimal capital-policy is $I(C) = 1$, a capital infusion. The range of capital levels for which capital infusions are optimal is substantially larger in Fig. 6b, reflecting the impact of the premium surcharge. One may also note that the solutions with respect to portfolio risk are almost the same as in Figs. 2a and 2b.

Thus, one effect of a premium differential is a wider range of maximal risk-taking, and another is that undercapitalized banks are apt to seek infusions of capital from outside sources. Provided the bank does not become insolvent before this additional capital is forthcoming, the infusion of capital will have a risk-mitigating effect. Due to the capital infusion, the bank returns to the well-capitalized level; hence, the probability of failure decreases. Therefore, if banks that have become undercapitalized have ready access to external sources of capital (a big "if"), the effect of a premium differential on banks' capital policies has the potential to mitigate the increase in risk due to their portfolio responses.

The effect of a higher capital requirement on banks' capital policies is less sanguine. We find that, in general, undercapitalized banks become less inclined to seek infusions of capital from external sources when the capital requirement is raised.

6.4. *Uninsured Liabilities*

Prior to passage of FDICIA, the FDIC usually granted full protection from losses to creditors of failed banks who technically were uninsured. Uninsured creditors were especially likely to receive protection at larger banks. Failures of sizeable banks generally were resolved in ways that protected all creditors against loss because of concerns that to do otherwise might disrupt the stability of the banking

[34] Note that we can no longer set $z(C, R, u) - C^* = y_0 R(u_B - u)$ in (2.5) and obtain (2.6). Instead, we set $z(C, R, u) - C^* = y_0 R(u_B - u) - IC^*$.

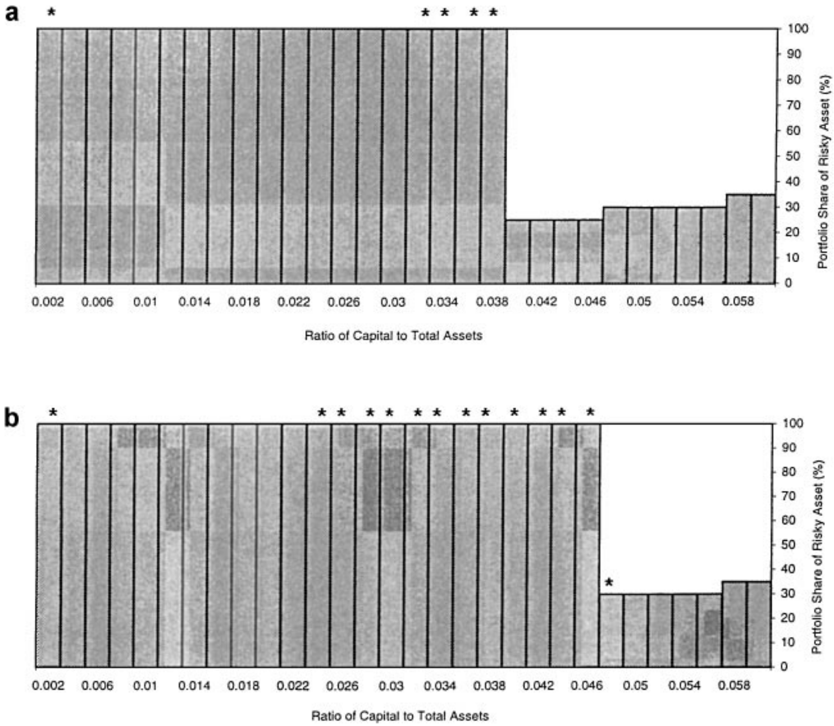

FIG. 6. Solution in the case of access to external capital: (a) with no premium surcharge on undercapitalized banks; (b) with a 5 basis point (0.0005) premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.06$; unit cost of deposits $r_0 = 1.048$; interest rate on safe asset $x = 1.06$; promised return on risky asset $y_0 = 1.1175$; risky asset individual default probability $d = 0.0875$; correlation parameter $b^2 = 0.25$; expected loss on risky asset $E[\mu] = 0.051$; expected return on risky asset $E[y(\mu)] = 1.061$. (*) Bank opts for an infusion of capital from external sources.

system.[35] Thus, historically, uninsured creditors have had little incentive to monitor a bank's portfolio allocation decisions.

