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Financing as a Supply Chain: The Capital Structure of Banks and Borrowers☆

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Abstract

We develop a model of the joint capital structure decisions of banks and their borrowers. Bank leverage of 85% or higher emerges because bank seniority both dramatically reduces bank asset volatility and incentivizes risk-taking by producing a skewed return distribution. Nonfinancial firms choose low leverage to protect their banks, presenting a partial resolution to the low-leverage puzzle. Our setup naturally extends to include government actions as we model bank assets using a modified Basel framework. Deposit insurance and bailout expectations lead banks and borrowers to take on more risk. Capital regulation lowers bank leverage but can increase bank risk due to a compensating increase in borrower leverage. Despite this, doubling current capital requirements reduces bank default risk by up to 90%, with only a small increase in loan interest rates.

Keywords: banking, capital structure, capital regulation, seniority, diversification

JEL Classification: G2, G18, G21, G28, G32, G38

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1. Introduction

In the wake of the recent financial crisis, there have been repeated calls from academics, practitioners, and policy makers to tighten the regulation of financial institutions and force banks to hold more equity capital. Business leaders have responded that leverage is a natural part of banking and that limiting it will inhibit credit access and impede economic growth.[1] This paper builds a quantitative model of banking that explains bank capital structure decisions and sheds light on fundamental questions about the nature of banking.

There is disagreement on the causes and effects of high bank leverage; however, there is no disagreement that banks and other financial institutions are indeed highly indebted. The average leverage of US banks, measured as the ratio of debt to assets, has been in the range of 87%–95% over the past 80 years.[2] At the same time, the average leverage of public US nonfinancials, measured in the same way, has been in the range of 20%–30% over a long period. This dramatic difference in financial structure between banks and nonfinancial corporations is puzzling. Further, the leverage of nonfinancials is in itself substantially less than most corporate finance models predict, giving rise to a large literature on the so-called low leverage puzzle.[3]

In this paper, we explain both the dramatic difference in financial structure and the low leverage of nonfinancials by modeling the interaction between a bank's debt decisions and the debt decisions of that bank's borrowers. Our framework blends the Vasicek (2002) model of bank portfolio risk, as used in the Basel regulatory framework, with standard capital structure models. Because our framework is built on commonly calibrated models, it naturally lends itself to quantitative analysis. The interaction between banks and borrowers explains the high leverage

[1]The Bank of England's recent attempts to tighten capital regulation led it to be described as the "capital Taliban" by a member of parliament who argued stronger regulation would starve businesses of loans. For the full story, refer to the Financial Times article available at http://www.ft.com/cms/s/0/a6367d06-f377-11e2-942f-00144feabdc0.html.

[2]Authors' estimates are based on historical Federal Deposit Insurance Corporation data, which are publicly available at http://www2.fdic.gov/hsob/HSOBRpt.asp.

[3]For example, see Goldstein, Ju and Leland (2001), Morellec (2004), and Strebulaev (2007).

of banks and the low leverage of firms. In our base case, banks opt for leverage of 85%, while firms choose leverage of only 29%, both close to real-world values. We also find that mechanisms that explain the gap are central to our understanding of how financial institutions work.

High bank leverage is feasible because bank assets are an order of magnitude less volatile than the assets of their borrowers. Even when lending to firms with asset volatility of 40%, the bank has asset volatility of only 2.6%. This result is very general. Even for conservative parameters, we find the volatility of a pool of bank loans is at least seven times lower than the volatility of the assets that back those loans. We show that this dramatic risk reduction is driven primarily by banks' status as senior creditors. This status effectively enables them to carry high debt without correspondingly high solvency risk. Seniority also makes the bank's return distribution more skewed. This increases the chance of bank failure, as it reduces the effectiveness of bank equity at preventing default which leads banks to seek less protection.

While low asset volatility allows banks to pursue high leverage with relative safety, our supply chain mechanisms compel them to do so. Banks provide financing to other agents but in doing so they incur their own financing costs. High bank leverage reduces these costs and in so doing allows debt benefits to be more effectively transported down this financing supply chain. The essence of the supply chain effects is that debt benefits originate only at the bank level. This is driven by a fundamental asymmetry between final users of financing (downstream borrowers) and those that act as intermediaries passing financing along (upstream borrowers). Even if the downstream borrowers have extremely low leverage, upstream borrowers—banks—still lever up, generate debt benefits, and pass those benefits downstream. However, if the upstream borrowers have similarly low leverage, no benefits are generated that can be passed along and, as a result, the downstream borrowers also pursue low leverage.

Beyond its effect on bank leverage, this financing supply chain leads to strategic interaction between bank and borrower debt decisions: bank leverage and firm leverage can act as both strategic substitutes and strategic complements. The strategic substitution effect arises because of bank distress costs. Imagine a scenario where banks are very highly levered and thus are less capable of weathering losses during economic downturns. If financial distress is costly, competitive banks pass this cost on to their borrowers. The borrowers respond by taking on less debt, effectively shielding banks by making their loan portfolio safer. In the opposite scenario, where banks have low leverage, these systemic risk costs are lessened, and bank borrowers take on more debt.

The strategic complementarity effect arises from the link between the benefits of debt for banks and those for borrowers. Banks pass their own debt benefits, such as tax benefits, downstream to their borrowers by charging lower loan interest rates. In a competitive banking environment, banks that use equity financing are competed out of business by more levered banks that can offer lower interest rates. A bank's borrowers get their own benefits from debt, but by paying interest to the bank, they decrease the bank's debt benefits unless the bank's debt is correspondingly increased.

Our supply chain effects are general enough to apply to many of the other bank financing frictions identified in the literature. We use the tax benefits and bankruptcy costs framework of Kraus and Litzenberger (1973).[4] However, the risk reduction and supply chain mechanisms we identify are much more general and play a similar role in the presence of other incentives to issue debt to our other classes of borrowers. Bank leverage remains high under models where banks are compensated for providing liquidity (e.g., DeAngelo and Stulz, 2015) or where debt and equity are discounted differently (e.g., Baker and Wurgler, 2015). These alternative debt benefits are also passed down the financing supply chain.

Because our framework is built on commonly calibrated models, it naturally lends itself to quantitative analysis. Regulators, academics, and policy makers can use our framework to analyze the impact of deposit insurance, bailouts, and capital regulation. Importantly, our model focuses

[4]This framework has been used extensively in the finance literature. See, for example, Leland, Harding et al. (2007), Hackbarth et al. (2007), or Hackbarth and Mauer (2012).

on a single bank and does not consider issues such as contagion or fire sales of assets. Therefore, our model speaks to micro-prudential regulation, rather than macro-prudential regulation.

We find that both deposit insurance and bailout expectations lead to moral hazard and increased bank leverage. These effects are highly nonlinear—a moderate amount of insured deposits (below 91% of bank liabilities) or bailouts with low probability (below 68%) has minimal impact on bank risk-taking, but larger interventions can induce dramatic gambling strategies.

Effective capital regulation reduces the moral hazard banks face, but ineffective capital regulation has its own hazards. Capital regulation that fails to take into account borrower risk can cause banks to lend to riskier borrowers due to the substitution effect, and it can lead to higher rates of nonbank defaults. The standardized approach of Basel II and III suffers from this flaw, which significantly reduces the effectiveness of these regulations. Deposit insurance, bailouts, or other subsidies to failed banks make these effects particularly pronounced. Stronger capital regulation or appropriately risk-weighted capital regulation is effective at preventing these effects, but can still be subject to gaming. For example, banks that can manipulate loan characteristics will dramatically and inefficiently increase their risk in response to moral hazard. This suggests that current capital regulation can be inadequate to the extent that banks can manipulate between-exposure correlation or other loan parameters.

Current capital regulation standards may be insufficiently strong and insufficiently targeted. For example, we find that doubling the equity requirements of Basel II—increasing equity capital requirements to 16% for the Basel standardized approach and doubling the equity requirements of the Basel internal ratings-based approach—lowers the bank failure rate by as much as 93%. Each percentage point of bank equity increases the cost of credit by 0.46 basis points, a low number that suggests such additional capital regulation may be warranted. The Basel Committee on Banking Supervision (2010) and Elliott, Salloy and Santos (2012) have dramatically higher estimates that range from 0.28% to 0.66%. We find dramatically lower costs because we allow for endogenous bank return on equity. This means the incremental frictions imposed by capital requirements are small.

