

Strategic Bank Liability Structure Under Capital Requirements

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Abstract. Banks strategically choose and dynamically restructure deposits and nondeposit debt in response to the minimum requirements on total capital and tangible equity. We derive the optimal strategic liability structure and show that it minimizes the protection for deposits conditional on capital requirements. Although, given any liability structure, regulators can set capital requirements high enough to remove the incentive for risk substitution, the strategic response to the capital requirements always preserves this incentive. Banks reduce leverage but increase the proportion of nondeposit debt if regulations raise the capital requirements.

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1. Introduction

Bank liability structure, which consists of deposits, nondeposit debt, and equity, has drawn attention from law makers and economists because of the recent crisis in the banking industry. After the global financial crises during 2007–2009, regulators around the world gradually rolled out new rules on bank liability structure.¹ Regulators and academics have been grappling with questions about both the level and composition of capital that banks should hold. Whereas the desired level of bank capital is controversial, there are debates on the amount of nondeposit debt a bank should hold along with deposits and equity.² Bank capital requirements often distinguish nondeposit debt from deposits, and they do not always treat deposits and nondeposits alike. Since the global financial crisis of 2007–2009, regulators have raised the capital requirements to mitigate bank risk taking.³

An important issue that the academic literature has left unaddressed is how banks' optimal liability structure may respond, *ex ante*, to the capital requirements set by the resolution authorities, such as the Office of the Comptroller of the Currency (OCC) and state banking commissions in the United States and the resolution authorities in other countries. Regulators typically set minimum capital requirements. Typically, some regulators have the authority to close and liquidate a bank if the bank cannot recapitalize to maintain its capital above a threshold required by the regulation.

The goal of this paper is to develop and solve a dynamic, structural, continuous-time model of banks that

strategically choose the composition of deposits and nondeposit debt to maximize the total bank value of shareholders in response to the capital requirements. We call this value-maximizing choice the strategic bank liability structure. Given the sweeping changes in bank capital regulation and the debate over capital requirements, we wish to understand how the regulatory changes influence the mix of deposit and nondeposit liabilities. We do this in a model that unifies different types of capital requirements with risk-based pricing of deposit insurance and costly liquidation of undercapitalized banks that are unable to recapitalize.

Our analytical solution to the model reveals a salient feature of the strategic liability structure: the bank chooses deposits and nondeposit debt to optimize the advantage of debt⁴ and minimizes the protection for the insurer of deposits. This choice of liability structure makes the risk of breaching the requirements coincide with the optimal default decision for the equity holders. Our comparative static analysis shows that this strategic bank liability structure is the key to understanding bank responses to regulations.

Banks are different from other firms as they take deposits. Deposits are different from other forms of debt because deposits are liquid, and banks provide banking services through deposit accounts. Banks pay little or no interest on deposits and earn fees from the banking services. The regulation on bank entry into the deposit markets implies that banks' cost of attracting deposits is lower than the cost of nondeposit debt.

Another important feature of banks is that a large part of deposits in commercial banks are under deposit insurance, and the insurance premium depends on the risk exposure of the deposits.⁵

Most importantly, regulators require each bank to maintain capital above certain levels relative to assets. Regulators have the authority to close and liquidate a bank if the bank cannot recapitalize to maintain its capital above the minimum requirements. In a unified model of these bank regulations, we show that, given the capital requirements, a bank chooses its liability structure, *ex ante*, in such a way to leave it indifferent between being liquidated by the regulatory authorities or being able to default on its debt obligations to maximize the market value equity.

This property of the strategic liability structure has an intuitive economic rationale. Deposits are cheaper than nondeposit debt as a financing source. Therefore, banks should generally prefer deposits to nondeposit debt when balancing the debt advantage with the risk of breaching capital requirements. However, as long as endogenous default (a default optimal for equity holders) does not happen before the breach of capital requirements, nondeposit debt does not affect the regulatory risk. The bank should, therefore, issue as much nondeposit debt as possible for availing the debt advantage and avoiding endogenous default happening when bank capital is still above the requirements. Hence, the optimal level of nondeposit debt sets the endogenous default and the breach of capital requirement concurrent.

A commonly stated purpose of capital requirements is to address the problem of risk taking by banks. This problem arises from the incentives for risk substitution: once debt is issued, shareholders may transfer value to themselves by shifting to riskier assets. We find an important property of the strategic bank liability structure is to preserve the incentives for risk substitution. Indeed, regulators can remove the incentives by raising the capital requirement if the bank liability structure does not optimally respond to regulation. However, if a bank strategically chooses liability structure to maximize the total bank value of shareholders, there are always incentives for risk substitution as if deposits and nondeposit debt are both unprotected. The reason is that banks can undo the protection by setting the endogenous default boundary at the same level as the regulatory boundary. This finding suggests that banks can adjust the relative proportion of deposits and nondeposit debt to reduce the effectiveness of capital requirements.

The comparative static analysis of the strategic choice of bank liability structure delivers some nontrivial theoretical implications that are unique to banks. The analysis shows that, if regulators raise capital requirements, the nondeposit ratio of a bank goes up, opposite to the

change in the deposit ratio. The analysis also shows that the nondeposit debt ratio is more sensitive to the profitability of deposits than the deposit ratio, leading to a higher credit spread. There have been regulations on deposit interest⁶ and bank entry that are intended to improve the stability of banks by making deposits profitable, but the regulation may increase the credit risk of banks if banks respond strategically. Moreover, the analysis shows that deposit insurance subsidy leads to higher credit spreads of banks. Each of these implications needs to be understood through the strategic adjustment of liability structure. These implications are absent in models that ignore the endogenous choice between deposits and nondeposit debt.

The strategic bank liability structure in our model accounts for the feedback between the risk-based deposit insurance premium and liability structure.⁷ Whereas a bank's choice of liability structure affects the insurance premium that the bank has to pay, the insurance premium also affects the bank's choice of liability structure. Our model is the first, to our knowledge, in the literature to incorporate this feedback channel, which is crucial in assessing the regulatory policies pertaining to deposit insurance. Several papers, eminently Merton (1977) and Ronn and Verma (1986), derive a risk-based deposit insurance policy for given bank capital structure. Duffie et al. (2003) value the Federal Deposit Insurance Corporation (FDIC) deposit insurance for given leverage and bankruptcy risk. Our model extends their work to incorporate the endogenous determination of regulatory closure risk when bank liability structure optimally adjusts for a risk-based insurance premium.

We first derive all the results from a model in which banks set the strategic liability structure only at the initial time but are able to dynamically issue equity to postpone default or meet capital requirements. This model is intuitive to understand and allows us to derive all the results analytically. After gaining insights from this intuitive model, we extend it to incorporate banks' dynamic restructuring decisions. We demonstrate that the findings from the model without dynamic restructuring continue to hold after incorporating dynamic restructuring. In the model without dynamic restructuring, we focus on the total capital requirement, which treats nondeposit debt as a capital to protect deposits. In the model with dynamic restructuring, we consider the tangible equity requirement, which mandates banks to keep a minimum level of tangible equity relative to the assets. The latter requirement is either the tier-1 capital requirement or leverage ratio requirement, which we explain in the model with dynamic restructuring.

Our model of strategic bank liability structure advances the literature that attempts to apply the structural continuous-time models of Merton (1974, 1977) and Leland (1994) to banks. Those models study the trade-off between equity and one type of debt, not the composition

of different types of debt. Rochet (2008) studies the endogenous default of banks, setting aside the choice of liability structure. Harding et al. (2007) directly apply Leland's (1994) model to banks by treating deposits as nondeposit debt without paying attention to deposit insurance or bank regulation. Auh and Sundaesan (2020) investigate a firm's composition of repo and unsecured debt in financing, but the firm does not have the properties of banks, such as capital requirements, deposit profitability, or deposit insurance. These special features of banks are central to our analysis. Our model of banks with dynamic restructuring differs from the Subramanian and Yang (2020) model, which assumes that the mix of deposits and nondeposit debt is *exogenously* given and fixed.⁸ By contrast, our model characterizes banks' *endogenous* choice between the two types of liabilities.

The road map for the rest of the paper is as follows. Section 2 develops and analytically solves the model of strategic bank liability structure under the assumption that the bank sets up the optimal liability structure only once. Section 3 provides comparative static analysis to show how the strategic bank liability structure responds to changes in regulations. Section 4 extends our model to allow banks to dynamically restructure their liabilities. Section 5 concludes and discusses further applications and extensions of our model.

2. Bank Liability Structure

Whereas banks share some common characteristics with nonbank firms, they differ in that banks take liquid deposits and provide banking services to their depositors through check writing; automated teller machines; and other transaction services, such as wire transfers, bill payments, etc. The business of taking deposits and providing banking services is under heavy regulation in most countries. A large part of deposits at commercial banks in the United States is FDIC-insured for which the FDIC charges risk-based insurance premiums and imposes regulations on depository institutions. The model of FDIC insurance has gained popularity outside the United States, and many countries and regions offer deposit insurance.⁹ Governments also impose regulations on both the opening of new banks and the closing of existing banks.

Deposits and the associated banking services, deposit insurance, and the regulations on opening and closing banks distinguish banks from other nonbank corporations and make the financial decisions of banks different from the decisions of other nonbank firms. Both nonbank firms and banks have access to cash flows generated by their assets, and both finance their assets by issuing debt and equity. Firms operate in a market with at least two major frictions: tax advantage of debt and bankruptcy costs. These frictions are crucial for the choice of firm capital structure as recognized in the

literature originating from Modigliani and Miller (1963) and Baxter (1967) and analyzed in the structural model by Leland (1994). Banks face these frictions too, but they need to incorporate additional considerations, such as payment services to deposit accounts, deposit insurance, and minimum capital requirements, in determining their liability structure. We provide a careful analysis of the structure in Section 2.1 and discuss deposit insurance and bank regulation in Section 2.2.

Following Leland (1994), we first use a time-independent framework in this section and assume that a bank makes a capital structure decision at the beginning and then extend it to allow dynamic restructuring in Section 4. The time-independent framework can be understood as an infinite-horizon Markov stationary environment. Leland (1994, p. 1215) explains its advantage as follows: "Time independence permits the derivation of closed-form solutions for risky debt value, given capital structure. These results extend those of Merton (1974) and Black and Cox (1976) to include taxes, bankruptcy costs, and protective covenants (if any). They are then used to derive closed-form solutions for optimal capital structure."

2.1. Bank Assets and Liabilities

A typical bank owns a portfolio of assets that generate cash flows. Most assets in banks are risky. Because our focus is on liability structure, we assume that the value of the risky asset portfolio, denoted by V , follows a stochastic process. Following Merton (1974) and Leland (1994), we assume the stochastic process is a geometric Brownian motion:

$$dV = (r - \delta)Vdt + \sigma VdW, \quad (1)$$

where r is the risk-free interest rate, δ is the rate of cash flow, σ is the volatility of asset value, and W is a Wiener process in the risk-neutral probability measure.

The instantaneous cash flow of the assets is δV . In a nonbank firm, δV is the total earnings, but in a bank, δV represents the earnings from bank assets, such as loans, but it does not include the profits from serving deposits. The cash flow δV follows a geometric Brownian motion with the same volatility σ , which summarizes the risk of the asset portfolio. One may alternatively assume that the asset cash flow follows a geometric Brownian motion with volatility σ and then show that the asset value follows the stochastic process in Equation (1).

We focus on the strategic liability structure, which is characterized by the ratios of deposits, nondeposit debt, and equity to assets. Whereas the strategic choice of assets along with the choice of liability is an interesting research topic, the strategic liability structure should be optimal relative to the optimal asset portfolio. Therefore, the formula of the strategic liability structure in our model is likely to hold in a model that optimizes the assets and liabilities simultaneously. For this reason, our

model can be used to shed light on the incentives for risk substitution as we will show later.