These policies changed after 1991, because FDICIA substantially limited the discretionary ability of the FDIC to protect uninsured creditors of failed banks.[36] As a result, uninsured creditors now have greater incentive to monitor a bank's risk-taking behavior. It seems reasonable to conjecture that the interest rate paid on uninsured liabilities now provide greater "market discipline" than in the past. In other words, uninsured liabilities are more likely to be priced to reflect the risk

[35] See FDIC (1998, Chap. 10) and Hanc (1998) for further details.

[36] Several years prior to FDICIA, the FDIC had begun to scale back protection of subordinated debt holders (Flannery and Sorescu 1996). FDICIA prohibited the protection of uninsured depositors and other creditors when such action would increase the cost to the insurance fund. An exception to the least-cost test is allowed in cases of systemic risk (two-thirds of the FDIC Board and two-thirds of the Federal Reserve Board would have to recommend that an exception be made.)

composition of a bank's asset portfolio ex ante, although empirical evidence in support of such a view is lacking.[37]

To explore the potential implications of market discipline, we extend the model by allowing that a constant fraction of bank assets are funded by uninsured liabilities. Further, we assume that uninsured depositors observe the bank's capital position C and its portfolio allocation R and require an interest rate that equates their expected return conditional on C and R to the interest rate paid on insured deposits.

Let r_{unins} denote the promised interest rate on uninsured deposits and let μ denote the fraction of uninsured deposits. The bank's end-of-period net return $Z(C, R, u)$ is

$$\begin{aligned} Z(C, R, u) &= x(1-R) + y(u)R - r(C)(1-\mu-C) - r_{\text{unins}}\mu \\ &\equiv Z'(C, R, u) - r_{\text{unins}}\mu, \end{aligned} \tag{6.6}$$

where we let $Z'(C, R, u)$ denote the return net of payments to uninsured depositors. If $Z(C, R, u) \geq 0$, the bank is solvent and each unit of uninsured deposits earns the contractual interest payment r_{unins}. If $Z(C, R, u) < 0$, the bank is insolvent, in which case uninsured depositors claim any return remaining after payment of insured depositors. In this case, if $Z'(C, R, u) > 0$, uninsured depositors earn $Z'(C, R, u)/\mu$ per unit of deposits, and if $Z'(C, R, u) \leq 0$, they receive zero.

The set of fractional losses u consistent with at least partial payment to uninsured depositors is bounded above by u_D, where u_D satisfies $Z'(C, R, u_D) = 0$. It follows that the expected end-of-period return of uninsured depositors, given beginning-of-period capital level C and portfolio allocation R, is

$$\left\{ \int_{u_A}^{u_D} [u_D y_0 R - u] g(u)\, du \right\} \Big/ \mu + r_{\text{unins}} \int_0^{u_A} g(u)\, du. \tag{6.7}$$

Let r_{ins} denote the interest rate paid to insured depositors (this will equal r_0 minus the base insurance premium.) Equating (6.7) with r_{ins} and rearranging terms, we obtain

$$r_{\text{unins}} G(u_A) = r_{\text{ins}} - \left\{ u_D y_0 R[G(u_D) - G(u_A)] + \int_{u_A}^{u_D} u g(u)\, du \right\} \Big/ \mu. \tag{6.8}$$

This condition and the condition $Z(C, R, u_A) = 0$ with $Z(C, R, u)$ defined by (6.6) simultaneously determine u_A and r_{unins}, given C and R. With u_A and r_{unins}

[37] Flannery and Sorescu (1996) present evidence that the prices of subordinated debt have become more responsive in recent years to general measures of bank insolvency risk, but they do not examine responsiveness to ex-ante measures of portfolio risk composition.