Better targeted capital regulation, where the banks subject to the most extreme moral hazard face the toughest restrictions, is more effective. Basel III moves toward this by imposing additional requirements on systemically important financial institutions. Capital regulation that goes farther and imposes higher equity requirements on banks with high levels of insured deposits can improve efficiency. Even when subject to Basel-style capital regulation, banks with insured deposits constituting more than 86% of their liabilities can have an incentive to gamble. Many banks have such high levels of insured deposits, and without strong capital regulation those banks may have an incentive to undertake risky behavior.

Tax benefits alone make it privately optimal for banks to take on high levels of debt. However, tax benefits to debt are a transfer and do not obviously create value. Our results suggest that equalizing the tax treatment of debt and equity would reduce systemic risk and make the financial system less prone to crises. Such equalization provides a simple alternative to complex financial regulation.

Our analysis yields a number of empirical predictions. For example, due to the strategic substitution effect, bank-dependent firms in our model choose dramatically less leverage (29%) than firms which can borrow from an intermediary with no frictions (54%). Along the same lines, borrowers that are more correlated with systematic risk will pay higher interest rates than borrowers with the same risk and less systematic risk. A bank subject to deposit insurance or bailouts can have the opposite supply chain effects, subsidizing systematically risky loans. A government guarantee of the bank's debt that occurs with 75% probability leads the bank to misprice risk and results in borrower leverage increasing to 66%. Capital regulation can combat this; however, capital regulation with crude risk-weightings leads banks to make riskier loans to the highest risk borrowers within any given risk weight.

A variety of mechanisms justify bank existence, and many of those could be incorporated into our framework. We build upon a venerable banking literature (see Thakor, 2014 for a comprehensive review, including influential early contributions, such as Diamond and Dybvig, 1983). Acharya et al. (2012), Acharya, Mehran and Thakor (2015), Allen, Carletti and Marquez (2015), DeAngelo and Stulz (2015), Diamond and Rajan (2000), Shleifer and Vishny (2010), Sundaresan and Wang (2016), and Della Seta, Morellec and Zucchi (2015) investigate bank optimal capital structures. The efficacy and design of bank regulation have been recently examined by Admati et al. (2013a), Admati et al. (2013b), Bulow and Klemperer (2013), Hanson, Kashyap and Stein (2011), Harris, Opp and Opp (2015), and Hugonnier and Morellec (2017). Bruno and Shin (2015) explore the transmission of financial conditions across borders by also utilizing a Vasicek-style model. A number of recent empirical studies, including Berger and Bouwman (2013), Berger et al. (2008), Bhattacharya and Purnanandam (2011), Kisin and Manela (2016), Schandlbauer (2017), and Schepens (2016) have enriched our understanding of banking.

The rest of the paper is structured as follows. In Section 2, we develop a supply chain model of bank and firm financing. In Section 3, we discuss our parameter assumptions. In Section 4, we present the quantitative results on bank and firm leverage. In Section 5, we consider firms that borrows using bonds in addition to bank loans. In Section 6, we analyze the impact of deposit insurance. In Section 7, we extend our analysis to bailouts, capital regulation, other debt benefits, bank bargaining power, and bond markets. Concluding remarks are given in Section 8.

2. A supply chain model of financing

In this section, we blend a structural model of bank portfolio returns with the trade-off theory of capital structure. Section 2.1 outlines a model of bank capital structure using the Vasicek (2002) framework, which applies a Merton (1974) style intuition to bank portfolios by assuming they are composed of loans secured by correlated lognormally distributed assets. Section 2.2 sets up a model of a firm that is subject to trade-off frictions and issues Merton (1974) style debt. Section 2.3 links the bank with the firm to derive a unified model of the financing supply chain.

The Vasicek model we use for bank assets underlies the internal ratings-based (IRB) approach to capital regulation, as set out by the Basel Committee on Banking Supervision (BCBS) in Basel II and Basel III.[5] This means our model of capital structure decision-making can be readily applied to the existing capital regulation framework. The IRB framework of Basel II concentrates on solvency defaults. In our model, solvency and liquidity defaults are treated identically because all debt matures on the same date.

Banks hold a variety of assets, and we develop two different approaches to address this. Section 2.1 details a model of bank capital structure where the bank lends to borrowers with fixed leverage. Sections 2.2 and 2.3 make the borrowers' capital structures endogenous. We use the first approach to model mortgage loans and the second approach to model loans to corporate borrowers. Together, these models allow us to explore the capital structure decisions of a bank that lends only to firms, only through mortgages, or to both households and firms.

2.1. Capital structure of banks

We model bank solvency risk by considering a portfolio of bank loans. These loans could be residential mortgages or loans to firms, encompassing the two most important assets on most bank balance sheets. Each loan i is collateralized by an asset that pays a one-off cash flow of A^i at the loan's time-T maturity. The value of this cash flow is lognormally distributed with

$$\log A^i \sim N\left(-\frac{1}{2}T\sigma^2, T\sigma^2\right), \tag{1}$$

where $N(\mu, \sigma^2)$ denotes the normal distribution with mean μ and standard deviation σ. This specification has the property that $\mathbb{E}\left[A^i\right] = 1$.

[5]See paragraph 272 of Basel Committee on Banking Supervision (2004) and paragraph 2.102 of Basel Committee on Banking Supervision (2013), respectively.

Each loan has a promised repayment of R_A due at time T. The time-T asset value A^i determines whether the loan is repaid or defaults. If A^i is greater than some threshold C_A, the loan does not default, and the bank receives a full repayment of R_A. (In Section 2.2, default thresholds and debt repayments are derived from firm capital structure decisions.) If the asset value is low, $A^i < C_A$, the borrower defaults, and ownership of the collateral passes to the bank. The bank recovers $(1-\alpha_A)A^i$, where α_A is the proportional bankruptcy cost incurred on defaulted bank loans.

Taking the default and repayment cases together, the bank's payoff from any loan i, B^i, is given by

$$B^i = R_A \mathbb{I}\left[A^i \geq C_A\right] + (1-\alpha_A)A^i \mathbb{I}\left[A^i < C_A\right], \tag{2}$$

where $\mathbb{I}[\cdot]$ is the indicator function.

A bank's portfolio consists of n identically structured loans. The assets that underlie these loans are exposed both to a common systematic shock and to loan-specific idiosyncratic shocks. We can write the time-T value of loan i's collateral in terms of these shocks:

$$\log A^i = \sqrt{\rho T}\sigma Y + \sqrt{(1-\rho)T}\sigma Z^i - \frac{1}{2}T\sigma^2, \tag{3}$$

where Y is the systematic shock, and Z^i is a loan-specific idiosyncratic shock, with the shock random variables $Y, Z^1, Z^2, \ldots, Z^n$ being standard normal and jointly independent.

The bank's portfolio value per loan, B, is the average of the payoffs (2) from each of the bank's loans:[6]

$$B = \frac{1}{n}\sum_{i=1}^{n} B^i = \frac{1}{n}\sum_{i=1}^{n}\left(R_A \mathbb{I}\left[A^i \geq C_A\right] + (1-\alpha_A)A^i \mathbb{I}\left[A^i < C_A\right]\right). \tag{4}$$

[6]We model loan recoveries directly from collateral value, which enables us to price debt consistently. This differs from most applications of the Vasicek (2002) model, which take recovery in default as fixed and model only the portion of loans that default.