Following Merton (1974) and Leland (1994), we assume that investors have full information about the asset value. In reality, active investors use all available information to assess bank asset value and cash flows, albeit only accounting values of assets are directly observable in quarterly filings. The full-information assumption sets aside the disparity between accounting value and intrinsic value. We interpret V as the fair accounting value. If the assets are of the same risk category, we can interpret V as the value of risk-weighted assets.¹⁰

When banks take deposits and provide banking services to depositors, deposits serve as an important source of funds for banks to finance their assets. Let D denote the deposits that a bank takes. Deposits are safe if they are under insurance that guarantees depositors to be paid in full. We assume all deposits are under insurance to focus on the trade-off between insured deposits and other forms of debt. Deposit insurance requires the bank to pay premiums, which we discuss in the next section. Insured deposits work like protected perpetual debt in the capital structure. A protected debt captures the effects of withdrawals and rollover of short-term debt in capital structure.¹¹

Banks charge fees for banking services such as money transfers, overdrafts, etc., and pay little or no interest on deposits. Depositors accept a lower interest rate than the risk-free rate because they value instantaneous liquidity and banking services. Let η be the bank's profit earned from providing banking services on each dollar of deposits. We use η to characterize the profitability of the bank's deposit business. The profits of deposits can be attributed to some local monopoly rents that banks enjoy because of barriers to entry. We do not explicitly analyze the market for deposits, but instead focus on the effects of deposit profitability on a bank's choice of liability structure. The deposit profitability η plays an important role in bank liability structure. It represents depositors' sacrifice for the liquidity and services provided by the bank. This sacrifice is a distinctive character of deposits. A bank's net cost of serving deposits, excluding deposit insurance premium, is $C_D = (r - \eta)D$. If we include insurance premium, denoted by I , the cost of serving deposits is $C_D + I$.

Nondeposit debt is another important funding source for banks. There is no banking service associated with nondeposit debt. A bank pays interest on nondeposit debt until the regulator closes the bank or the equity holders default on debt. The holders of nondeposit debt have a lower priority than depositors in claiming a bank's liquidation value. The lower priority of nondeposit debt can potentially protect deposits, and thus, some nondeposit debt qualifies for being tier-2 capital in bank regulations. Nondeposit debt comes

with a cost: its interest rate contains a credit premium to compensate the debt holders for bearing the risk of bank closure or default. We solve the endogenous credit spread in the model; the spread depends on both the asset risk and the liability structure. Let s be the credit spread, B be the value of nondeposit debt, and C_B be the interest cost. These variables are related by $C_B = (r + s)B$.

Equity holders garner all the residual value and earnings of the bank after paying the contractual obligations on deposits and nondeposit debt. The first slice of the value that equity holders lay claim to is the asset value exceeding the value of deposits and nondeposit debt: $T = V - (D + B)$. This slice is referred to as tangible equity. This is the value that equity holders receive if the bank liquidates its assets at fair value without incurring liquidation costs and pays off deposits and nondeposit debt at their par values. A larger tangible equity means a smaller loss for debt holders after liquidation. Hence, regulators regard tangible equity as bank capital of the highest quality: tier-1 capital.¹²

Because equity holders receive the net earnings of the bank, the present value of the net earnings is the bank's charter value. The net earnings contain the benefits of financial leverage. Following the literature, we assume that the benefit of debt is proportional to interest costs: $\tau(C_D + C_B)$, where $\tau \in (0, 1)$ because the most important benefit of debt is the tax deductibility of interest costs. We simply interpret τ as a tax rate. The tax rules in the United States also allow banks to deduct the insurance premiums paid to the FDIC.¹³ Therefore, the total benefit of financial leverage is $\tau(I + C_D + C_B)$. The dividend available to be paid to equity holders is the asset cash flow plus the benefits of leverage and minus the insurance and interest costs: $\delta V - (1 - \tau)(I + C_D + C_B)$.

The total value generated for the original bank shareholders by the liability structure is the combined value of deposits, nondeposit debt, and equity. So $F = D + B + E$ is the total bank value of shareholders. Because equity value depends on its dividend, it depends on the liability structure. The triplet (I, C_D, C_B) , therefore, determines the liability structure of a bank and, thus, determines the total bank value. We provide a closed-form formula of the total bank value in the Online Appendix. Without loss of generality, we ignore the costs of structuring liabilities here, but we later incorporate such costs in the model of banks that dynamically restructure their liabilities.

Our model of liability structure distinguishes banks from nonbank firms but is consistent with the structural model of firms. If we set $C_D = I = 0$ but keep $C_B > 0$, the model is equivalent to Leland (1994) for nonbank firms that issue equity and corporate bonds but do not take deposits. Our model extends Leland's (1994) model to

banks and offers a consistent framework for understanding the similarities and differences between banks and nonbank firms. Most importantly, our framework allows banks to strategically adjust the mix of deposits and nondeposit debt in response to regulations; this is the unique feature of our model.

2.2. Bank Regulation and Deposit Insurance

Without deposit insurance, deposits bring a bank the risk that depositors may run—a major challenge commonly faced by banks. As experienced in the crises of U.S. banking history and theorized in the academic literature, depositors may run from a bank if they think the bank has difficulty in repaying its deposits promptly upon their demand. Diamond and Dybvig (1983) pioneered the bank run literature by showing that bank runs can emerge as an equilibrium. Allen and Gale (1998) and others extend the literature significantly. The establishment of the FDIC was to deter bank runs by guaranteeing deposits to be paid in full. Therefore, insured deposits are exposed to no risk of bank run in our model.

A bank's charter authority, which is typically either the bank's state banking commission or the OCC, is the regulator that has the authority to close and liquidate the bank. The charter authority closes a bank if the bank is insolvent or the bank's capital is too low to recapitalize. Regulators categorize a bank as critically undercapitalized when the total capital that protects deposits drops to a fraction of the assets.¹⁴ We model this capital requirement and closure policy exactly as they are in the U.S. bank regulation. The total capital that protects deposits consists of tangible equity and nondeposit debt. This is equivalent to $T + B = V - D$ in our model. The capital requirement is the minimum capital for a bank to operate as modeled in Rochet (2008). The charter authority shuts down a bank when the bank cannot recapitalize to keep capital above the minimum requirement. Regulations typically specify a capital requirement as a ratio to the asset value, denoted by β in our model. If the capital requirement is 2% as in the closure policy of the FDIC, then $\beta = 2\%$. Let V_b be the asset value when the charter authority closes the bank. Then, $V_b - D = \beta V_b$, which implies $V_b = D / (1 - \beta)$. Therefore, the regulator closes the bank when the bank asset value drops to V_b . We call V_b the regulatory total capital boundary. This traditional form of capital requirement requires banks to maintain the total capital ratio above a certain level. The bank regulation developed after the 2008 financial crisis requires each bank to maintain additional tangible equity as a conservation buffer. We extend our model to incorporate alternative capital requirements in Section 4.2.

The FDIC functions as the insurer of a bank's deposits and the receiver of the bank when it is closed by its regulator. As a receiver, the FDIC liquidates the assets of a closed bank in its best effort to pay back the bank's

creditors. Suppose the liquidation cost is αV_b , proportional to the asset value V_b of the closed bank.¹⁵ As an insurer, the FDIC pays D to the depositors of the closed bank. The insurance corporation loses $D - (1 - \alpha)V_b$ if $(1 - \alpha)V_b < D$. Thus, the loss function of the insurer is $[D - (1 - \alpha)V_b]^+$, where $[x]^+ = x$ if $x \geq 0$ and $[x]^+ = 0$ if $x < 0$. Because $V_b = D / (1 - \beta)$, the loss function is positive if $\beta < \alpha$, in which case the FDIC expects to suffer a loss after a bank closure. In practice, the FDIC expects a chance of loss because the liquidation cost is uncertain. To keep our analysis tractable, we assume $\beta < \alpha$ so that the FDIC expects a loss after a bank closure. Otherwise, there is no reason for the insurer to charge any insurance premium. After the FDIC liquidates the bank assets, it pays the depositors first and, if there is money left, the debt holders next. The payoff to the debt holders is, therefore, $[(1 - \alpha)V_b - D]^+$. It follows that the debt value at the regulatory closure is $B(V_b) = [(1 - \alpha)V_b - D]^+$.

To cover its potential loss, the FDIC charges insurance premiums. In 2006, Congress passed reforms that permit the FDIC to charge risk-based premiums. To determine deposit insurance assessment, the FDIC places each insured depository institution into one of four risk categories each quarter, depending primarily on the institution's capital level and supervisory evaluation. A riskier bank pays a higher insurance premium than a safer bank. In principle, the insurer should assess insurance premiums based on the deposits under insurance.¹⁶ If the assessment rate is g , the deposit insurance premium paid by a bank is $I = gD$. Since April 2011, the assessment rate may also depend on the credit rating of the bank and on the level of nondeposit debt that protects deposits.¹⁷

The fair insurance premium should make the insurance contract worth zero to each party of the insurance contract. It should depend on the deposit ratio and the risk exposure of the deposits. We derive, in the Online Appendix, a closed-form formula of the fair assessment rate:

$$g^\circ = \frac{r[\alpha - \beta]^+}{1 - \beta} \cdot \left[\frac{D/V}{1 - \beta} \right]^\lambda \left(1 - \left[\frac{D/V}{1 - \beta} \right]^\lambda \right)^{-1}, \quad (2)$$

where λ is the positive solution to the quadratic equation $\sigma^2 \lambda(1 + \lambda) / 2 - (r - \delta)\lambda - r = 0$. If the cash flow of the assets is zero, that is, $\delta = 0$, we have $\lambda = 2r / \sigma^2$, which is proportional to r and inversely proportional to σ^2 .

The fair insurance premium for deposits D is $I^\circ = g^\circ D$. Equation (2) indicates that the fair assessment rate g° increases with D . Therefore, if deposits expand, the insurance premium increases not only because of the expansion of deposits, but also because of the rise in the assessment rate. The rate is increasing with D because an expansion of deposits exposes the FDIC to a bigger risk. If $\beta < \alpha$, the fair premium I° is positive. It converges to zero as β rises to α . If $\beta \geq \alpha$, the fair

premium is zero because the closed bank has enough assets to pay for the deposits.

The FDIC, however, may not charge a fair insurance premium. Duffie et al. (2003) argue that the FDIC does not charge enough insurance premium to cover its risk exposure.¹⁸ A low premium provides subsidized insurance to banks. When the premium is subsidized, it can alter the bank value and affect its choice of liability structure. We use ω to denote the insurance subsidy as a fraction of the fair insurance. To allow a subsidized insurance premium, we assume that the assessment rate of deposit insurance is $g = (1-\omega)g^\circ$ and the insurance premium is $I = gD$. It is natural to expect that an insurance subsidy increases bank value because the bank pays a reduced insurance premium for enjoying the full risk-free value of deposits. It is, however, not obvious how the subsidy affects the bank liability structure.

The equity holders default on the bank's debt obligations and liquidate assets if the equity value reaches zero because this default strategy maximizes equity value and is, thus, optimal for equity holders. Before the equity value reaches zero, it is optimal for equity holders to issue new equity at market price to recapitalize. When the equity value reaches zero, the bank cannot recapitalize to keep the bank running and, thus, defaults on the debt. This is referred to as endogenous default. The endogenous default boundary is the asset value, denoted by V_d , that gives zero equity value. In the Online Appendix, we derive the formula of the endogenous default boundary for banks:

$$V_d = (1-\tau) \frac{\lambda}{1+\lambda} \frac{I + C_D + C_B}{r}, \quad (3)$$

given insurance premium I , the deposit liability C_D , and the nondeposit debt liability C_B . The formula indicates that the endogenous boundary is an increasing function of each liability.