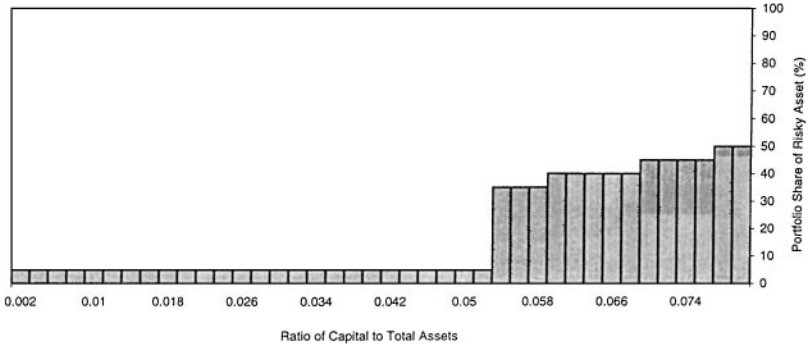

FIG. 7. Solution when a fraction of liabilities are uninsured, with a 10 basis point premium surcharge on undercapitalized banks. *Calibration:* minimum capital standard $C^* = 0.08$; unit cost of deposits $r_0 = 1.05$ interset rate on safe asset $x = 1.06$; promised return on risky asset $y_0 = 1.1133$; risky asset individual default probability $d = 0.08$; correlation parameter $b^2 = 0.25$; expected loss on risky asset $E[\mu] = 0.047$; expected return on risky asset $E[y(\mu)] = 1.061$.

thus determined, the extended version of the model is completed by substituting $Z(C, R, u)$ as defined by (6.6) into the dynamic programming problem (2.5).

This extended version of the model contains an additional parameter, μ, which must be calibrated. In recent years (1992 through 1997), the typical U.S. commercial bank with at least 300 million dollars in assets has had about 15% of its liabilities in uninsured or partly insured instruments (deposits at foreign branches, certificates of deposit exceeding \$100,000, and subordinated debentures.)[38] Consistent with this observation, we set $\mu = 0.15$. In addition, for consistency with the current regulatory environment, we calibrate the regulatory capital requirement (assumed, for simplicity, to be a fixed requirement) at 8%, and we set π (the premium surcharge on undercapitalized banks) equal to 0.001.

Solving the model under the various calibrations used earlier, we consistently find that uninsured depositors have a strong market discipline effect on undercapitalized banks. The range of maximal risk-taking disappears entirely, indicating that the pricing of risk by uninsured depositors acts as a strong deterrent to risk-taking among undercapitalized banks. In the case of a well-capitalized bank, however, we find that risk-taking generally is unchanged by the introduction of uninsured deposits. Given an 8% regulatory requirement, a well-capitalized bank is sufficiently remote from insolvency so that marginal risk-taking has only a small effect on the risk premium required by its uninsured depositors. As a result, these depositors have little influence on the bank's portfolio allocation decision. These findings are illustrated in Fig. 7, which depicts the results obtained when parameters other than μ are calibrated as in Fig. 5b. The range of maximal risk-taking vanishes, but risk-taking by a well-capitalized bank is unchanged in comparison to Fig. 5b.

[38] See English and Nelson (1998).

The calibration $\mu = 0.15$ may overstate the proportion of uninsured liabilities at U.S. commercial banks, for two reasons. First, although most deposits at foreign branches are technically uninsured, there is some question as to the extent to which they are implicitly insured.[39] For instance, a bank may be able to quickly obtain coverage for these deposits (if they belong to U.S. citizens or corporations) by initiating payment of premiums to the FDIC. Second, large certificates of deposit are granted $100,000 in deposit insurance coverage. When the model is calibrated with $\mu = 0.10$ to account for these factors, the results are found to be similar to the $\mu = 0.15$ case. The results also are robust to setting $\mu = 0.23$, which about equals the fraction of liabilities in uninsured or partly insured instruments in recent years at the typical bank that ranks among the 100 largest U.S. commercial banks (at least 6 billion dollars in assets.)[40]

Although this extension of the model suggests that market pricing of uninsured liabilities provide a strong deterrent to risk-taking by undercapitalized banks, this result is driven by the assumption that uninsured depositors can observe the bank's portfolio allocation R. As noted, empirical support for such an assumption is lacking. In contrast, the original version of the model suggests that when uninsured depositors observe C but not R, then the risk premium they assess on uninsured liabilities in response to a decline in capital is analogous to an increase in the insurance-premium surcharge π and aggravates the moral-hazard problem.