If the bank's loan portfolio is composed of many small loans, the idiosyncratic shocks to each loan are diversified away and the only variation that matters is the systematic shock, which can cause multiple borrowers to default at once. Taking $n \to \infty$, so that the bank's portfolio is perfectly fine-grained, we get $B \to \mathbb{E}\left[B^i|Y\right]$ almost surely from the strong law of large numbers.[7]

For a bank with many small loans, portfolio value becomes a function of Y, the aggregate shock:

$$\begin{aligned} B &= \mathbb{E}\left[B^i|Y\right] = R_A \mathbb{P}\left[A^i \geq C_A|Y\right] + (1-\alpha_A)\mathbb{E}\left[A^i \mathbb{I}\left[A^i < C_A\right]|Y\right] \\ &= R_A \Phi\left(\frac{-\log C_A - \frac{1}{2}T\sigma^2 + \sqrt{\rho T}\sigma Y}{\sqrt{(1-\rho)T}\sigma}\right) \\ &\quad + (1-\alpha_A)e^{\sqrt{\rho T}\sigma Y - \frac{1}{2}\rho T\sigma^2}\,\Phi\left(\frac{\log C_A - (\frac{1}{2}-\rho)T\sigma^2 - \sqrt{\rho T}\sigma Y}{\sqrt{(1-\rho)T}\sigma}\right), \end{aligned} \tag{5}$$

where Φ is the cumulative distribution function of the standard normal. Here and elsewhere, we consider a bank with many small loans and write the bank-level cash flows and values on a per-loan basis so that they are scaled by $1/n$.

Models of capital regulation, including those based on the Vasicek (2002) framework, typically assume the exogenous existence of bank capital. In reality, banks make capital structure decisions in response to capital regulation and financial frictions. We focus on corporate tax and distress cost frictions. Importantly, we abstract from other financing frictions, such as equity issuance costs. Our model could be extended to consider these frictions by following the analysis of Hugonnier and Morellec (2017).

A bank with an accounting profit owes corporate income tax. If the bank does not issue debt, it pays tax on the repayments it receives, B, less the cost of its portfolio, which we denote V_{AD}. The

[7] As $\mathbb{E}\left[B^i|Y\right] - B^i$ is zero mean, bounded, and pairwise uncorrelated, a law of large numbers (e.g., Theorem 4.80 in Modica and Poggiolini, 2012) ensures $\frac{1}{n}\sum_i^n \left(\mathbb{E}\left[B^i|Y\right] - B^i\right)$ converges to zero almost surely.

bank pays corporate income tax at rate τ on this taxable income,[8] for an unlevered cash flow of

$$B - \tau \max\{0, B - V_{AD}\}. \tag{6}$$

The bank can reduce this tax obligation by issuing debt and deducting the interest on that debt from its taxable income. Banks are assumed to have access to competitive debt markets, and the bank's debt is thus fairly priced. As in the Merton (1974) model, we assume that the bank's debt is zero coupon. Let V_{BD} denote the price of the bank's debt and R_B denote the amount the bank must pay to its creditors at time T. The bank's interest obligation is then $R_B - V_{BD}$, and it can use this interest payment to reduce its tax bill for an after-tax cash flow of

$$B - \tau \max\big\{0, \underbrace{B - V_{AD}}_{\text{Tax base}} - \underbrace{(R_B - V_{BD})}_{\text{Tax benefit}}\big\}. \tag{7}$$

Debt introduces the possibility of financial distress. The bank defaults if its after-tax cash flow is less than the amount the bank owes its creditors so that the bank's payoff to equity holders would be negative if default did not occur. We can write the bank's default condition as

$$B - \tau \max\{0, B - V_{AD} - (R_B - V_{BD})\} < R_B. \tag{8}$$

Because $V_{AD} > V_{BD}$, this condition simplifies to

$$B < R_B. \tag{9}$$

The bank defaults if, and only if, its portfolio value at time T is below the amount it owes its creditors. Ownership of a defaulting bank passes to its creditors (ignoring for now the possibility

[8]Here, the bank pays tax on profit but does not get a tax rebate from losses. A tax system where the bank partially or fully recovered taxes from losses could easily be introduced into this model and would produce similar results.

of government intervention). These creditors recover $(1-\alpha_B)B$, the bank's portfolio value less the proportional bankruptcy costs of α_B.

Discounting the resulting cash flows to time zero, the bank's equity value, V_{BE}, and debt value, V_{BD}, are given by

$$V_{BE} = e^{-Tr_f}\mathbb{E}\left[\left(B - \tau\max\left\{0, B - V_{AD} - R_B + V_{BD}\right\} - R_B\right)\mathbb{I}\left[B \geq R_B\right]\right] \tag{10}$$

and

$$V_{BD} = e^{-Tr_f}\mathbb{E}\left[R_B\mathbb{I}\left[B \geq R_B\right] + (1-\alpha_B)B\mathbb{I}\left[B < R_B\right]\right]. \tag{11}$$

The bank's total value is the sum of the values of the debt and equity claims. We can express that value as the expectation of the bank's unlevered value, plus the tax benefit of the banks debt (limited to the bank's tax bill), minus the bank's bankruptcy costs:

$$\begin{aligned} V_B &= V_{BD} + V_{BE} \qquad (12)\\ &= e^{-Tr_f}\mathbb{E}\Bigg[\underbrace{B - \tau\max\left\{0, B - V_{AD}\right\}}_{\text{Unlevered value}} + \underbrace{\tau\max\left\{\min\left\{R_B - V_{BD}, B - V_{AD}\right\}, 0\right\}}_{\text{Tax shield}} - \underbrace{\alpha_B B\mathbb{I}\left[B < R_B\right]}_{\text{Bankruptcy costs}}\Bigg]. \end{aligned}$$

This value, V_B, can be maximized by promising an appropriate repayment, R_B. As in a standard trade-off model, higher repayments increase default costs, and lower repayments increase tax costs.

2.2. Capital structure of nonfinancial firms

We model the capital structure decisions of nonfinancial firms by adding firm-level tax and bankruptcy costs to the Merton (1974) model of risky corporate debt.[9] This allows us to endogenize the loan variables that we took as exogenous in the previous section.

[9]The Merton model, which is the foundation of the contingent claims framework, underlies modeling of corporate financial decisions and pricing of default-risky assets (e.g., Leland, 1994).

Consider a single firm that balances the tax benefit of debt against the cost of financial distress. This firm has a single, time-T, pre-tax cash flow F^i with

$$\log F^i \sim N\left(-\frac{1}{2}T\sigma^2, T\sigma^2\right). \tag{13}$$

The firm pays corporate income tax at a linear rate τ on its cash flow for a tax burden of τF^i. To reduce that tax burden, the firm can issue zero-coupon debt with face value R_F, maturity T, and price V_{FD}. For now, assume that the firm's debt is priced by competitive, risk-neutral investors without financing frictions. (In Section 2.3, the firm's interest rate will be tied to the bank's financing costs.) As with the bank, the firm's interest payment reduces its tax liability. The firm pays $R_F - V_{FD}$ in interest at time T, and so the firm's equity holders realize a tax benefit of $\tau(R_F - V_{FD})$ against any tax owed by the firm.

Under these assumptions, the firm's time-T after-tax cash flow is

$$F^i - \tau \max\left\{0, F^i - (R_F - V_{FD})\right\}. \tag{14}$$

The firm defaults if this cash flow is less than the firm's debt obligations, i.e.,

$$F^i - \tau \max\left\{0, F^i - (R_F - V_{FD})\right\} < R_F. \tag{15}$$

As $R_F > V_{FD}$, the firm's default condition can be simplified to

$$F^i < C_F = R_F + \frac{\tau}{1-\tau}V_{FD}, \tag{16}$$

where C_F is the firm's default threshold. In default, the firm's value is impaired by proportional bankruptcy costs of α_F, so that the firm's creditors receive $(1-\alpha_F)(1-\tau)F^i$.[10] Discounting

[10] A defaulting firm does not pay interest and so cannot deduct it; therefore, the firm's creditors get a cash flow of $(1-\alpha_F)F^i$ less tax costs of $\tau(1-\alpha_F)F^i$.

the expectation of these cash flows, the firm's time-zero equity and debt values are

$$V_{FE} = e^{-Tr_f}\mathbb{E}\left[\left(F^i - \tau \max\left\{0, F^i - R_F + V_{FD}\right\} - R_F\right)\mathbb{I}\left[F^i \geq C_F\right]\right] \tag{17}$$

and

$$V_{FD} = e^{-Tr_f}\mathbb{E}\left[R_F\mathbb{I}\left[F^i \geq C_F\right] + (1-\tau)(1-\alpha_F)F^i\mathbb{I}\left[F^i < C_F\right]\right]. \tag{18}$$

The firm's initial value, V_F, is the sum of the values of the debt and equity claims:

$$V_F = V_{FE} + V_{FD} = e^{-Tr_f}\mathbb{E}\big[\underbrace{1-\tau}_{\text{Unlevered value}} + \underbrace{\tau\left(R_F - V_{FD}\right)\mathbb{I}\left[F^i \geq C_F\right]}_{\text{Tax shield}} - \underbrace{\alpha_F(1-\tau)F^i\mathbb{I}\left[F^i < C_F\right]}_{\text{Bankruptcy costs}}\big]. \tag{19}$$

A firm subject to these financing frictions chooses a promised repayment, R_F, that maximizes the firm's time-zero value. Because firms and banks face the same distress and tax frictions, our expressions for the firm's value, in Eq. (19), and bank's value, in Eq. (12), have very similar forms.[11]

2.3. Joint capital structure decision of firms and banks

This section develops a model of the joint capital structure decisions of banks and firms by linking the model of bank financing in Section 2.1 with the model of firm financing in Section 2.2. By endogenizing the capital structure of both banks and firms simultaneously, we derive a plethora of interesting results. For simplicity, we assume that firms can raise financing only by issuing equity and borrowing from banks. While a reasonable assumption for small- and medium-sized firms, this is less realistic for large firms that can choose between debt markets and banks. In Section 5, we extend the model to include firms with access to debt markets.