A bank ceases to operate and its assets go to liquidation when either the regulator closes the bank or the equity value reaches zero, whichever happens earlier. Then, the boundary for the bank to liquidate assets is $V_l = \max\{V_b, V_d\}$. We call V_l the liquidation boundary of the bank. Because the claims of the depositors take priority over the claims of nondeposit debt holders, the value of nondeposit debt at the liquidation boundary is $B(V_l) = [(1-\alpha)V_l - D]^+$.

2.3. Strategic Liability Structure

Table 1 summarizes the exogenous parameters discussed in the preceding sections as well as the assumptions on their range. Deposit business generates profit ηD with $0 < \eta < r$. Deposits and nondeposit debt bring the benefit of leverage: $\tau(I + C_D + C_B)$ with $0 < \tau < 1$. Liquidation results in a cost of cost αV_l with $0 < \alpha < 1$. A bank's total capital has to meet a minimum requirement:

Table 1. Exogenous Parameters of the Model

Parameter	Notation	Range
Asset volatility	σ	$(0, \infty)$
Asset cash flow	δ	$[0, \infty)$
Risk-free interest rate	r	$(0, \infty)$
Deposit profitability	η	$(0, r)$
Debt advantage	τ	$(0, 1)$
Liquidation cost	α	$(0, 1)$
Capital requirement	β	$[0, \alpha]$
Insurance subsidy	ω	$[0, 1]$

Note. The range of each parameter is the range allowed in the model.

$V \geq V_l = D/(1-\beta)$ with $0 \leq \beta < \alpha$. The FDIC may subsidize the insurance premium $g = (1-\omega)g^\circ$ with $0 \leq \omega < 1$. These assumptions are not only realistic, but also the requisite mathematical conditions for valuation and optimization.

The strategic choice of liability structure ($D^*/V, B^*/V$) maximizes the total value of the original equity holders. A bank can adjust either assets or nondeposit debt or both to achieve a desired liability structure even if the bank accepts deposits passively from depositors. A value-maximizing bank accounts for the cost of deposit insurance when trading off the debt advantage and deposit profitability with the capital requirements and liquidation risk. The bank in our setting is fully aware that any decision pertaining to the liability structure has a consequence on the insurance premium because it pays risk-based insurance premium $I = gD$, where $g = (1-\omega)g^\circ$ is the assessment rate and g° depends on D and other parameters of the bank as described in Equation (2). The bank cares about the increase in the premium caused both directly by the expansion of deposits as well as indirectly by the rise of the assessment rate. The bank should, therefore, be mindful of this channel in its choice of liability structure. The relation between risk-based insurance premium and liability structure captures the feedback channel from the insurance cost to the bank and vice versa.

Our first proposition about bank strategic liability structure is that a bank must hold some nondeposit debt along with deposits. The detailed derivation of this proposition is provided in the Online Appendix.

Proposition 1. *A bank can increase its value by increasing nondeposit debt if the current nondeposit debt ratio is so low such that the endogenous default boundary is lower than the regulatory total capital boundary. That is, the liability structure with $V_d < V_b$ is suboptimal.*

The most important implication of this proposition is that the nondeposit debt in a strategic liability structure must be positive. It is suboptimal for a bank to have only deposits and equity in its liability structure. Nondeposit debt is necessary for a bank that strategically chooses its liability structure to maximize value. The

bank must hold at least sufficient nondeposit debt so that $V_d \geq V_b$. Song and Thakor (2007) argue that banks issue nondeposit debt to match the risk of loans in relationship banking. The strategic bank liability structure in our model offers a different perspective for banks to issue nondeposit debt.

If asset volatility σ and liquidation cost α are both very high and the capital requirement β is very close to zero, the risk-based assessment rate can be so high that it cancels out the profits of deposits. This unusual and unrealistic situation makes deposits more expensive than nondeposit debt. To keep our formulation succinct for the rest of this section, we assume that the parameters exclude this situation. That is, we assume that the asset volatility σ , liquidation cost α , and capital requirement β are realistic so that the risk-based assessment rate is small relative to the service income. More precisely, we assume that the insurance subsidy ω and the capital requirement β are high enough so that

$$g < \frac{\eta}{1 + \lambda}. \quad (4)$$

This assumption means that the assessment rate g should not be so high that it wipes out the value of η in the provision of liquid deposits. We call this the regularity assumption. For all the practical asset volatility and liquidation cost used in our comparative static analysis in Section 3, we actually find that the regularity assumption holds for each capital requirement $\beta \in [0, \alpha)$.

The next proposition, derived in the Online Appendix, provides a complete characterization of the strategic liability structure.

Proposition 2. *A bank's strategic liability structure sets the deposit and nondeposit debt ratios so that the endogenous default boundary coincides with the regulatory total capital boundary: $V_b^*/V = V_d^*/V = \pi^{1/\lambda}$, where π is the state price of regulatory total capital boundary, and it is related to the parameters by*

$$\pi = \frac{1}{1 + \lambda} \cdot \frac{\eta(1 - \tau)\lambda(1 - \beta) + r\tau(1 + \lambda)}{\eta(1 - \tau)\lambda(1 - \beta) + r\tau(1 + \lambda) + r(1 - \tau)\lambda[(1 - \omega)\alpha + \omega\beta]}. \quad (5)$$

The deposit and nondeposit debt ratios are related to the parameters by

$$D^*/V = (1 - \beta)\pi^{1/\lambda},$$

$$B^*/V = \left(\frac{\tau}{1 - \tau} + \beta + (1 - \beta) \frac{\eta}{r} \frac{\lambda}{1 + \lambda} + \frac{1 - \pi}{\lambda} \right) \pi^{1/\lambda}. \quad (6)$$

The credit spread and assessment rate are related to the parameters by

$$s^* = \frac{r\pi}{1 - \pi}, \quad g^* = (1 - \omega) \frac{\alpha - \beta}{1 - \beta} \cdot \frac{r\pi}{1 - \pi}. \quad (7)$$

The strategic liability structure maximizes the total value by balancing the benefits and costs. The benefits

are the deposit service income and debt advantage. The costs are the risk-based premium for deposit insurance and risk of costly liquidation. The proposition shows that the strategic bank liability structure depends on the following parameters: $r, \sigma, \delta, \eta, \alpha, \beta, \omega$, and τ . The parameters σ, δ, η , and α are likely to be heterogeneous among banks, whereas the parameters β, ω , and τ mainly depend on regulations and government policies.

If we set both the profit of serving deposits (η) and the subsidy of deposit insurance (ω) to zero, the strategic liability structure reduces to the optimal firm capital structure derived by Leland (1994). In this sense, Leland's (1994) model of capital structure of a nonbank firm is a special case of our model of bank liability structure. Nesting the model of nonbank firms as a special case is useful for comparing banks with nonbank firms and examining the special properties that make the banks different from nonbank firms.

The ratio of deposits to assets, D^*/V , and the ratio of nondeposit debt to assets, B^*/V , in Proposition 2 determine the optimal bank liability structure. Regulators and investors monitor these ratios closely. They measure the leverage of a bank by its tangible equity ratio, $T^*/V = 1 - (D^* + B^*)/V$, for which we can have a closed-form formula from Equation (6). A lower tangible equity ratio means a higher leverage. Proposition 2 suggests that a value-maximizing bank strategically determines these financial ratios.

It is important to note that banks strategically use nondeposit debt to set the endogenous default boundary relative to the asset value. The regulatory total capital boundary determines the risk that the regulator closes the bank. The strategic bank liability structure in Proposition 2 sets the endogenous default boundary V_d to be same as the regulatory total capital boundary V_b . Recall that the endogenous default boundary is the optimal point for equity holders to default in the absence of total capital requirement. Therefore, the strategic liability structure balances deposits and nondeposit debt so that the regulatory total capital boundary is optimal for equity holders. The coincidence of the two boundaries implies that the capital is exactly the minimum required by regulation at the time the equity holders choose to default optimally. This strategy leaves no extra capital to protect the deposit insurer. Therefore, the strategic choice of the liability structure minimizes the protection for the deposit insurer.

We can intuitively understand the strategic response as follows. Deposits bring profits from banking services in addition to the tax advantage, and the extra cost of taking deposits is the insurance premium. By contrast, nondeposit debt brings only the tax advantage, whereas it bears the credit premium. If the assessment rate of deposit insurance is lower than the credit spread, the bank should issue as much nondeposit debt as possible to avail the tax advantage but should avoid issuing too

much nondeposit debt to move the endogenous default boundary above the regulatory total capital boundary. Therefore, the bank should use nondeposit debt to set the two boundaries exactly equal.

An important issue related to the choice of capital structure is the incentives for risk substitution. There are such incentives if the market value of equity is an increasing, convex function of asset value. In this case, equity resembles a call option on asset value. The call option value is higher for a riskier underlying asset. The literature points out that corporate debt may create incentives to substitute assets with higher risk (e.g., Green 1984, Harris and Raviv 1991). Leland (1994, 1998) shows that the unprotected debt in a highly leveraged firm has such incentives because the market value of equity is an increasing, convex function of asset value. The literature suggests that such incentives may arise in banks as well when deposits are insured (e.g., Schneider and Tornell 2004, Pennacchi 2006). The incentives for risk substitution are important for banks because banks use high leverage.¹⁹ Leland (1998) and Toft and Prucyk (1997) show that protection (covenant) for debt can mitigate the incentives for risk substitution. Because capital requirements are expected to protect deposits, they are analogous to covenants that protect firm debt. One may, therefore, expect capital requirements to mitigate the incentives for risk substitution.

The next proposition presents two implications about the incentives of risk substitution in the context of bank liability structure.

Proposition 3. (1) For given nondeposit debt obligation C_B , there are \bar{D} and $\bar{\beta}$ with $\bar{D} > 0$ and $0 < \bar{\beta} < \alpha$ so that, for any given deposit ratio $D/V \in (\bar{D}/V, +\infty)$ and any capital requirement $\beta \in (\bar{\beta}, \alpha)$, the market value of bank equity is an increasing, concave function of asset value. (2) However, if a bank strategically chooses a liability structure to maximize bank value, the market value of bank equity is always an increasing, convex function of asset value for all β .

The proposition is derived in the online appendix. The first part of the proposition says that the regulator can raise the capital requirement β high enough but below the bankruptcy cost α to remove the incentives for risk substitution given a fixed composition of nondeposit debt and deposits in the bank liability structure. The lower bound \bar{D} is given in the online appendix that derives the proposition. The lower bound specifies the minimum deposits in the balance sheet such that the incentives for risk substitution can be removed by raising the capital requirement. The reason is that capital requirement protects deposits but does not protect nondeposit debt. If the bank holds too few deposits, protecting merely deposits does not have enough impact on the value function of bank equity. These mirror the

results of Leland (1998) and Toft and Prucyk (1997), who show that protection (covenant) of debt can mitigate the incentives for risk substitution.

The second part of the proposition shows that a bank's strategic liability structure preserves the incentives for risk substitution by keeping the market value of equity an increasing, convex function of asset value. When a bank sets the endogenous default boundary at the same level as the regulatory total capital boundary to optimize the total bank value, the entire debt, which includes deposits and nondeposit debt, is essentially unprotected. As a result, the equity value with unprotected debt is increasing and convex as a function of asset value. This consequence is not noted in the existing theories of bank capital structure that abstract from the strategic choice between deposits and nondeposit debt.²⁰

3. Comparative Static Analysis

The strategic bank liability structure in our model depends on several factors. Debt advantage (τ), asset volatility (σ), and liquidation cost (α) are well-known factors in the capital decision in all firms. The unique factors for banks are the minimum total capital requirement (β), the profitability of deposits (η), and the deposit insurance with potential subsidy (ω). We focus on the effects of the three banking factors (η , β , and ω). We first examine the effects of deposit services because it distinguishes bank liabilities from nonbank firm's liabilities.