7. POLICY IMPLICATIONS

The model we have developed has a number of implications for the effectiveness of current regulatory policy and the merits of proposed reforms.

7.1. *The Effectiveness of Risk-Based Capital Standards*

In theory, capital regulation has two major goals:[41] (1) curtail the risk-shifting benefits of deposit insurance and the associated moral hazard; (2) limit taxpayer exposure to costs arising from fraud, mismanagement, or mistakes made by bankers (so-called "operational risks).[42] Our model indicates that to satisfy these goals, banks simply must hold sufficient capital to be well removed from moral hazard (be

[39] These deposits represent about 1.5% of total liabilities at the typical U.S. commercial bank that has at least 300 million dollars in assets.

[40] Additionally, the model may overstate the potential for market discipline because a bank may, at some cost, reduce its reliance on insured liabilities when its probability of insolvency rises (Goldberg and Hudgins 1996). We can account for this possibility by incorporating a constraint $r_{\text{unins}} \leq r_{\max}$ into the model. For reasonable calibrations of $r_{\max}$ (e.g., 150 basis points over r_0, which is comparable to the cost of brokered, insured deposits), the results are robust.

[41] See Berger *et al.* (1995) and Mingo (1998) for further discussion.

[42] In addition, the goal of limiting the banking system's exposure to systemic risk is often attributed to capital regulation. This goal is briefly addressed below. Capital standards also serve an informational purpose, because a bank's ability to maintain compliance with a capital standard may signal information about the quality of its assets and management. In addition, a capital standard represents a legal tool facilitating supervisory intervention at financially weak institutions.

located sufficiently outside the range of maximal risk-taking), including sufficient capital to serve as a buffer against operational risks. In principle, these goals can be achieved via either a flat capital requirement or a risk-based standard. A risk-based requirement (in theory) is fairer and more efficient to the extent that different banks face different opportunities for risk-taking. Under a flat standard, banks with comparatively limited risk-taking opportunities must hold more capital than necessary and thus must bear a disproportionately high cost.

Our model and recent empirical evidence suggests that the current capital standards have achieved these goals in recent years. However, significant changes may be needed going forward.

Gorton and Rosen (1996) argue that the increase in bank failure rates during the 1980s reflected, in part, a natural restructuring of the industry in response to reduced demand for the services of commercial banks and increased competition from non-bank competitors. They also present evidence that operational risks (in particular, managerial deficiencies) were partly responsible for the initial losses of capital at banks that ultimately failed, and that banks were subject to moral hazard only after their capital had substantially eroded. This evidence suggests that during the 1980s, supervisory capital standards perhaps did not provide an adequate add-on for operational risks. Since the early 1990s, partly in response to new capital regulations and strengthened supervision, a typical bank in compliance with supervisory standards has held considerably more capital in relation to total assets than its counterpart would have held during the 1980s. This fact suggests that the major goals of capital regulation have been achieved in recent years.

Despite this apparent success, many banks, particularly the larger ones, are becoming increasingly adept at evading the capital standards by exploiting shortcomings in the risk-weighted measure of total assets that forms the denominator of the risk-based capital ratio. In recent years, securitization and other financial innovations have enabled banks to lower their effective capital requirements per dollar of risk—a process known as regulatory capital arbitrage (Jones (1999)).[43] If this trend continues, the major goals of capital regulation may no longer be met. A worst case scenario is that the financial conditions of some large banks may deteriorate to where they have little capital to shield them against operational risks and are close to being subject to moral hazard, without these banks violating the regulatory capital standard.

Further, under the current risk-based capital rules, broad risk categories of assets that are only loosely related to actual credit risks are defined for the purpose of assigning risk weights. Consequently, regulatory capital costs may be distributed in a fairly arbitrary manner across institutions, raising issues of fairness and efficiency that are analogous to those associated with a flat standard.