[11]The slight structural difference between expressions (12) and (19) arises because banks deduct their loan costs from their taxable income, while firms lack a similar deduction. Enriching our model by allowing firms to deduct investment costs from their taxes does not change the model's results.

Suppose the bank in Section 2.1 lends to a large number n of firms, where each firm is as described in Section 2.2, and all firms pursue identical financing policy. Each firm i uses its future cash flow F^i as collateral to borrow V_{FD} from the bank with an agreed repayment of R_F, with these variables replacing A^i, V_{AD}, and R_A, respectively, in the bank's loan equation. The bank's recovery on a defaulted loan, formerly $(1-\alpha_A)A^i$, is replaced by the firm's creditor's recovery in bankruptcy, $(1-\alpha_F)(1-\tau)F^i$. Therefore, the bank's loan payoff expression (2) becomes

$$B^i = R_F \mathbb{I}\left[F^i \geq C_F\right] + (1-\alpha_F)(1-\tau)F^i \mathbb{I}\left[F^i < C_F\right], \tag{20}$$

with the other bank value equations being similarly adjusted.

For now, we focus on a competitive bank. A competitive bank passes everything it raises with equity and debt issuance to its borrowers. For example, consider two banks in Bertrand competition who each choose a single contract to offer to all of the identical firms. If either bank did not pass all of its value to borrowers, the other bank could undercut it by offering a contract the firm preferred that earned positive economic profit.

In this competitive banking system, the bank sets loan proceeds to equal the amount by which the loan increases the bank's value. Given that the bank makes loans to n identical firms, the total amount disbursed across the n loans is equal to the amount the bank raises in debt and equity:

$$nV_{FD} = nV_B = nV_{BE} + nV_{BD}, \tag{21}$$

and each firm's loan proceeds are equal to its marginal contribution to the bank's value:

$$V_{FD} = V_{BE} + V_{BD}. \tag{22}$$

Thus, the total value of a firm at date zero is the sum of the value of the firm's equity, Eq. (17), and the value the firm's loan contributes to the bank, Eq. (12):

$$V_F = e^{-Tr_f}\mathbb{E}\Bigg[\underbrace{1-\tau}_{\text{Unlevered value}} - \underbrace{\alpha_F(1-\tau)F^i\mathbb{I}\left[F^i < C_F\right]}_{\text{Firm bankruptcy costs}} - \underbrace{\alpha_B B\mathbb{I}\left[B < R_B\right]}_{\text{Bank bankruptcy costs}} + \underbrace{\tau\left(R_F - V_{FD}\right)\mathbb{I}\left[F^i \geq C_F\right]}_{\text{Firm tax shield}} - \underbrace{\tau \max\left\{0, B - V_{FD} - R_B + V_{BD}\right\}}_{\text{Bank tax costs and tax shield}}\Bigg]. \tag{23}$$

A competitive bank chooses a capital structure that maximizes the value it delivers to its borrowers. In equilibrium, both the bank's debt repayment, R_B, and the firm's debt repayment, R_F, are set to maximize firm value. Thus, combined value is impacted by both bank and firm financing frictions. Any financing frictions the firm creates for the bank reduce the bank's surplus and thus the amount a competitive bank can pay to the firm.[12]

2.4. Supply chain effects

A financing "supply chain" arises because when households and firms borrow from banks, those banks, in turn, must borrow from debt markets. Both firms and banks get tax benefits from debt.[13] The consequences of this interest tax shield for nonfinancial firms have been recognized and explored by generations of corporate finance models. However, banks that receive interest payments from firms must pay corporate tax on that interest.

To illustrate the economic intuition behind the supply chain mechanism, consider two examples, both featuring a bank lending to a single firm. First, consider a firm borrowing from an all-equity bank, with $R_B = V_{BD} = 0$. Eq. (23) is simplified by the removal of the bank's

[12]Section 7 shows that giving the bank bargaining power increases bank tax costs and increases bank leverage.

[13]Households get a tax benefit from mortgage interest in many countries, including the United States. The intuition in this section also applies to such a mortgage interest tax deduction.

bankruptcy costs and interest tax shield:

$$V_F = e^{-Tr_f}\mathbb{E}\left[1-\tau-\alpha_F(1-\tau)F^i\mathbb{I}\left[F^i<C_F\right]+\tau\left(R_F-V_{FD}\right)\mathbb{I}\left[F^i\geq C_F\right]-\tau\max\left\{0,B^i-V_{FD}\right\}\right]$$
$$= e^{-Tr_f}\mathbb{E}\left[\underbrace{1-\tau}_{\text{Unlevered value}}-\underbrace{\alpha_F(1-\tau)F^i\mathbb{I}\left[F^i<C_F\right]}_{\text{Firm bankruptcy costs}}-\underbrace{\tau\max\left\{0,(1-\alpha_F)F^i-V_{FD}\right\}\mathbb{I}\left[F^i\geq C_F\right]}_{\text{Tax bank pays on defaulted loan (if any)}}\right]. \tag{24}$$

There are three terms here. First, we have the unlevered firm value. Second, the firm's bankruptcy costs are subtracted off. Third, the taxes an all equity bank pays on defaulted loans are subtracted off as well, because of the tax loss provisions.[14] Importantly, the interest-tax shield created by the firm's borrowing has disappeared.

Effectively, firm interest payments constitute bank taxable income, and thus a firm's increased interest deduction is a bank's increased taxable income. Because these effects cancel each other, the *only* real tax savings come from the bank's interest tax shield. This effect ensures that the firm's value with any level of debt borrowed from an all-equity bank is always lower than the firm's unlevered value.

At the other extreme, consider an all-debt bank with $R_B = R_F$ and $V_{BD} = V_B = V_{FD}$, again lending to a single firm. Under these values, the bank's tax shield cancels out the bank's tax cost, and the bank tax term disappears dropped from Eq. (23):

$$V_F = e^{-Tr_f}\mathbb{E}\Bigg[\underbrace{1-\tau}_{\text{Unlevered value}}-\underbrace{\alpha_F(1-\tau)F^i\mathbb{I}\left[F^i<C_F\right]}_{\text{Firm bankruptcy costs}}-\underbrace{\alpha_B B\mathbb{I}\left[B<R_B\right]}_{\text{Bank bankruptcy costs}}$$
$$+\underbrace{\tau\left(R_F-V_{FD}\right)\mathbb{I}\left[F^i\geq C_F\right]}_{\text{Firm tax shield}}\Bigg]. \tag{25}$$

[14]This term exists because the bank faces a tax obligation for these loans, but the offsetting firm tax shield is lost in bankruptcy. For normal parameter values, the bank loses money on all defaulted loans, and so this term cancels out.

Because the bank has no tax costs, every dollar of the firm's tax shield is creating real value for shareholders. If we ignore bank-level bankruptcy costs, we have a perfect pass through of debt benefits.