3.1. Effects of Banking Factors

To examine the effects of deposits, we imagine a comparable nonbank firm that holds the same assets as a bank but does not take deposits. The firm issues nondeposit debt and equity as in the model of Leland (1994). The parameters (η , β , ω) do not affect the nonbank firm's capital structure. One may regard the firm as a bank that constrains deposits to zero. Without deposits on its balance sheet, the firm liquidates when it endogenously defaults. There is no regulatory capital requirement.

Let \bar{B} be the optimal nondeposit debt issued by the comparable nonbank firm that holds the same assets as the bank. The tangible equity in the optimal firm capital structure is $\bar{T} = V - \bar{B}$ because there are no deposits. The following proposition compares the strategic liability structure of a bank that takes deposits with the optimal capital structure of the nonbank firm that holds the same assets as the bank but does not take deposits. All propositions in this section are derived in the online appendix.

Proposition 4. The strategic bank liability structure has higher leverage, higher default risk, and a higher credit spread

than the optimal capital structure of a nonbank firm that holds the same assets. That is,

$$\frac{T^*}{V} < \frac{\bar{T}}{V}, \quad \frac{V_d^*}{V} > \frac{\bar{V}_d}{V}, \quad s^* > \bar{s}, \quad (8)$$

where \bar{V}_d is the endogenous default boundary and \bar{s} is the associated credit spread of the debt in the optimal capital structure of the nonbank firm.

The most striking prediction of this proposition is that a bank uses higher leverage than a comparable nonbank firm even if they hold the same assets. It is well-known that bank leverage is higher than firm leverage, but some academic papers attribute the high bank leverage to principal agent problems in banks and argue for reducing bank leverage to a level similar to the leverage of nonbank firms. In our model, banks maximize the total bank value. So there is no principal agent problem in our model. Yet the optimal leverage of banks is still much higher than the optimal leverage of nonbank firms after we control their assets to be same. Because the business of serving deposits is the difference between the bank and nonbank firm in the proposition, it is the reason for higher bank leverage.

As explained in our model, the strategic liability structure internalizes the capital requirement to make the regulatory boundary optimal for equity holders. We, therefore, first consider the effects of a change in the minimum capital requirement on bank liability structure.

Proposition 5. *In response to tighter capital requirements, a bank chooses a lower deposit ratio but a higher nondeposit debt ratio. The overall leverage is lower because the drop in deposit ratio is larger than the rise in nondeposit debt ratio. The associated assessment rate and credit spread are lower if the capital requirement is higher. The assessment rate is more sensitive to the capital requirement than the credit spread. The following inequalities summarize these effects of capital requirement:*

$$-\frac{\partial(D^*/V)}{\partial\beta} > \frac{\partial(B^*/V)}{\partial\beta} > 0, \quad \frac{\partial T^*}{\partial\beta} > 0, \quad \frac{\partial g^*}{\partial\beta} < \frac{\partial s^*}{\partial\beta} < 0. \quad (9)$$

According to this proposition, tightening the minimum capital requirement leads the deposit and nondeposit debt ratios to be adjusted in opposite directions. Most importantly, a bank uses more nondeposit ratio relative to assets if the capital requirement is higher. This proposition makes predictions not only about the direction of the effects, but also about the relative sensitivity of the financial ratios to the capital requirement. The first chain of inequalities in the proposition says that the drop in the deposit ratio is larger than the rise in the nondeposit debt ratio. It follows that $\partial(T^*/V)/\partial\beta > 0$, which means that a tighter capital requirement leads to a lower leverage as expected. However, the different

effects on deposits and nondeposit debt are not discovered in models that do not distinguish deposits and nondeposit debt.

As mentioned earlier, deposits are profitable because of banks' market power under the regulation on the entry to the market. We, therefore, examine the effects of deposit profitability on bank liability structure.

Proposition 6. *The strategic liability structure has a higher deposit ratio and a higher nondeposit debt ratio in a bank if its deposit business is more profitable. The associated assessment rate and credit spread are both higher. The nondeposit debt ratio is more sensitive to deposit profitability than the deposit ratio, and the credit spread is more sensitive than the assessment rate. The following inequalities summarize these effects of deposit profitability:*

$$\frac{\partial(B^*/V)}{\partial\eta} > \frac{\partial(D^*/V)}{\partial\eta} > 0, \quad \frac{\partial s^*}{\partial\eta} > \frac{\partial g^*}{\partial\eta} > 0. \quad (10)$$

The first chain of inequalities in (10) shows that the deposit and nondeposit debt ratios are both increasing functions of deposit profitability. It immediately follows that the tangible equity ratio is a decreasing function of deposit profitability: $\partial(T^*/V)/\partial\eta < 0$. This means banks use higher leverage if deposits are more profitable.

Given that deposit profitability is a benefit of bank leverage, the positive effect on deposit ratio is not surprising. However, a nontrivial result in Proposition 6 is that the nondeposit debt ratio is more sensitive to deposit profitability than the deposit ratio. The positive and relatively larger effect on nondeposit debt ratio runs counter to the intuition that a bank should mainly increase the deposit ratio if deposit profitability increases. Such intuition overlooks the strategic response of bank liability structure. If a bank raises its deposit ratio, it also needs to raise the nondeposit debt ratio to keep the regulatory total capital and endogenous default boundaries at the same level so that the bank value is maximized.

Another nontrivial result of our model is that both the assessment rate and the credit spread have positive relations to deposit profitability as shown in the second chain of inequalities in Proposition 6. Before 1980, the U.S. bank regulation prohibited banks from paying interest on deposits and limited bank competition for deposits based on the belief that making deposit business more profitable would reduce bank failures. This line of thought ignores the strategic response of banks to the changes in deposit profitability. Proposition 6 shows that a bank's strategic response is to raise both the deposit and nondeposit debt ratios when deposit service is more profitable. This response raises the regulatory total capital boundary. Then, the risks to FDIC and nondeposit debt holders are higher, which leads

to higher assessment rate and wider credit spread, respectively.

The next proposition concerns how a change in insurance subsidy affects the strategic bank liability structure.

Proposition 7. *A bank chooses higher deposit and nondeposit debt ratios if the insurance subsidy is larger. The deposit ratio is more sensitive to the insurance subsidy than the nondeposit debt ratio. The associated credit spread is higher if the insurance subsidy is larger but the assessment rate is lower. The following inequalities summarize these effects of insurance subsidy:*

$$\frac{\partial(D^*/V)}{\partial\omega} > \frac{\partial(B^*/V)}{\partial\omega} > 0, \quad \frac{\partial s^*}{\partial\omega} > 0, \quad \frac{\partial g^*}{\partial\omega} < 0. \quad (11)$$

It is expected that a bank chooses a higher deposit ratio if the insurance is more subsidized, but it is less obvious why the bank also chooses a higher nondeposit debt ratio. To understand this, we need to recall that a higher deposit ratio implies a higher regulatory total capital boundary. For the bank liability structure to be optimal, the nondeposit debt ratio needs to be higher so that the endogenous default boundary matches the regulatory total capital boundary. This channel of the insurance subsidy effect is not revealed if the model does not consider the endogenous choice between deposits and nondeposit debt.

Whereas Proposition 7 predicts that the insurance subsidy lowers the insurance rate as expected, it also predicts that the insurance subsidy leads to higher credit spread. The effect on credit spread is nontrivial. To understand it, we again need to consider the strategic response of banks to regulation. A larger insurance subsidy causes banks to choose not only a higher deposit ratio but also a higher nondeposit debt ratio. The combination of two higher ratios leads to a higher credit spread.

Most of the predictions in these propositions are unique to our model. The predictions are not only qualitative, but also quantitative. To better understand the quantitative nature of the predictions, we present numerical examples in the next section to illustrate these theoretical predictions.

3.2. Numerical Illustration

3.2.1. Effects of Including Deposits in Liabilities. In Table 2, we present a numerical example to illustrate the comparison between the strategic bank liability structure and the optimal firm capital structure of a nonbank firm. For the special parameters about banking in this example, the total capital requirement is assumed to be $\beta = 2\%$, the deposit profitability is assumed to be $\eta = 3\%$, and the subsidy in the insurance premium is assumed to be $\omega = 10\%$. For the other general parameters, the asset volatility is assumed to be $\sigma = 5\%$, the cash-flow rate of the assets is assumed to be $\delta = 8\%$, the

liquidation cost is assumed to be $\alpha = 27\%$, the benefit of debt (tax rate) is assumed to be $\tau = 15\%$, and the risk-free interest rate is assumed to be $r = 5\%$. These parameters are only for illustration although they are, on average, consistent with the observed historical data during 1984–2013. More detailed information about the historical averages can be found in the Online Appendix.

The example demonstrates some distinctive properties of the strategic bank liability structure. The first property to notice is that the bank takes a significant amount of deposits. The deposit ratio is 45.30%. Another noticeable property of the strategic bank liability structure is the magnitude of nondeposit debt. The nondeposit debt ratio is 46.49%, almost same as the deposit ratio. Another interesting property is the high leverage. The strategic bank liability structure has a tangible equity ratio as low as 8.23%.

The financial ratios in this example are broadly comparable to the average liability structure of the FDIC-insured commercial banks and savings institutions. Based on data of the FDIC, the deposits are 45% of those banks' assets, on average, during 1984–2013. The other debt is 47% of the bank assets on average. The equity is 8% of the bank assets on average.

The last column of Table 2 presents the optimal capital structure of a comparable nonbank firm. Such a firm uses much lower leverage than the bank. The tangible equity ratio of the firm is nearly 40% of the assets, much higher than the 8% tangible equity ratio of the bank. The firm issues only slightly more nondeposit debt than the bank. The liquidation boundary of the firm is 35.28% of the asset value, lower than the liquidation boundary of the bank, which is 46.20% of the bank assets.

As noted in Proposition 2, the strategic bank liability structure sets nondeposit debt to a level such that the regulatory total capital boundary is optimal for the bank equity holders. The numerical example shows that this strategy leads the bank to higher leverage and liquidation risk than the comparable firm. Higher liquidation risk leads to a higher credit spread for the bank. In Table 2, the credit spread for the bank is 227 basis

Table 2. Comparison of the Strategic Bank Liability Structure and the Optimal Capital Structure of a Comparable Firm That Does Not Take Deposits

Endogenous variable	Bank	Firm
Ratio of deposit to assets	D/V 45.28	
Ratio of nondeposit debt to assets	B/V 46.49	\bar{B}/V 60.03
Ratio of tangible equity to assets	T/V 8.24	\bar{T}/V 39.97
Ratio of default boundary to assets	V_d/V 46.20	\bar{V}_d/V 35.28
Credit spread	s 2.27	\bar{s} 1.02
Assessment rate	g 0.53	

Notes. The values for the endogenous variables are reported in percentage points. The exogenous parameters are $\eta = 0.03$, $\sigma = 0.05$, $\alpha = 0.27$, $\beta = 0.02$, $\omega = 0.1$, $\tau = 0.15$, $\delta = 8\%$, and $r = 5\%$.

points, whereas the credit spread for the firm is only 102 basis points.