[43] Jones (1999) reports that the most common technique for regulatory capital arbitrage is so-called "cherry picking," which involves unbundling and repackaging a loan pool's cash flows through securitization or other means so that the bulk of the credit risk is concentrated within financial instruments having a lower capital charge. See Jones (1999) for detailed discussion of this and other methods of regulatory capital arbitrage.

A logical way to address these evolving difficulties would be to adopt a more comprehensive and risk-sensitive regulatory capital framework. At present, there is movement in this direction. The Basel Committee on Banking Supervision has announced an intention to move toward an international supervisory framework that would rely on banks' internal credit risk classifications as the basis for assigning assets regulatory risk grades (Basel Committee on Banking Supervision (1999)).[44]

A third goal often attributed to capital regulation is that of limiting the banking system's exposure to systemic risk. Stated more formally, the goal is to achieve a probability of insolvency that accounts for the external costs and systemic risks associated with bank failures. Our model suggests that if this is indeed a goal of capital regulation, then it will be difficult to attain. Recall that once a bank has sufficient capital to be well above the range where maximal risk-taking occurs, a reduction in the bank's probability of insolvency to some exogenous, target level can be achieved only by means of a stringent and precisely calibrated risk-based standard. The standard must require just the right amount of capital for each unit invested in the risky asset. It is doubtful that regulators would have sufficient information to accomplish such a calibration.[45]

7.2. Policies Mandated by the FDICIA

Our analysis calls into question the effectiveness of capital-based deposit insurance pricing. A premium surcharge on undercapitalized banks is counterproductive if, as our model suggests, it aggravates the moral hazard problem among these banks but has little deterrent effect on risk-taking by well-capitalized banks. The banking industry in the 1990s has been characterized by record profitability and a very low frequency of troubled institutions and failures, in contrast to the experience of the 1980s. Consequently, little attention has been focused on the effectiveness of capital-based deposit insurance pricing, which was introduced in 1993. Our model suggests, however, that should conditions in the industry worsen, premium surcharges on undercapitalized banks may promote risky behavior.

On the other hand, the model offers a favorable evaluation of the supervisory policy of prompt corrective action. This policy was recently instituted in accordance with the legislative requirements of the FDICIA, where the overriding goal was to preclude supervisory forbearance. The prompt corrective action framework requires progressively more strict regulatory intervention as a bank's capital declines.[46] Our analysis demonstrates the potential value of close regulatory supervision of seriously undercapitalized banks.

[44] Jones and Mingo (1999) argue that ultimately it may be appropriate to rely on banks' internal credit risk models to help calibrate regulatory capital requirements.

[45] Attempting such a calibration may cause more harm than good, since regulators may overshoot and excessively discourage risk-taking.

[46] The *prompt corrective action* regulations define five capital zones. Banks in capital zone 1 (*well capitalized*) face no mandatory restrictions on activities. Those in zone 2 (*adequately capitalized*) are subject to increased regulatory scrutiny, including more frequent supervisory exams and prior

7.3. Subordinated Debt Proposals

Our analysis also has implications for recent proposals that banks be required to issue subordinated debt. Proposals under consideration would require that a bank have total subordinated debt in excess of 2% of risk-weighted assets, and that this subordinated debt be held by independent third parties (Meyer, 1999). It appears likely that any such requirement would be applied exclusively to large banks.

Various potential "market discipline" effects have been cited in support of a subordinated debt requirement. One argument is that bank risk-taking would be curtailed because a bank that holds a riskier portfolio will have to pay higher prices for subordinated debt.[47] Our model suggests caution in evaluating the merits of this particular argument.[48] We find that pricing of risk by uninsured creditors tends to have no measurable effect on the portfolio allocation decision of a well-capitalized bank. It may deter risk-taking by undercapitalized banks, but only if pricing of risk occurs ex ante in response to changes in portfolio risk composition. Pricing of risk ex post in response to actual losses or erosion of capital may aggravate the moral hazard problem among undercapitalized banks.