The observation that debt benefits originate only at the bank level is driven by a fundamental asymmetry between final users of financing (downstream borrowers) and those that act as intermediaries passing financing along (upstream borrowers). Even if the downstream borrowers—firms—have extremely low leverage, it is still optimal for the upstream borrowers—banks—to lever up, generate debt benefits, and pass those benefits downstream. However, if the upstream banks had low leverage, no benefits are generated for them to pass along and, as a result, the downstream firms do not lever up.

This supply chain mechanism is fundamentally similar to the impact of personal tax on corporate debt tax benefits. In models such as Miller (1977) or DeAngelo and Masulis (1980), firms get tax benefits from debt, but issuing debt causes a firm's investors to pay higher personal tax. In the supply chain model, a firm's debt issuance increases the corporate tax of the bank holding that debt. In both types of model, downstream borrowers cannot capture the full tax benefits of debt because of the tax costs debt imposes on upstream debt holders. The supply chain intuition also shows that, while traditional models of capital structure (as well as contingent-claim models of credit risk) do not specify the identity of debt buyers, they cannot be banks or similar institutions, as these institutions would impose their own financing frictions. The same logic holds for a firm with a supplier that acts as a trade creditor.

3. Benchmark parameter values

Our framework is a combination of the Vasicek (2002) model used by bank regulators and the trade-off model used in the corporate finance literature. These are both widely used and commonly calibrated models, thus we can readily quantify our results.

We model a bank as having three types of asset: (1) residential mortgages, (2) corporate debt, and (3) risk-free assets, such as government bonds or cash. Based on Federal Deposit Insurance Corporation (FDIC) data, our benchmark case is a bank whose assets are 60% residential mortgages, 20% corporate debt, and 20% risk-free government securities. This simplified model excludes many bank assets, such as retail exposure, commercial real estate, and farmland loans. However, the framework can easily include any other asset class as well as be applied to a specific bank. Our goal here is not to exactly match bank assets; rather, it is to explore the capital structure of a plausible bank.

The bank offers competitive prices to each class of borrower. Specifically, we assume that the bank earns the risk-free rate on its risk-free assets, prices mortgages so that it breaks even on the combined portfolio of risk-free assets and mortgages, and prices loans to firms so that it breaks even on its entire portfolio.[15] Different allocations of financing costs or profit lead to only slightly different results, and the intuition from Section 2 continues to hold.

3.1. Benchmark parameter values for firms

Our benchmark parameter values for corporate debt are based on empirically motivated proxies. Because many parameters of interest are challenging to estimate with good precision, we conduct extensive comparative statics exercises. For the reader's convenience, Table 2 summarizes the assumption laid out in this section.

We set the benchmark value of our firm asset correlation parameter, ρ_F, to 0.2.[16] This is similar to the values assumed by regulators. The Basel II (and Basel III) IRB approach sets its loan-specific correlation parameter, $\hat{\rho}$, to between 0.12 and 0.24 based on the following formula:

$$\hat{\rho} = 0.12\,\frac{1-e^{-50PD}}{1-e^{-50}} + 0.24\,\left(1-\frac{1-e^{-50PD}}{1-e^{-50}}\right), \tag{26}$$

[15]This means that firms borrowing money internalize the impact their choices have on bank capital structure. This is consistent with a model where banks can freely enter into the business of lending only risk-free borrowers, lending proportionally to mortgages and risk-free borrowers, or lending to all three lines of business.

[16]We use the subscripts F and A to denote parameters related to firms and residential mortgages, respectively.

where PD is the loan default probability (see paragraph 272 of BCBS (2004) for more details).[17] Our value of 0.2 is also similar to the values estimated by Lopez (2004), who uses KMV software to derive values ranging from 0.1 to 0.3 based on firm size. However, the finance literature lacks a consensus on the appropriate value for this parameter. For example, Dietsch and Petey (2004) find asset correlations in the range of 0.01–0.03 for small- and medium-sized enterprises in Europe.

We set annual firm asset volatility, σ_F, to 0.4, a value broadly consistent with empirical estimates. Annualizing the figures from Choi and Richardson (2016) gives volatilities in the 0.25–0.65 range, varying with firm leverage. Schaefer and Strebulaev (2008) find asset volatility to be on the order of 0.2–0.28 for large bond issuers. While public corporate debt typically has a maturity of 7–15 years at origination, bank debt is of shorter duration. For example, the loans studied by Roberts and Sufi (2009) have an average time to maturity of 4 years, and the BCBS (2002) prescribes a time to maturity of 2.5 years (see paragraph 279). To be consistent with our later treatment of mortgages, we assume a time to maturity, T, of five years. Time to maturity is important primarily because of its impact on total volatility, $\sigma\sqrt{T}$, and so by using a longer time to maturity we are increasing the volatility of loan collateral. This will tend to reduce both bank and firm leverage. We perform additional robustness checks using $T = 2.5$. We also set the risk-free rate, r_f, to 0.025.

Following estimates suggesting that the effective tax rate US companies pay is less than the statutory federal corporate tax rate of 0.35, we use a value of 0.25. For example, Graham and Tucker (2006) show that the average S&P 500 firm paid less than 18 cents of tax per dollar of profit in each year between 2002 and 2004 (see also Graham, 1996, 2000). Djankov et al. (2010) show similar rates apply globally. We set firm distress costs, α_F, at 0.1. This assumption is likely conservative. Some recent estimates, such as Davydenko, Strebulaev and Zhao (2012), find that, conditional on experiencing distress, large firms incur sizable total distress costs of 20%–30% of asset value at the time of distress onset. In a theoretical work, Glover (2016) suggests

[17] The regulatory correlation is subject to a downward adjustment of up to 0.04 for loans to small firms.

that distress costs may be even higher. There is little empirical evidence on bank bankruptcy costs. James (1991) and Bennett and Unal (2015) find direct bank bankruptcy costs equal to 8%–10% of assets and total losses on assets in default of 16%–30%. We set bank distress costs, α_B, to 0.2 which generates an empirically reasonable loss on assets in default of 25%. Because distress costs are an important driver in our model, we conduct extensive robustness tests with respect to these parameters.

3.2. Benchmark parameter values for mortgage loans

The most popular form of mortgage loan in the US is a 30-year, fixed rate mortgage with a loan-to-value ratio at origination of about 80% (e.g., Bokhari, Torous and Wheaton, 2013). This type of mortgage features equal monthly payments and a gradually amortizing loan principal. Such a loan could go into delinquency or default at any time up to its maturity, or it could be refinanced at the borrower's choice. Default and refinancing decisions depend not only on the value of the underlying house but also on interest rates and the borrower's personal situation.

These complications make modeling mortgages notoriously difficult. We therefore abstract from them and study the "skeleton" of mortgages using the model in Section 2.1. Our goal is to provide a simple account of how holding mortgages affects bank capital structure decisions and the consequences of those decisions. Our model could be extended to a fuller mortgage risk model such as that of Campbell and Cocco (2015). Below, we summarize not only our parameter assumptions but also the extent to which these assumptions likely need to be modified in a more realistic mortgage model.

We model mortgages as five-year term loans. Although mortgages typically have much longer maturities, we use $T = 5$ because empirical evidence suggests that mortgage defaults peak in the first five years, and there is no refinancing risk for banks under the assumption of constant interest rates (e.g. Westerback et al., 2011 and Fig. 1.8 of International Monetary Fund, 2008). Our benchmark case uses an 80% of loan-to-value ratio at origination, which maps to a repayment of $R_A = 0.8e^{-Tr_f}$. Our model assumes that the full principal is to be repaid at maturity. In practice, amortization reduces the principal outstanding and leads to seasoned, older mortgages with lower loan-to-value ratios making up a significant portion of a bank's portfolio. Excluding the run-up to the recent financial crisis, the average loan to value of outstanding mortgages is normally closer to 60% (e.g., Bullard, 2012). The seasoning effect would make bank mortgage portfolios less risky than in our model, as seasoned mortgages have better risk characteristics.

We assume that a firm defaults strategically and reneges on its debt whenever its value is below the promised repayment. A household, on the other hand, is more likely to default for liquidity rather than strategic reasons. Empirically, the majority of underwater homeowners do not default, even if they are deep underwater (e.g., Fig. 3 of Krainer and LeRoy, 2010 or Amromin and Paulson, 2010). At the same time, some households default even though they have positive equity in the house. We approximate this behavior by assuming half of all the mortgages that are underwater at maturity default and other mortgages do not. The cost of foreclosure, α_A, is assumed to be 0.25. This matches empirical studies such as the one by Qi and Yang (2009) who find an average loss of 25% for defaulting mortgages, where the house value is equal to the mortgage debt.