Whereas the numerical example assumes that the bank and the comparable nonbank firm hold the same assets, banks generally do not hold the same assets as firms. In the Online Appendix, we show that the volatility of the assets held by the nonbank firms is much higher than the volatility of assets held by banks. If we increase the asset volatility from 5% to 30%, the tangible equity ratio of the firm is even higher. The association between low bank asset volatility and high bank leverage suggests that low volatility is part of the strategic choices by banks. As we point out earlier, if a bank optimizes its assets and liabilities simultaneously, the strategic liability structure should still maximize total bank value given any portfolio of assets.

3.2.2. Effects of Total Capital Requirement. The responses of bank liability structure to the changes in minimum total capital requirement are undoubtedly an important issue. Figure 1 provides an illustration of these effects. As we vary β from 0% to 25%, the deposit and nondeposit ratios respond in opposite ways. The deposit ratio does down from 45% to 33%, but the nondeposit debt ratio goes up from 46% to 51%. Overall, the tangible equity ratio rises from 8% to 15%. The reduction in leverage is smaller than the drop in the deposit ratio because of the increase in the nondeposit debt ratio. The reduction in the deposit ratio leads to a lower assessment rate, and the reduction in leverage leads to a smaller credit spread. Panel (b) of the figure shows the magnitude of these effects, which are predicted by Proposition 5.

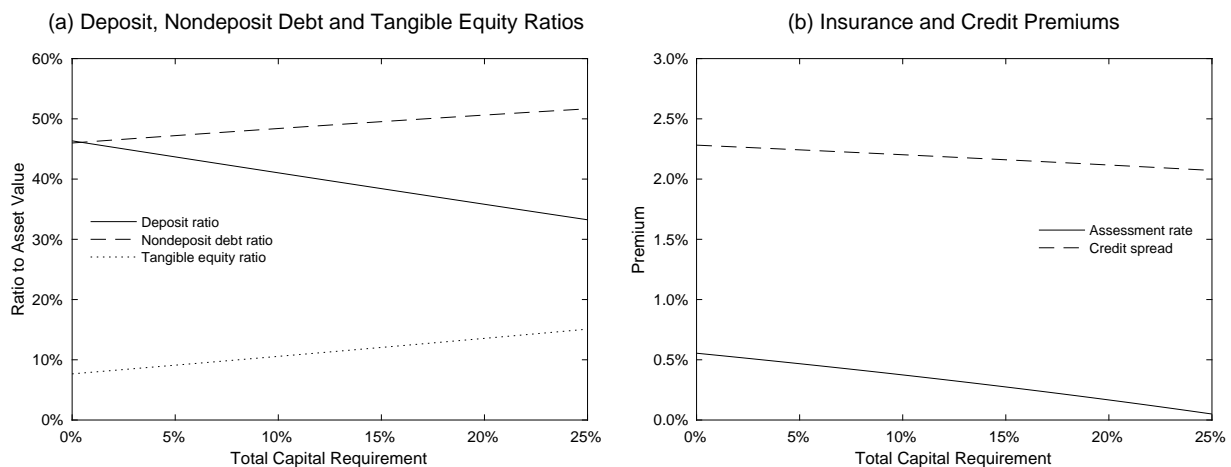
The positive effect on the nondeposit debt ratio deserves special attention. This is a result from setting the regulatory total capital boundary to be the same as

the endogenous default boundary. If the bank keeps its liability structure fixed, an increase in β pushes the regulatory total capital boundary above the endogenous default boundary. The bank needs to increase the non-deposit debt ratio to bring the endogenous default boundary up to the same level of the regulatory total capital boundary.

The regulatory boundary actually moves in the opposite direction of the total capital requirement. When β is higher, the drop in deposits is so large that it counteracts the direct effect of β on the regulatory total capital boundary. To understand the inverse relation between the total boundary and the capital requirement, we must not ignore the strategic response of the bank. Figure 2 illustrates how such a response complicates the relation. In the figure, we first optimize the liability structure of the bank for $\beta = 2\%$, and then, we let β change. If we do not strategically adjust the liability structure for β , the total capital boundary, $V_b/V = (D/V)/(1-\beta)$, should be an increasing function of β (shown as the dashed line in the figure) for the fixed D/V . However, when the strategic liability structure adjusts to the change in β , the relation between the total capital boundary and the capital requirement is completely different; the total capital boundary drops from 46% to 45% of the asset value as β moves up from 0% to 25%. The total capital boundary $V_b^*/V = (D^*/V)/(1-\beta)$ is a complicated function of β because the bank optimally reduces the deposit ratio D^*/V in response to the increase in β .

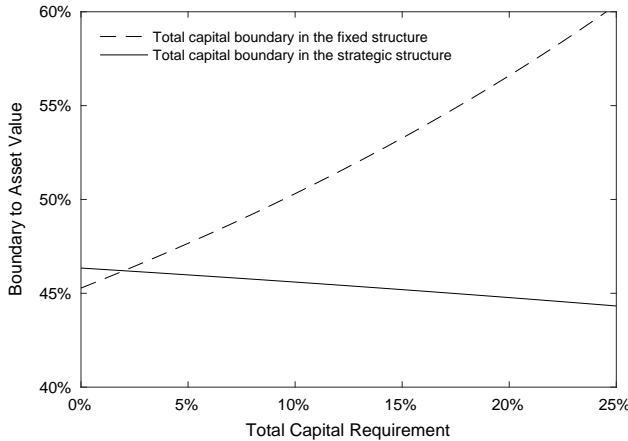
Empirically testing the effects of capital requirements on bank liability structure is a challenging task. Changes in bank capital requirements are endogenous because regulators increase the requirements usually when they perceive that banks have taken excessive risks. An empirical design needs to isolate the effects of capital

Figure 1. Effects of Total Capital Requirement on the Strategic Bank Liability Structure



Notes. When β varies, the other parameters are fixed at the values set in Table 2. In panel (a), the solid line is the ratio of deposits to assets, the dashed line is the ratio of nondeposit debt to assets, and the dotted line is the ratio of tangible equity to assets. In panel (b), the solid line is the assessment rate of deposit insurance, and the dashed line is the credit spread of nondeposit debt.

Figure 2. The Regulatory Total Capital Boundary of Bank Liability Structure



Notes. We first calculate the strategic liability structure for the parameters in Table 2. When we vary β in a range from 0% to 25%, we keep the liability structure fixed and plot the regulatory total capital boundary V_b/V for each value of β in the fixed liability structure. Then, we reoptimized for each changed β and plot the total capital boundary V_b/V in the reoptimized liability structure.

requirement changes from the effects of asset risk changes. Most empirical studies of capital requirements actually examine the effects on bank assets and credit portfolios (e.g., Aiyar et al. 2014, Jimenez et al. 2017, among others) instead of the effects on bank liability structure. An exception is the recent study by Passmore and Temesvary (2022), who empirically find that investors’ demand for safe assets causes a negative relationship between banks’ capitalization and short-term funding. This empirical finding mirrors the negative effect of capital requirement on deposit ratio in our model.

3.2.3. Effects of Deposit Profitability. Figure 3 illustrates the effects of deposit profitability. The leverage goes up

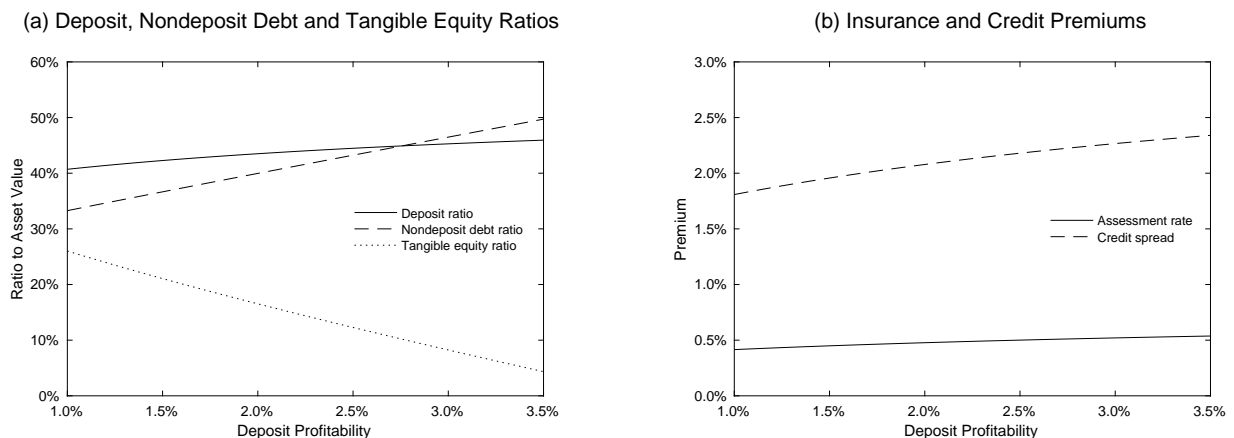
when deposits are more profitable. As η changes from 1% to 3.5%, the tangible equity ratio decreases from about 36% to less than 5% (dotted line in panel (a)). Both the deposit and nondeposit debt ratios go up. So an improvement in deposit profitability does not have a substitution effect between the deposit and nondeposit debt ratios. They both go up because a higher deposit ratio raises the regulatory total capital boundary, giving more room for nondeposit debt. Thus, the strategic liability structure has a higher nondeposit debt ratio as well as a higher deposit ratio if deposits are more profitable.

The effects of deposit profitability on bank leverage are similar to the idea of DeAngelo and Stulz (2015), who suggest that the profitability of deposits is responsible for banks’ high leverage. However, the deposits in their paper are uninsured. Nor do they incorporate regulatory capital requirements. Another distinction of our analysis from that of DeAngelo and Stulz (2015) is that their banks do not issue nondeposit debt.

As predicted by Proposition 6, panel (a) of Figure 3 shows that the nondeposit debt ratio rises faster than the deposit ratio. This is difficult to understand if we ignore the strategic combination of deposits and nondeposit debt.

Panel (b) of Figure 3 illustrates that both the assessment rate and credit spread have positive relations to deposit profitability. As we point out earlier, a U.S. bank regulation once prohibited banks from paying interest on deposits and limited bank competition for deposits. The belief was that making more profitable deposits would reduce bank failures. This belief ignores the strategic response of banks. Figure 3 shows that a bank’s strategic response to higher deposit profitability is to raise both the deposit and nondeposit debt ratios. This response raises the regulatory total capital boundary and leads to a higher assessment rate and wider

Figure 3. Effects of Deposit Profitability on the Strategic Bank Liability Structure



Notes. When η varies, the other parameters are fixed at the values set in Table 2. In panel (a), the solid line is the ratio of deposits to assets, the dashed line is the ratio of nondeposit debt to assets, and the dotted line is the ratio of tangible equity to assets. In panel (b), the solid line is the assessment rate of deposit insurance, and the dashed line is the credit spread of nondeposit debt.

credit spread. Also, note that the credit spread in the figure rises faster than the assessment rate as predicted by Proposition 6. These complicated consequences underscore the importance of banks' strategic choice of bankruptcy risk.

A bank's profitability of deposits reflects the bank's market power. Then, a higher value of η implies a greater market power for a bank in the deposits market as they can issue deposits at a lower cost. The second chain of Inequalities (10) and panel (b) of Figure 3 mean that a bank with more market power in the deposits market has a wider credit spread on nondeposit debt. The reason is that a bank uses far more deposits than nondeposit debt as shown in the first chain of inequalities of (10) and panel (a) of Figure 3. Then, each dollar of nondeposit debt shoulders more bankruptcy risk because deposits are stable, protected debt. Our theoretical finding that a bank with greater market power relies more on stable funding is supported by the empirical work of Li et al. (2019).