8. CONCLUDING REMARKS

This paper sets up a model of the banking firm, calibrates it using realistic parameter values, and applies it to analyze the impacts on bank risk-taking of increased capital standards, capital-based premium differentials, and risk-based capital requirements. A bank is assumed to operate in a multiperiod setting; the bank's capital and its portfolio choices may fluctuate over time depending on the realized returns on loans. Thus, we consider the dynamics of bank portfolio choices and the behavior of well-capitalized as well as undercapitalized banks.

A general implication of the model is that the amount of risk a bank undertakes depends on the bank's current capital position, where the relationship is roughly U-shaped. In particular, a severely under-capitalized bank tends to take on maximal

FDIC approval to accept brokered deposits. Banks in capital zone 3 (*undercapitalized*) face several mandatory restrictions; for instance, these banks are prohibited from accepting brokered deposits and from paying dividends or management fees, and are subject to restrictions on asset growth. Those in zone 4 (*significantly undercapitalized*) are subject to the same restrictions as those in zone 3 plus several additional ones. Banks in capital zone 5 (*critically undercapitalized*) generally must be placed in receivership or conservatorship within 90 days after being assigned to this category.

[47] Proponents of mandatory subordinated debt cite a number of other potential benefits. For example, yields on subordinated bond issues traded in the secondary market and at issuance might provide regulators with potentially useful information on the market's perception of likelihood of default. See, for example, Evanoff (1993).

[48] Many large banks already issue subordinated debt in the amounts stipulated by existing proposals (2% or more of their risk-weighted assets), although most is held by parent companies (Meyer 1999). The model in Section 6 presumes that portfolio risk would be priced regardless of the identities of the uninsured creditors. Hence, we can draw implications from the model in Section 6 as calibrated for large banks.

risk. This result suggests that moral hazard is a serious problem among banks near to insolvency; thus, it provides a formal rationale for the *prompt corrective action* provisions of FDICIA. As capital rises to a more modestly undercapitalized level, maximal risk-taking typically is replaced by much more limited risk-taking. Then, as capital rises to the regulatory standard, a bank tends to take on more risk.

In the case of a flat capital requirement, if the capital requirement is increased, then an ex-ante well-capitalized bank will take on additional portfolio risk as it adds capital to comply with the new standard. This is consistent with the overall U-shape of the solution, whereby beyond the lowest capital levels, risk-taking tends to increase with capitalization. The model also suggests that an increased-risk-based capital standard is analogous to a higher flat standard. That is, an ex-ante well-capitalized bank tends to respond to the increased standard by raising additional capital and taking on more portfolio risk. These results suggest that once a bank is capitalized well beyond the range of maximal risk-taking, a significant reduction in the bank's probability of insolvency is difficult to achieve by mandating further additions to capital. Thus, there are limitations to the usefulness of capital regulation as a means of reducing probability of insolvency.

The model has striking implications with respect to the impact of capital-based deposit insurance premia. A primary intent of the Congress in mandating risk-related pricing of deposit insurance was to create a disincentive against banks engaging in risky activities. In our model, however, the premium surcharge has no appreciable impact on the behavior of a well-capitalized bank. Moreover, a premium surcharge aggravates the moral hazard problem among undercapitalized banks, as reflected in a substantial widening of the capital range over which maximal risk-taking occurs.

On the other hand, a premium surcharge may encourage undercapitalized banks to seek infusions of capital from outside sources. This effect of a premium differential on banks' capital policies has the potential to mitigate the increase in risk due to their portfolio responses.

We also examined the potential role of the pricing of uninsured liabilities as a deterrent to risk-taking. Here, the implications of the model depend critically on the assumed ability of uninsured creditors to monitor a bank's portfolio allocation decision. If monitoring of the asset portfolio is feasible, so that uninsured liabilities are priced to reflect the portfolio's risk composition ex ante, then risk-taking by undercapitalized banks will be effectively deterred. If, however, uninsured creditors respond only to declines in capital or to analogous ex-post indicators of increased probability of insolvency, then the risk premia they assess will tend to aggravate moral hazard.

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