We use $\sigma_A = 0.25$ for house price volatility. This is in line with Zhou and Haurin (2010) who find volatility ranging from 13%–25%. The Basel regulation contains no guidance on house price volatility. We assume that the correlation between the price movements of different houses in a bank's mortgage portfolio is $\rho_A = 0.2$.[18] The Basel regulation assigns a lower value of 0.15. We use a higher value of 0.2 to match the recent US experience of higher correlation (e.g., Cotter et al., 2011). To see how these assumptions perform over the long run, it is useful to conduct a long-term volatility exercise. Our values of $\sigma_A = 0.25$ and $\rho_A = 0.2$ produce a five-year index volatility of 25%, which is close to the 21% five-year volatility of Case-Shiller index.

[18]Like the Basel IRB framework, our analysis implicitly uses a single factor model. This means that house prices comove with firm asset values as both are exposed to the bank risk factor. Our framework can be easily extended to include multiple factors.

A 2008-style housing crisis with a 40% five-year house price decline occurs approximately once per century under our model, which again matches the Case-Shiller index.

Beyond the characteristics of mortgage loans, it is important to comment on how banks hold mortgages. Guarantees and securitization are defining features of the US mortgage market. More than half of US mortgages are guaranteed by government-sponsored enterprises, such as Fannie Mae or Freddie Mac, or by government agencies, such as the Federal Housing Administration or the Department of Veterans Affairs (e.g., Congressional Budget Office, 2010). The majority of these guaranteed mortgages, along with many mortgages that lack such guarantees, are then packaged into mortgage-backed securities and sold. If the bank takes the securitized or guaranteed mortgages off its balance sheet, the model needs no adjustment. If these structures remain on a bank's balance sheet, they can alter that bank's risk. Guarantees can dramatically reduce bank risk as the credit risk is borne by the guarantor. Securitizations can reduce or concentrate risk, depending on their structure and the risk the bank chooses to retain. Our model assumes that the bank retains no interest in any securitizations and no guaranteed assets; however, the model could be extended to cover a richer case.

4. Quantitative analysis of bank and borrower capital structure

Highly levered banks arise from most plausible parameter variations. Table 3 shows the capital structure and default risk implications of our model for a variety of parameter values. The first two columns consider a firm borrowing from a bank and show the firm market leverage ratio, $V_{FD}/(V_{FE}+V_{FD})$, and the associated annual firm default probability. The next two columns show the capital structure and default rate of the bank, where the bank's market leverage ratio is given by $V_{BD}/(V_{BE}+V_{BD})$.[19] For comparison, the final two columns show the capital structure and default probability of a firm that issues bonds in the public market and does not borrow from the bank.

[19] A competitive bank has equal book and market values for both bank equity and bank assets.

Two results immediately stand out. First, bank leverage is very high indeed. Our benchmark case yields banks with 85% leverage, a value that would be extremely high for a nonfinancial firm (indeed, a nonfinancial firm with such leverage would almost automatically be regarded as in distress) but in line with the empirical evidence on the capital structure of financial firms. For example, FDIC data show that the average book leverage of banks has been 87%–95% for the past 80 years.[20] Furthermore, all of the parameter variations in Table 3 produce high bank leverage. As discussed in the next section, this result is driven by the confluence of seniority and diversification effects that dramatically reduces bank risk and allows banks to afford high leverage. A good illustration of the relative safety of banks is that in our base case, banks have an annual default rate of only 0.08%. The historical US bank failure rate is of the same magnitude, at 0.25%.[21] If we plausibly assume banks internalize only half of their distress costs, we match the observed default rate. Section 6.1 explores this further.

Second, firm leverage is an empirically reasonable 29%. Many standard corporate finance models cannot explain the low levels of firm leverage seen in practice. This low leverage puzzle has sprung its own stream of research (e.g., Leland, 1994, 1998; Goldstein, Ju and Leland, 2001; Morellec, 2004; Ju et al., 2005; Strebulaev, 2007). Supply chain frictions provide a natural solution to this puzzle. A firm borrowing through a financial intermediary bears some of that intermediary's capital structure costs and, as a result, borrows less. For the benchmark parameter estimates, our model produces firm leverage of 29%, in line with the average quasi-market leverage ratio of 25%–30% for US public firms between 1962 and 2009 (e.g., Strebulaev and Yang, 2013). For comparison, when we exclude supply chain frictions in the public debt market case, firm borrowing jumps from 29% to 55%. This is again in line with empirical

[20] Authors' estimates based on historical FDIC data, which are publicly available at http://www2.fdic.gov/hsob/HSOBRpt.asp.

[21] Authors estimates based on FDIC data, which are publicly available at http://www2.fdic.gov/hsob/. In Table CB02, the FDIC reports 2,429 commercial bank failures out of 968,458 bank-year observations for the period of 1934 to 2013.

evidence, such as Faulkender and Wang (2006), who show that among firms with positive debt, those with bond market access have higher leverage (28.5%) than those without (20.5%).

Bank leverage ends up being *56% higher* than firm leverage. This sizable gap arises for three reasons. First, a firm does not enjoy the same diversification and seniority protections that banks do. Second, a firm borrowing through a bank bears that bank's default costs, and so it borrows less to protect the bank (the strategic substitution effect). Finally, the borrowing firm captures only some of the tax benefits of debt as the rest are lost through the bank's tax costs—the financing supply chain is not completely frictionless. Together, these forces simultaneously explain high bank leverage and low firm leverage.

Bank leverage is high for a variety of borrowers and types of loans, as illustrated by Table 4. Higher borrower leverage results in lower bank leverage, but the bank still pursues high leverage for a variety of portfolio compositions.

4.1. Return volatility

The combination of diversification and seniority have two effects. First, they greatly reduce the volatility of bank assets. Second, they give bank asset returns a fat left tail that reduces the banks' desire and ability to protect against default.

Diversification and seniority reduce bank asset volatility by an order of magnitude. Fig. 1 and Table 1a show that diversification reduces portfolio volatility by half, seniority cuts volatility by a factor of three, and both effects together lead to a 15-fold decrease in volatility. Although diversification is an important driving force, it is the seniority and the joint effect of seniority and diversification that produce such a dramatic effect.

From Diamond (1984) onward, the diversification effect has been extensively documented in the banking literature; however, the seniority effect has been less explored. The seniority effect arises from the priority of bank loans in a borrower's capital structure. Banks are generally senior creditors: for corporate debt, banks are generally senior both to bondholders and trade creditors; and for mortgages, banks are secured creditors with first claim on the borrower's

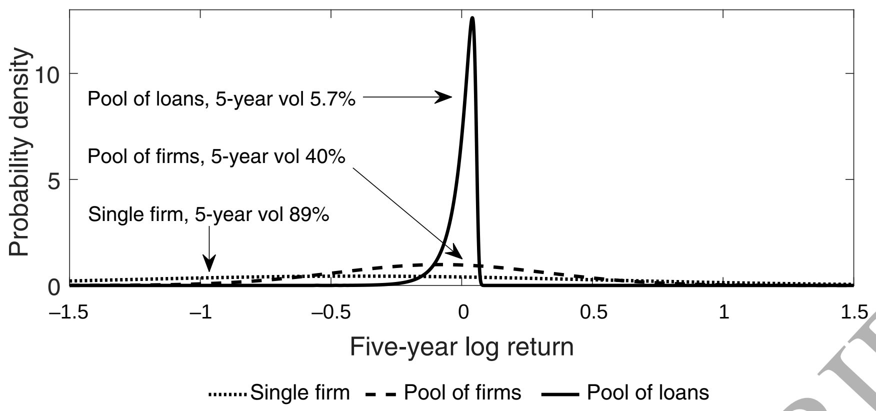


Fig. 1. Impact of seniority and diversification on distribution of returns. Fig. 1 shows the probability density function of returns on a single firm's assets (dotted), a diversified portfolio of firms (dashed), and a diversified portfolio of loans to those same firms (solid). For this illustration, we set the firm's repayment, R_F, to produce 25% firm leverage, and we model firm performance using the assumptions in Section 3.1.

house. This seniority means a bank will not suffer losses on a loan until the borrower performs very poorly. For a bank to experience financial distress, a significant fraction of its borrowers must concurrently suffer significant financial hardship.