3.2.4. Effects of Insurance Subsidy. Figure 4 illustrates Proposition 7. We examine various sizes for subsidy, ranging from zero to 40%. When the deposit ratio goes up from 45% to 47%, the nondeposit debt ratio moves up from 46% to 47% (panel (a)). Not surprisingly, insurance subsidy encourages bank leverage, but the figure suggests that the effect of insurance subsidy on leverage is modest. As the subsidy increases from zero to 40%, the tangible equity ratio drops from about 9% to about 5%. It is worth noting that the tangible equity ratio is still lower than 10% even if the insurance subsidy is zero. This suggests that insurance subsidy is not a major factor in bank leverage. Panel (b) of Figure 4 shows that the bank credit spread goes up if the FDIC subsidizes the banks more in deposit insurance. This

nontrivial theoretical implication is counterintuitive if one does not distinguish nondeposit debt from deposits but understandable if we recognize the adjustment in liability structure.

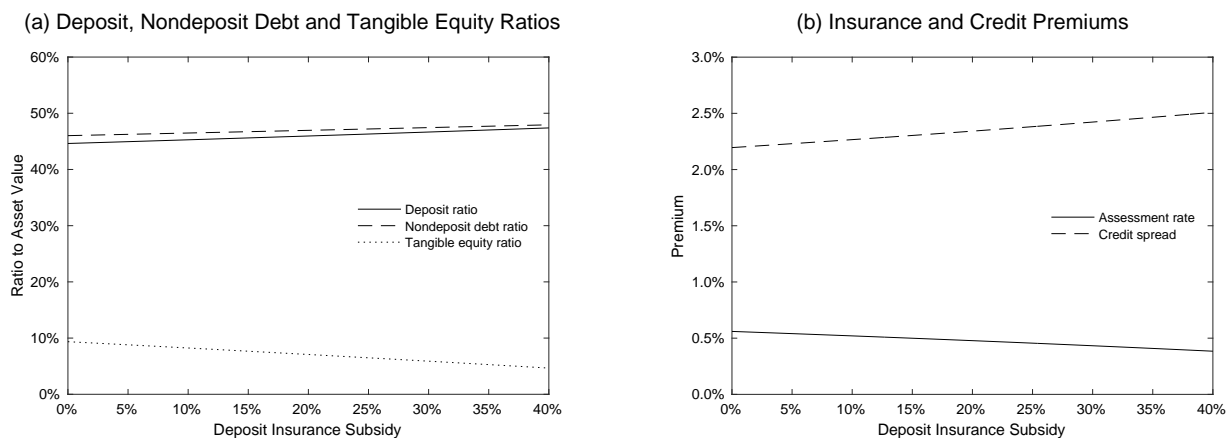
4. Dynamic Restructuring

In the analysis of bank liability structure, we have so far assumed that a bank chooses its liability structure only once and does not restructure later. In reality, banks adjust their liability structure over time. We extend our model to incorporate dynamic restructuring. In Section 4.1, we consider dynamic restructuring subject to a minimum requirement on the total capital that protects deposits, the same capital requirement examined in the previous sections. In Section 4.2, we add an additional capital requirement: the minimum tangible common equity requirement, which became more stringent after the 2008 global financial crisis. Our model of dynamic restructuring is along the lines of the Goldstein et al. (2001) model of capital structure of a nonbank firm but incorporates deposits and capital requirements.

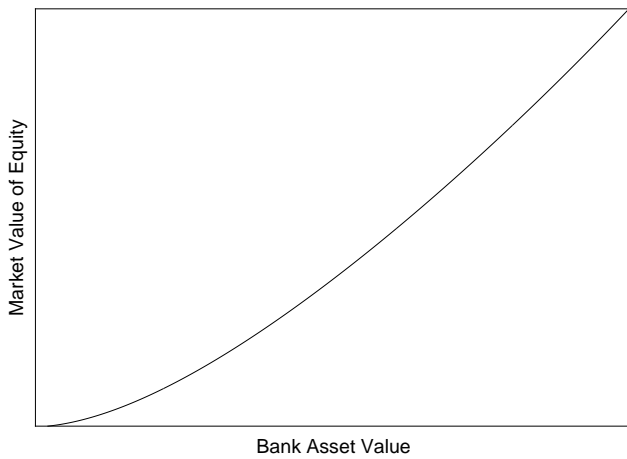
4.1. Restructuring Under Total Capital Requirements

We continue to assume that the bank asset value follows a geometric Brownian motion (1) as in Section 2.1, but we let the bank restructure its liabilities if the asset value is up by a factor of H_0 , where $H_0 > 1$. We refer to H_0 as the endogenous hurdle for restructuring. The time of first restructuring is $t_1^h = \inf \{t \geq 0 : V_t \geq H_0 V_0\}$. Let t_i^h be the time of the i^{th} restructuring; then, the time of next restructuring is $t_{i+1}^h = \inf \{t \geq t_i^h : V_t \geq H_i V_i\}$, where H_i is the new hurdle and V_i denotes the asset value at time t_i^h . The hurdles $\{H_i\}_{i=1,2,\dots}$ are part of the restructuring decision of the bank. This approach to model dynamic restructuring follows Goldstein et al. (2021).

Figure 4. Effects of Insurance Subsidy on the Strategic Bank Liability Structure



Notes. When ω varies, the other parameters are fixed at the values set in Table 2. In panel (a), the solid line is the ratio of deposits to assets, the dashed line is the ratio of nondeposit debt to assets, and the dotted line is the ratio of tangible equity to assets. In panel (b), the solid line is the assessment rate of deposit insurance, and the dashed line is the credit spread of nondeposit debt.

Figure 5. Incentive for Risk Substitution

Notes. We first calculate the strategic liability structure for asset value $V_0 = 100$. Under this liability structure, we plot the market value of equity for asset values deviating from V_0 . The parameters are $\eta = 0.03$, $\beta = 0.02$, $\omega = 0.1$, $\sigma = 0.09$, $\alpha = 0.27$, $\tau = 0.15$, $\delta = 8\%$, $r = 5\%$, and $\theta = 0.01$.

After each restructuring, the asset value may drop to a level that either causes the regulator to close the bank or causes the equity holders to default bank liabilities. Let D_i be the deposits at restructuring time t_i^h and D_0 be the deposits at $t = 0$. The regulatory total capital boundary is $V_{bi} = D_i/(1-\beta)$ for the period from the i^{th} restructuring to the next restructuring. The ratio of the boundary to the initial asset value during this restructuring period is

$$L_{bi} = \frac{V_{bi}}{V_i} = \frac{D_i/V_i}{1-\beta}. \quad (12)$$

The endogenous default boundary is discussed later in more detail. In general, suppose the bank is liquidated when the asset value reaches $L_i V_i$, where $L_i \in (0, 1)$, in the period following the i^{th} restructuring. Then, the liquidation time is $t_i^l = \inf\{t \in [t_i^h, t_{i+1}^h) : V_t \leq L_i V_i\}$. The liquidation cost is $\alpha L_i V_i$, where $L_i V_i$ is the asset value at liquidation.

At any restructuring time t_i^h , the risk-neutral probability (or state price) for asset value V_t to reach the hurdle of the next restructuring before liquidation can be shown to be

$$\pi_{hi} = \frac{H_i^\lambda}{1-(H_i/L_i)^{\lambda-\lambda'}} + \frac{H_i^{\lambda'}}{1-(L_i/H_i)^{\lambda-\lambda'}}. \quad (13)$$

In this formula, λ and λ' are, respectively, the positive and negative roots of equation $\sigma^2 \lambda(1+\lambda)/2 - (r-\delta)\lambda - r = 0$. The risk-neutral probability (or state price) for V_t to reach the liquidation boundary before the next restructuring can be shown to be

$$\pi_{li} = \frac{L_i^\lambda}{1-(L_i/H_i)^{\lambda-\lambda'}} + \frac{L_i^{\lambda'}}{1-(H_i/L_i)^{\lambda-\lambda'}}. \quad (14)$$

The derivation of these probabilities is similar to those in Goldstein et al. (2021).

Let D_i , B_i , and E_i be the deposits, nondeposit debt, and equity value, respectively, at the i^{th} restructuring time t_i^h , where $i = 1, 2, \dots$. We also allow $i = 0$ so that D_0 , B_0 , and E_0 are the deposits, nondeposit debt, and equity value at $t = 0$. Immediately after the i^{th} restructuring, the interests paid to depositors are $C_{D_i} = (r-\eta)D_i$. The coupon paid to nondeposit debt holders during the same time is $C_{B_i} = (r+s_i)B_i$, where s_i is the credit spread, which is endogenously determined along with the price of nondeposit debt in our model.

The bank chooses the threshold H_i to be above one when restructuring is costly. Recent literature examines the effects of committing to restructure at a threshold (see DeMarzo and He 2020) on the capital structure of nonbank firms. Benzoni et al. (2020) and Dangi and Zechner (2021) show that the effects are insignificant if there are costs for restructuring. In view of these studies, we follow Goldstein et al. (2021) to assume that there are costs for issuing nondeposit debt and taking deposits. The costs are $\theta_B B_i$ and $\theta_D D_i$, respectively, where $\theta_B \in (0, 1)$ and $\theta_D \in [0, 1)$. In general, we expect $\theta_D < \theta_B$, but our model works as well if $\theta_D \geq \theta_B$.

When a bank chooses its initial liability structure or restructures its liabilities, it maximizes the total value of the current bank shareholders. If the cost of issuing new debt is zero, the total bank value is $F_i = D_i + B_i + E_i$ as we assume in Section 2.3. Because the cost of issuing new debt is nonzero here, the total bank value is $F_i = (1-\theta_D)D_i + (1-\theta_B)B_i + E_i$. The choice variables of the bank in maximizing the initial value F_0 are the sequence of deposit liability $\{C_{D_i}\}_{i=0,1,\dots}$, nondeposit debt liability $\{C_{B_i}\}_{i=0,1,\dots}$, and the hurdles $\{H_i\}_{i=0,1,\dots}$ for restructuring.

In the model with dynamic restructuring, we preserve the assumption that the FDIC insurance premium is risk-based, which depends on deposits and the regulatory total capital boundary V_{bi} . Because deposits vary over time across the restructuring periods, the deposit insurance premium varies over time. The risk-based insurance assessment rate also changes. Let g_i be the assessment rate for the period from the i^{th} restructuring to the next restructuring. The risk-based insurance premium during this period is $I_i = g_i D_i$.

At each time of restructuring, the bank calls back the preexisting nondeposit debt. Therefore, the nondeposit debt issued from the i^{th} restructuring is valued as B_i at time t_{i+1}^h if the bank has not liquidated by then. If liquidation occurs before t_{i+1}^h , the nondeposit debt value at liquidation is the residual value after subtracting the deposits: $[(1-\alpha)L_i V_i - D_i]^+$. Given coupon C_{B_i} of nondeposit debt, we show in the Online Appendix that the value of nondeposit debt issued from the i^{th} restructuring is

$$B_i = \frac{C_{B_i}}{r} \cdot \frac{1-\pi_{hi}-\pi_{li}}{1-\pi_{hi}} + [(1-\alpha)L_i V_i - D_i]^+ \frac{\pi_{li}}{1-\pi_{hi}}. \quad (15)$$

The equity value at each restructuring time is the residual value beyond the preexisting deposits after calling

back the preexisting nondeposit debt. Therefore, the equity issued from the i^{th} restructuring is valued as $F_{i+1} - (D_i + B_i)$ at time t_{i+1}^h if the bank has not been liquidated by then. If liquidation occurs before t_{i+1}^h , the equity value is zero. In the Online Appendix, we show that the equity value issued from the i^{th} restructuring is

$$E_i = V_i - (1 - \tau) \frac{I_i + C_{D_i} + C_{B_i}}{r} (1 - \pi_{hi} - \pi_{li}) + [F_{i+1} - (D_i + B_i) - H_i V_i] \pi_{hi} - L_i V_i \pi_{li}. \quad (16)$$

These debt and equity values assume that the liquidation boundary $L_i V_i$ is given. The endogenous default boundary is the liquidation boundary that maximizes the equity value. We use V_{di} to denote the endogenous default boundary during $[t_i^h, t_{i+1}^h)$ and let $L_{di} = V_{di} / V_i$. Because the bank can be liquidated by either the shareholders or the regulator, the liquidation boundary during $[t_i^h, t_{i+1}^h)$ is $L_i V_i = \max\{V_{bi}, V_{di}\}$, where $L_i = \max\{L_{bi}, L_{di}\}$.