A synergy between the seniority and diversification effects doubles the strength of their combined effect. This synergy arises from a subtle interplay whereby seniority potentiates diversification. Any asset volatility a bank experiences can only come from those loans in a bank's portfolio that fail. Even in bad states of the world, many borrowers experience positive idiosyncratic shocks and will therefore not default. As these loans do not contribute to the bank's asset volatility, seniority implies that systematic risk is only coming through on a portion of the bank's portfolio. This dramatically reduces the bank's asset volatility.

These effects mean that a bank can lend to risky borrowers and still have a safe portfolio. A portfolio of loans to firms, where each firm has 25% leverage and 40% asset volatility, produces a bank asset volatility of just 2.6%, much lower than the volatility of the borrower firms. Running the same calculation for mortgages with an 80% loan-to-value ratio gives an asset volatility of 2.3%. These volatilities are empirically reasonable. For example, Ronn and Verma (1986) and Hassan et al. (1994) find bank asset volatility ranging from 0.9% to 2.3%.

Although seniority dramatically reduces volatility, it gives bank assets a return distribution with negative skew, or a fat left tail. This makes bank assets are more subject to large drawdowns than their asset volatility would suggest. To illustrate, consider a bank with a portfolio of loans to firms, where each firm has 25% leverage. That bank can have 89% leverage and only face a 1% default rate. Part of that is because the bank's loan exposure has five-year volatility of 5.7%, as above. However, if the bank had a lognormally distributed cash flow with 5.7% five-year volatility, it would be even safer. The bank with lognormal cash flows has a 64% lower default rate of just 0.36%, holding leverage and asset volatility constant.

Because of this, models of bank capital that assume bank assets are normally distributed (rather than assuming borrower assets are normally distributed) could thus substantially underestimate both bank solvency risk and banks' desire to take risk.

4.2. Strategic interaction

The strategic link between bank and borrower financing decisions means that these decisions can be both *strategic complements* and *strategic substitutes.* Fig. 2 considers a bank that lends only to firms and shows how firm leverage responds to exogenous variation in bank leverage, where leverage is defined as the ratio of debt to total value.

The strategic complementarity effect arises because lower bank leverage reduces a firm's ability to capture the tax benefits of debt. A bank with low leverage pays substantial tax on its interest income and must charge high interest rates to make up for that tax burden. As shown in expression (24), a firm's interest payment generates a net tax benefit only to the extent that the receiver of that interest payment can avoid paying tax on it. This supply chain effect makes bank and firm leverage strategic complements. At the extremum, consider a firm borrowing from an all-equity bank, as shown on the far left in Fig. 2. An all-equity bank cannot pass on any tax benefits of debt, and thus a firm borrowing from such a bank gains no tax benefit from leverage. The firm's interest tax deductions are effectively the bank's taxable income, and thus the net tax benefit is zero. The presence of distress costs means the firm then issues no debt.

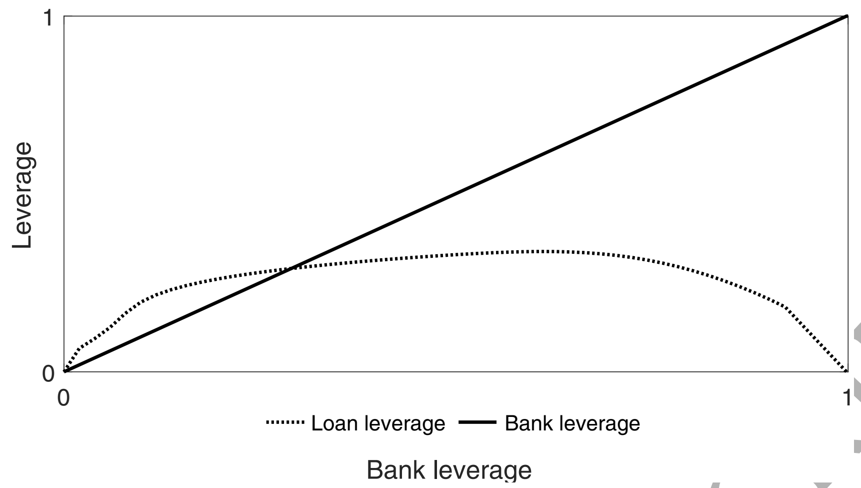


Fig. 2. Optimal firm leverage for given bank leverage. Fig. 2 illustrates how varying bank leverage (solid) impacts firm leverage (dotted) for a bank that lends to a portfolio of firms using the assumptions in Section 3.1.

For relatively low bank leverage, this strategic complementarity effect dominates, which reduces the total indebtedness of the economy.

The strategic substitution effect arises because lower bank leverage reduces the risk of bank failure and therefore expected bank distress costs. This effect decreases firm borrowing costs and allows a firm to increase its leverage without jeopardizing the bank's financial stability. Of course, this effect is only important if the firm is properly incentivized to increase its leverage (i.e., if bank leverage is high enough that tax benefits are marginally important). This effect is thus likely to dominate for relatively high bank leverage. Consider an extremely highly levered bank that will be pushed into distress by even a small loss. This instability translates into higher firm borrowing costs, which will reduce a firm's debt issuance. Effectively, a firm builds up a safety cushion to protect its bank. On the far right of Fig. 2, a fully levered bank means the firm chooses not to borrow.

Fig. 3 explores strategic substitution from another angle by showing how the leverage of a bank that lends only to firms responds to exogenous variation in those firms' leverage. As firm leverage decreases, and firm debt becomes senior to a larger tranche of firm equity, bank leverage increases correspondingly. At the far right, when the bank has no seniority at all, leverage is

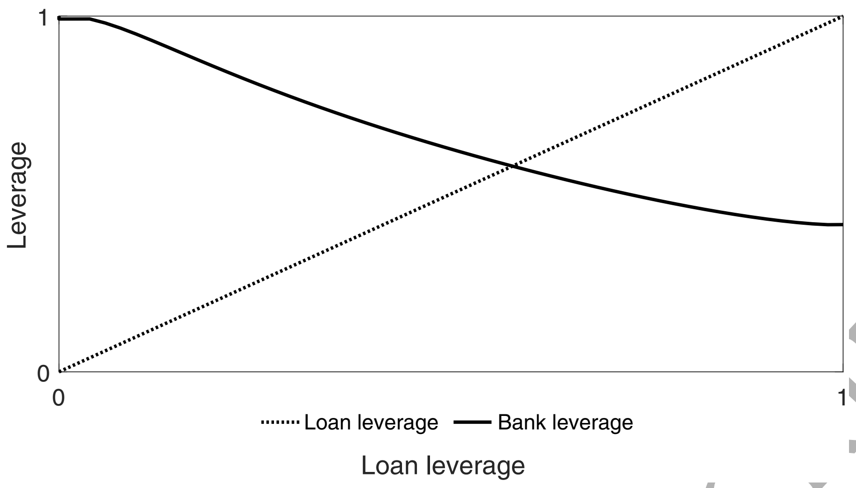


Fig. 3. Optimal bank leverage for given firm leverage. Fig. 3 illustrates how varying firm leverage (dotted) impacts bank leverage (solid) for a bank that lends to a portfolio of firms using the assumptions in Section 3.1.

reduced to 41.4%. Similar results would hold for a bank lending only through mortgages with varying leverage. Section 5 extends this mechanism by introducing junior bond debt into a firm's capital structure.

Without supply chain effects, bank leverage would be much lower. Firms borrowing directly from the bond market take 55% leverage. If the bank lent to such firms, it would take only 63% leverage. This shows the importance of strategic interaction in making bank assets safe.