The pricing Equations (13)–(16) allow us to derive a closed-form formula of the total bank value of the shareholders:

$$\frac{F_i}{V_i} = \frac{1}{1 - H \pi_{hi}} \left\{ 1 + (1 - \theta_D - \pi_{hi}) \frac{D_i}{V_i} + (1 - \theta_B - \pi_{hi}) \frac{B_i}{V_i} - (1 - \tau)(1 - \pi_{hi} - \pi_{li}) \frac{I_i + C_{D_i} + C_{B_i}}{r V_i} - H_i \pi_{hi} - L_i \pi_{li} \right\}. \quad (17)$$

We provide the details of the formula in the Online Appendix. The bank maximizes the total value by choosing the sequence of $\{C_{D_i}, C_{B_i}, H_i\}_{i=0,1,2,\dots}$.

We can analytically show that the result of Proposition 1 continues to hold in the model with dynamic restructuring.

Proposition 8. *Suppose $\theta_B < \tau(1 - \pi_{hi})$. Bank shareholders can increase the total bank value by issuing more nondeposit debt if the current nondeposit debt ratio is so low such that the endogenous default boundary is lower than the regulatory total capital boundary. More precisely, the liability structure with $L_{di} < L_{bi}$ is suboptimal.*

This proposition again predicts that a strategic bank liability structure must hold at least some nondeposit debt so that the endogenous default boundary matches up with the regulatory boundary. That is, we must have $L_{di}^* \geq L_{bi}^*$ in a strategic bank liability structure. The condition $\theta_B < \tau(1 - \pi_{hi})$ means that the cost of issuing new nondeposit debt should not be so big that it wipes out the expected value of the debt benefit. Obviously, if the cost is too big, issuing new debt may not increase the total bank value. We derive the proposition in the Online Appendix.

It is tedious to show that $L_{di}^* = L_{bi}^*$ analytically given the complexity of the model of dynamic restructuring. We find this property always holds in our numerical solutions of the strategic liability structure. We numerically solve the dynamic optimization problem for the bank. Table 3 shows the strategic liability structure at time zero for a set of parameters similar to those we have used earlier. In addition, we need to set the value of θ_D and θ_B , the costs of taking new deposits and issuing new nondeposit debt. We choose $\theta_D = 0.005$ and $\theta_B = 0.01$ for illustration. The restructuring hurdle H_i is an endogenous variable determined by optimization. For the purpose of comparison, the table also presents the numerical solution of the strategic liability structure without dynamic restructuring for the same parameters.

An important result in Table 3 is the equality of default and regulatory boundaries relative to the initial asset value: $L_{d0}^* = L_{b0}^* = 42.01\%$. It confirms that the salient feature of matching boundaries derived from the simpler model in Section 2 remains when the model incorporates dynamic restructuring. The boundary for the bank with restructuring is lower than the boundary for the bank without restructuring. So, restructuring delays bankruptcy.

Goldstein et al. (2021) find that a nonbank firm that restructures dynamically issues less debt at the beginning time because it has the flexibility to issue more later. This is not necessarily true for the nondeposit debt in banks. A new finding unique to our model is

Table 3. Strategic Bank Liability Structure Under Total Capital Requirement

Endogenous variable		With dynamic restructuring	No dynamic restructuring
Ratio of deposit to assets	D_0^*/V_0	41.17	42.61
Ratio of nondeposit debt to assets	B_0^*/V_0	46.23	45.18
Ratio of tangible equity to assets	T_0^*/V_0	12.59	12.22
Credit spread of nondeposit debt	s_0^*	2.69	2.64
Assessment rate of deposit insurance	g_0^*	0.57	0.61
Hurdle for restructuring	H_0^*	114.66	
Total capital boundary/assets	L_{b0}^*	42.01	43.48
Endogenous default boundary/assets	L_{d0}^*	42.01	43.48

Notes. The values for the endogenous variables are reported in percentage points. The exogenous parameters are $\eta = 0.03$, $\beta = 0.02$, $\omega = 0.1$, $\sigma = 0.09$, $\alpha = 0.27$, $\tau = 0.15$, $\delta = 8\%$, $r = 5\%$, $\theta_D = 0.005$, and $\theta_B = 0.01$. The first column of numbers is for the bank with dynamic restructuring, and the last column is for the bank that does not restructure.

that restructuring causes a bank to have a higher non-deposit debt ratio. The nondeposit debt ratio is 46.23% in the bank with restructuring in contrast to 45.18% in the bank without restructuring. The reason is that the bank has the flexibility to reduce the deposit ratio. The overall leverage is lower for the bank with dynamic restructuring. In Table 3, the tangible equity ratio is 12.59% in the bank with restructuring in contrast to 12.22% with no restructuring.

The differential effects of restructuring on deposits and nondeposit debt would be missed if we did not distinguish deposits from nondeposit debt. The differential effects are important for understanding the higher credit spread and the lower deposit insurance assessment rate in banks that dynamically restructure their liabilities.

The numerical solutions in Table 3 demonstrate that dynamic restructuring does not qualitatively change the results we presented in Sections 2 and 3. The quantitative difference between the two columns in the table is rather small. Although the quantitative difference depends on the parameters, the qualitative properties are similar.

We show earlier that the strategic liability structure without restructuring always has the incentive for risk substitution. Dynamic restructuring does not change this property of the strategic liability structure. Once the bank sets its liability structure strategically, the market value of equity is an increasing, convex function of the asset value. Figure 5 shows the market value of equity as a function of asset value around the initial value $V_0 = 100$. We choose the liability structure in the figure to be optimal for $V_0 = 100$, but we keep it same when the asset value V deviates from V_0 . The figure clearly shows that the curve of the market equity value is increasing and convex.

4.2. Restructuring Under Tangible Equity Requirements

An important capital regulation in Basel II and III requires banks to maintain a minimum tangible common equity relative to its assets. Tangible equity is also referred to as tier-1 capital, which excludes the “goodwill value” derived from the continuing operation of the bank. The capital requirement is a minimum ratio of tangible equity to bank assets. This ratio is also referred to as a tier-1 ratio. In this section, we add this type of capital requirement as an additional capital requirement.

The tangible equity of a bank is the value of equity that the shareholder receives in the event of an immediate bank liquidation. In our model, the tangible equity at time t is $T_t = V_t - D_t - B_t$. This excludes the value of future profits earned from serving deposits and from holding debt. The ratio of tangible equity to assets, T_t/V_t , measures the bank’s ability to absorb losses. It is used by regulators to determine whether the bank is solvent.

Regulations require banks to maintain a tangible equity ratio above a specified level. Let $\gamma \in (0, 1)$ be the required minimum tangible equity ratio for the bank.

After the i^{th} restructuring, the time for the tangible ratio to reach the minimum ratio γ is $t_i^c = \inf \{t \geq t_i : T_t \leq \gamma V_t\}$. Because $T_t \leq \gamma V_t$ is equivalent to $V_t \leq (D_i + B_t)/(1 - \gamma)$, the time to hit the minimum ratio is $t_i^c = \inf \{t \geq t_i : V_t \leq (D_i + B_t)/(1 - \gamma)\}$. Let $V_{ci} = V_{t_i^c}$. We refer to it as the regulatory tangible equity boundary, which is another regulatory boundary, to distinguish it from the regulatory boundary V_{bi} imposed by the total capital requirement. The ratio of the tangible equity boundary to assets is $L_{ci} = V_{ci}/V_i$. Because nondeposit debt value is nonnegative, it is obvious that $V_{ci} \geq V_{bi}$.

Similar to the previous section, let π_{hi} be the risk-neutral probability (state price) that the next restructuring happens before the tangible equity ratio drops to γ . Let π_{li} be the risk-neutral probability that the tangible equity ratio drops to γ before the next restructuring.

The values of debt and equity have similar formulae as in the previous section except that the lower boundary in the valuation formulas is $L_i = \max\{L_{bi}, L_{ci}, L_{di}\}$. Notice that L_{ci} endogenously depends on the value of nondeposit debt. If the bank issues more nondeposit debt, the tangible boundary tends to be higher.

We can show that a liability structure with $L_{di} < L_{ci}$ is suboptimal, but we use a numerical solution to show that we actually have $L_{di} = L_{ci}$ in a strategic liability structure. Table 4 presents the numerical solution to the strategic liability structure for a set of parameters similar to the previous illustrations. The new parameter in this table is the tangible equity ratio γ . We choose $\gamma = 4.5\%$, $\gamma = 7\%$, and $\gamma = 9.5\%$ because, in Basel III, the basic ratio is 4.5%, the countercyclical capital buffer is 2.5%, and the capital surcharge on systemically important banks is an additional 2.5%. The basic tangible equity ratio and countercyclical buffer add up to the 7% tangible equity ratio requirement for all banks. With the capital surcharge, systemically important banks face the tangible equity ratio requirement of at least 9.5%. To show the effects of the minimum tangible equity ratio requirement, in the table we also include the numerical results for the bank without tangible equity ratio requirements.

The first important observation from Table 4 is that the endogenous default boundary and tangible equity boundary are always exactly same in each strategic liability structure. They are both 41.76% if the minimum tangible equity ratio is 4.5%. For a higher minimum tangible equity ratio, the two boundaries are lower, appearing counterintuitive. This is similar to what we observe earlier in the effects of the total capital requirement: if the regulator raises the required capital ratio, the optimal adjustment of bank liability structure lowers the default boundary. We also note that a higher tangible equity requirement leads to a lower credit spread for

Table 4. Dynamic Strategic Bank Liability Structure Under Tangible Equity Requirement

Endogenous variable		Minimum tangible equity ratio, γ			
		NA	4.5%	7.0%	9.5%
Ratio of deposit to assets	D_0^*/V_0	41.17	39.81	38.42	37.01
Ratio of nondeposit debt to assets	B_0^*/V_0	46.23	46.67	47.06	47.41
Ratio of tangible equity to assets	T_0^*/V_0	12.59	13.52	14.52	15.58
Credit spread of nondeposit debt	s_0^*	2.69	2.65	2.60	2.54
Assessment rate of deposit insurance	g_0^*	0.57	0.53	0.50	0.47
Hurdle for restructuring	H_0^*	114.66	115.03	115.38	115.73
Endogenous default boundary/assets	L_{d0}^*	42.01	41.69	41.31	40.89
Tangible equity boundary/assets	L_{c0}^*		41.69	41.31	40.89
Total capital boundary/assets	L_{b0}^*	42.01	40.62	39.26	37.76

Notes. The values for the endogenous variables are reported in percentage points. The exogenous parameters are $\eta = 0.03, \beta = 0.02, \omega = 0.1, \sigma = 0.09, \alpha = 0.27, \tau = 0.15, \delta = 8\%, r = 5\%, \theta_D = 0.005, \text{ and } \theta_B = 0.01$. The last three columns of numbers are for the bank with the alternative minimum tangible equity ratio requirements, and the first column is for the bank without such requirements.

nondeposit debt, which might explain the increased use of nondeposit debt with a higher tangible equity requirement.

As expected, the tangible equity ratio in the strategic liability structure is higher if the minimum tangible equity ratio is higher. It is not surprising that a bank reduces its overall leverage in response to a raise in the tangible equity requirement. However, Table 4 shows a nontrivial consequence: the nondeposit debt ratio is higher if the minimum tangible equity ratio is higher. A bank reduces the overall leverage by cutting the deposit ratio instead of the nondeposit debt ratio. This may not be a desired consequence because banks are supposed to provide financial intermediation by serving deposits. This consequence is overlooked if we ignore the strategic allocation between deposits and nondeposit debt.

4.3. Distinctions from Other Models with Dynamic Restructuring

Following Goldstein et al. (2021), a large body of corporate finance literature uses corporate capital structure models with dynamic restructuring. This literature focuses on the choice of corporate debt and equity. Our model extends the model of Goldstein et al. (2021) by considering the optimal combination of deposits and nondeposit debt in addition to equity. The distinction between deposits and nondeposit debt in the liability structure is particularly relevant for banks as opposed to nonbank corporate entities. The dynamic optimization problem is also subject to capital requirements, which are imposed on all depository institutions. The problem to optimize the mix of deposits with other debt subject to capital requirements is unique to banks and more complex than the model of Goldstein et al. (2021) for nonbank firms as we show.

Subramanian and Yang (2020) (SY) introduce a model of bank capital structure with dynamic restructuring, but our model with dynamic restructuring bears important distinctions from SY’s model. The most important distinction is that the banks in our model allocate

liabilities optimally between deposits and nondeposit debt. By contrast, SY’s model assumes that bank liabilities are fixed, exogenously given combinations of deposits and debt. The endogenous choice between deposits and nondeposit debt is ignored. SY’s model examines the optimal choice only between debt and equity as in the model of Goldstein et al. (2021). The distinction between deposits and nondeposit debt is central to modeling bank liability structure as serving deposits is unique to banks. This distinction allows us to discover the differential responses of deposit and nondeposit ratios to changes of capital requirements.

In their valuation of bank debt, Subramanian and Yang (2020), in fact, treat the entire bank debt as nondeposit debt. They assume that all debt holders become equity holders when the bank is in financial distress as is made clear in the formulation of boundary conditions in their equation (12). This is clearly not how deposits are treated upon financial distress: depositors enjoy priority relative to nondeposit creditors and should be paid back first as much as possible. Assuming the entire debt to become equity is equivalent to assuming the entire debt to be nondeposit debt. In this sense, their valuation model is a model of a nonbank firm. However, they interpret their debt malleably. When they examine the effect of deposit insurance, they assume that the bank debt contains an exogenously fixed proportion of deposits. This approach abstracts from the differential effects of regulation on deposits and nondeposit debt.

Another important distinction of our model is that capital regulations are constraints under which banks make capital decisions. In reality, capital regulations are specified as minimum capital ratios that restrict bank capital decisions, but the decisions are made by the private owners of the banks. The thrust of our model is to derive the endogenous composition of deposits and nondeposit debt under the constraints imposed by bank regulations. The composition of deposits and nondeposit debt and the minimum capital ratios are the issues that

are unique to banks. Subramanian and Yang (2020) consider the role of regulators in directly choosing bank liability structure to maximize some social objective function. We abstract from this consideration.

5. Conclusion

We provide a framework for characterizing the strategic bank liability structure. Such a framework can be useful in understanding the responses of banks to changes in regulation. A regulation typically attempts to solve a problem in some part of bank liability structure or asset structure (see Santos 2001). Arguments for a proposed change in regulation often implicitly assume that the other parts remain unchanged after the regulatory change, ignoring the endogenous responses of banks that strategically adjust other parts of their liability structure. The approach developed in our model is useful for evaluation of regulatory changes because it takes into account banks' strategic responses.

We show that banks respond to capital requirements by strategically choosing their liability structure, taking into account deposit insurance. The value maximization principle implies that a bank acts in the interest of its claim holders. Our focus on value maximization sets aside the principal-agent problems, such as management's conflict of interests with some stake holders although these problems may play roles in banks' choices of liability structures (Admati et al. 2018). Value-maximizing banks do not maximize social welfare, such as reducing systemic risks or expanding banking services for the economy. Whereas social welfare implications of bank liability structure are unquestionably important, a good understanding of banks' strategic choice of liability structure is a necessary step for a proper social welfare analysis of bank capital regulations. Moreover, a general equilibrium treatment is essential to properly understand the welfare implications.

Assuming that banks set their liability structure only once, we provide a closed-form solution of the strategic bank liability structure that explicitly incorporates an array of factors important for banks. The special factors for banks are capital requirements, deposit profitability, and deposit insurance. These factors are absent in the classic models of nonbank (corporate) capital structure. We then extend the analysis to banks that dynamically restructure their liabilities.

We discover a salient feature of the strategic bank liability structure. A value-maximizing bank uses as much nondeposit debt as possible to take advantage of debt benefits but not so much to offer extra protection for the deposit insurer. This choice makes the risk of bankruptcy optimal for equity holders. Our comparative static analysis shows that this salient feature is a key element in understanding how various factors affect a bank's liability structure as well as its credit

risk. This salient feature has important implications to bank regulation and the principal-agent problems in banks. Although regulators can set the capital requirement high enough, given any liability structure, to remove the incentives for risk substitution, the strategic liability structure always preserves the incentives for risk substitution.

A direct, careful, empirical test of our model is the recent study by Gambacorta et al. (2021), who provide empirical evidence that banks strategically adjust liability structure in response to changes in government tax policy as predicted by our model. Recall that the tax advantage of leverage is a factor of bank liability structure in our model, and the tax effects presented by Gambacorta et al. (2021) lend a strong empirical support to our model. Direct empirical evidence of the model's predictions on the effects of other factors (especially regulations) should be interesting future research.

Our model of strategic bank liability structure provides tools for studying additional issues in banking. An important component in bank capital structure is bank's liquidity reserves. Hugonnier and Morellec (2017) use our model to examine the liquidity reserve in banks. Our model is also suitable for studying the effects of tax policy changes on banks. Our model can also be applied to examine the roles of contingent capital, bail-in debt, and bailout in bank strategic choices of capital structures. Berger et al. (2019) and Lambrecht and Tse (2020) are such applications. Using our framework, Vissers (2020) explores the effects of jumps in asset value.

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Endnotes

¹ In the United States, the Dodd–Frank Act of 2010 brought sweeping regulatory reforms ranging from deposit insurance to equity capital adequacy. Worldwide, bank regulators agreed on Basel III in 2011 to control the risks in bank liabilities.

² Whereas Admati and Hellwig (2013) argue for lowering bank leverage to a level similar to the leverage of nonfinancial firms, Tarullo (2013) argues that holding nondeposit debt can improve the safety and resolution of banks, consistent with some academic papers (e.g., Flannery and Sorescu 1996). However, some scholars opine the opposite (e.g., Gorton and Santomero 1990).

³ Basel III raises the capital requirement for all banks and imposes additional requirements for large banks that are regarded as systemically important. Both European and U.S. regulators have laid out new capital requirements for banks in accordance with Basel III.

⁴ The main advantage of debt financing is the benefit of tax deductibility of interest costs. This benefit is especially important for banks because of their high leverage. Debt financing can also have other advantages, such as the benefit to control ownership and to retain profits.

⁵ In an earlier version of the paper, we also present a model in which deposits are uninsured and depositors can run. In that model, a bank is closed when depositors run at a threshold of asset value.

⁶ The Banking Act of 1933, known as the Glass–Steagall Act, prohibits banks from paying interest on demand deposits and authorizes the Federal Reserve to impose ceilings on interest paid on time deposits. The restrictions on deposit interests were removed by the Depository Institutions Deregulation and Monetary Control Act of 1980 and the Depository Institutions Act of 1983, the latter of which is the Garn–St. Germain Act.

⁷ The Dodd–Frank Act requires the FDIC to reform its deposit insurance policy, reducing or eliminating the deposit insurance subsidy, because the subsidy may incentivize banks to use leverage. See Federal Deposit Insurance Corporation (2011).

⁸ In Section 4.3, we provide a detailed discussion of the difference between our model and that of Subramanian and Yang (2020).

⁹ The International Association of Deposit Insurers (IADI), formed on May 6, 2002, works to enhance the effectiveness of deposit insurance systems by promoting guidance and international cooperation. At the end of 2014, the IADI represented 79 deposit insurers from 76 countries and areas.

¹⁰ Also following Leland (1994), we assume that V is the after-tax value of assets, and thus, δV is the after-tax cash flow. Alternatively, one may start the model with the before-tax value of the assets as in Goldstein et al. (2021).

¹¹ Leland (1994, p. 1234) explains this well: “An alternative contractual arrangement approximating this case would be a continuously renewable line of credit, in which the borrowing amount and interest rate are fixed at inception. At each instant the debt will be extended (rolled over at a fixed interest rate) if and only if the firm has sufficient asset value to repay the loan’s principal; otherwise bankruptcy occurs. Thus the roll-over process proxies for a positive net-worth requirement. With this latter interpretation, the differences between the unprotected debt and protected debt analyzed *may capture many of the differences between long-term debt and (rolled over) short-term financing.*”

¹² It is useful to point out that the tangible equity of a bank can be negative in both theory and practice. For example, the U.S. operation of Deutsche Bank reported a total asset value of \$355 billion and negative \$5.68 billion tier 1 capital in its December 2011 filing as a bank holding company.

¹³ However, some recent proposed changes in tax law (IRC Section 162(r)) intend to phase out the deductibility of insurance premiums paid by large bank holding companies with at least \$50 billion assets. We can adjust our model to reduce or exclude tax deductibility of the deposit insurance premium, but we assume that deposit insurance premiums are deductible, consistent with the current tax law for typical commercial banks.

¹⁴ The FDIC categorizes a bank as critically undercapitalized when the total capital drops to 2% of its asset value. The total capital includes nondeposit debt that protects deposits. For a review of the rules about categorizing banks as critically undercapitalized, we refer readers to Shibut et al. (2003). The capital requirement in our model mirrors the policy of the FDIC.

¹⁵ The cost of liquidation by the FDIC may be different from the costs of liquidation through bankruptcy courts. Because the FDIC does not go through the lengthy procedure of bankruptcy, there is a belief that the FDIC liquidation cost is smaller than the typical bankruptcy cost in the private sector. Title II of the Dodd–Frank Act reflects the belief as it authorizes the FDIC to receive and liquidate failed large financial institutions to avoid lengthy and costly bankruptcy procedures.

¹⁶ There have long been concerns that banks switch deposits to nondeposit debt temporarily at quarter ends to lower the deposits on bank books. To deter such switches, the Dodd–Frank Act (Section 331) requires the FDIC to modify the assessment base as the difference between the risk-weighted assets and the tangible equity.

¹⁷ For more details, see Federal Deposit Insurance Corporation (2011). Garnett et al. (2020) provides a history of risk-based premiums at the FDIC.

¹⁸ They also suggest that a lower premium may be necessary to compensate banks for the costs of reporting requirements and following regulations.

¹⁹ A large literature on bank loans pays attention to the incentives for risk substitution. For example, Gorton and Kahn (2000) consider these incentives in the design of bank loans.

²⁰ Proposition 3 does not imply that capital requirements lead to higher or lower incentives for risk shifting. The proposition only states that the incentives for risk shifting are preserved instead of being removed if banks use the strategic liability structure. Because asset risk is fixed, our model does not speak about the effects of capital requirements on credit portfolios, which are the subject in most empirical studies of capital requirements (for examples, see Aiyar et al. 2014, Jimenez et al. 2017). A theory related to this issue is perhaps in the model of Della Seta et al. (2020), which shows that short-term debt may engender greater risk-taking propensity.

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