If bank leverage cannot adjust in response to borrower leverage, bank defaults become more common. Fig. 4 holds bank leverage fixed and looks at how borrower leverage impacts bank default probabilities. Holding bank leverage fixed at 85% and increasing firm leverage from 30% to 60% causes the one-year default probability of a bank that lends to firms to increase sevenfold, from 0.90% to 6.55%. Holding bank leverage at 90% and increasing mortgage loan-to-value ratios from 80% to 100% similarly causes the default probability of an all-mortgage bank to increase to from 0.10% to 1.22%. Both high firm leverage and high bank leverage are associated with more frequent bank defaults. As a potential illustration, the run-up to the recent financial crisis was associated with a dramatic increase in the leverage of households. Banks that failed

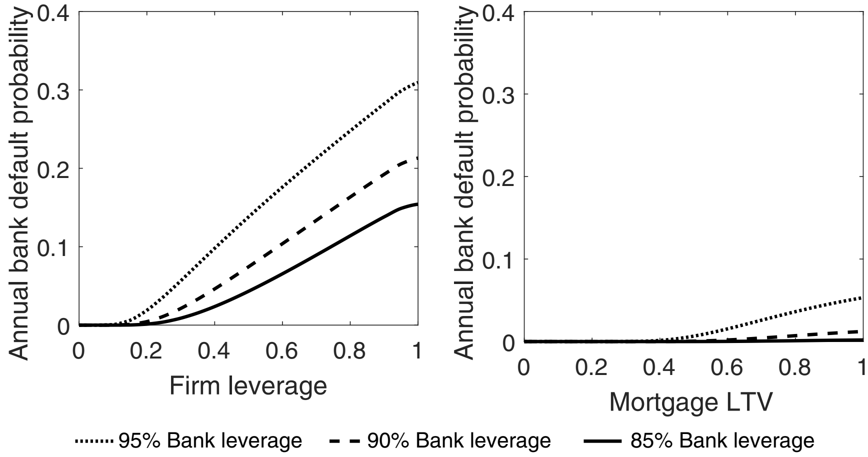


Fig. 4. Impact of borrower leverage on bank default rates. Fig. 4 shows how varying leverage impacts bank default rates for banks with fixed capital structures. The left plot shows results for firms modeled using the parameters in Section 3.1. The right plot shows results for mortgages modeled using the parameters in Section 3.2.

to model such an increase in leverage would have been extremely vulnerable to systemic shocks due to their unexpectedly inadequate seniority.

4.3. Impact of systematic and idiosyncratic risk

Varying the correlation between loans has a nonmonotonic effect on bank and firm leverage, as illustrated by Fig. 5a. Low correlation, and therefore low systematic risk, leads to highly levered banks and firms because better diversified exposures reduce systematic risk costs. In the extreme example of $\rho = 0$, the Diamond (1984) case, banks are optimally fully levered as their risk is completely diversified. Adding systematic risk causes a gradual decrease in both firm and bank leverage. There are two related effects. First, banks reduce their leverage to protect against default as increasing correlation raises their portfolio volatility. Lower bank leverage makes banks less effective at passing along the tax benefits of debt, which raises borrowing costs for firms and reduces firm leverage in due turn. Second, because firms internalize the distress costs they impose on banks, an increase in systematic risk causes the firm to borrow less. More correlation between firms implies banks need to hold more equity and charge higher interest rates, which reduces firm borrowing.

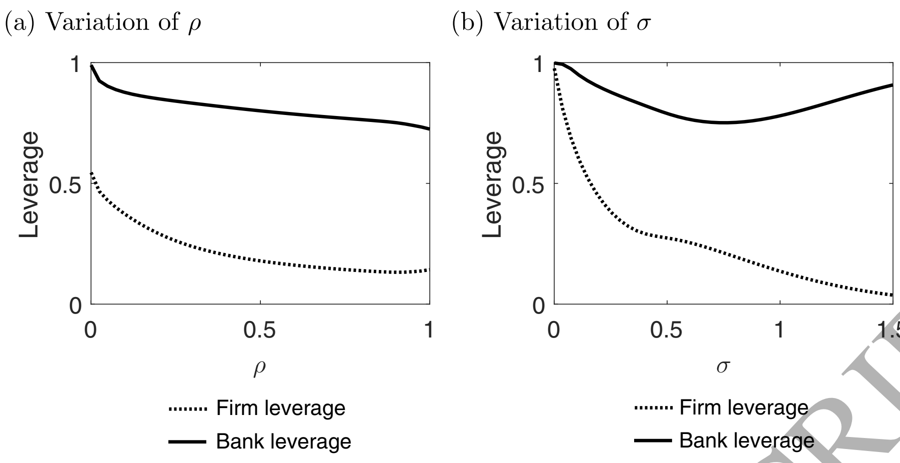


Fig. 5. Impact of systematic risk and volatility on leverage. Fig. 5 shows how varying systematic risk (5a) and collateral volatility (5b) impacts the leverage of banks (solid) and firms (dotted). The bank is modeled using the parameters in Section 3.

As the level of systematic risk increases further, a marginal dollar of bank equity capital becomes less and less effective at guarding against default. If risk is largely systematic, it is more efficient for firms to increase their equity buffers than for the bank to increase its equity buffer. For levels of ρ near 1, firms' shocks are almost perfectly correlated, and the bank's portfolio is thus extremely volatile. This volatility renders low firm leverage ineffective at preventing bank defaults and eventually reduces the marginal safety benefit firms get from an extra dollar of equity. As can be seen in Fig. 5a, this causes firms to lower their equity buffer, as it is no longer effective.

Fig. 5b shows the impact of varying asset volatility, σ, on bank and firm leverage and default likelihood.[22] Bank leverage decreases with higher volatility. This behavior is well documented in the capital structure literature both theoretically and empirically (e.g., Leland, 1994; Adrian and Shin, 2010). As loan portfolios become more volatile, banks decrease their leverage to protect themselves against default. Firm leverage follows a similar pattern.

[22]Note that while we vary σ, we are interested in the impact of total volatility, $\sigma\sqrt{T}$. The primary impact of varying T is through its impact on total volatility; therefore, a chart that shows leverage and default probabilities as T varies would be qualitatively similar to Fig. 5b.

In interpreting the parameters ρ and σ, one needs to keep in mind that it can vary both with the nature of the bank and with macroeconomic conditions. For a national bank, ρ would be the exposure of a bank's portfolio firms to systematic shocks. For a regional bank, ρ would also incorporate regional shocks, and so its value might be higher. We would expect such banks to pursue lower leverage or lend to safer firms to compensate for their increased portfolio volatility. To the extent that volatility and asset comovement increases during recessions, poor macroeconomic conditions would be associated with higher ρ and higher σ.

4.4. Impact of taxes and bankruptcy costs

If borrower leverage is held constant, trade-off frictions have their expected impact on capital structure. For a bank that lends only through mortgages, increasing tax rates leads to an increase in bank leverage as the value of the tax shield to the bank increases. This matches the results of Schandlbauer (2017) and Schepens (2016) who use tax changes in US states and in Belgium, respectively, to show that higher tax rates increase financial institution leverage. Intuitively, higher bank or borrower bankruptcy costs have the opposite effect, by causing the bank to decrease its leverage in response to more costly bankruptcy or more likely bankruptcy, respectively.

If borrower leverage is endogenous, these effects are more ambiguous. For example, higher tax rates cause firms to take on higher leverage and therefore increase the amount of risk banks have in their portfolio. This strategic substitution effect lowers bank leverage, leading to an indeterminate overall effect of taxes on bank leverage. Along the same lines, higher firm-level bankruptcy costs decrease firm leverage and correspondingly decrease bank risk. As another example, the strategic complementarity effect means higher firm-level bankruptcy costs can increase bank leverage, as the increase in bank portfolio risk from higher firm bankruptcy costs can be outweighed by the decrease in risk from lower firm leverage.

5. Bond markets

Trade credit and public debt are also important sources of debt financing. This section adds these forms of debt into our model, using a framework similar to Black and Cox (1976). Because these forms of debt are typically junior to bank loans, they reduce the impact of firm indebtedness on bank risk. Adding public market debt increases firm leverage, as firms can take on more debt without endangering the bank.

In the base model, where all firms borrows only from the bank, R_F denotes each firm's debt obligation to the bank. With multiple sources of funding, we use R_F as the total debt repayment promised by the firm and R_L as the amount the firm agrees to repay to the bank. The remaining $R_F - R_L$ of the firm's repayment is promised to the firm's bondholders. If the firm is solvent at loan maturity (i.e., if $F^i \geq C_F$) the bank and the firm's bondholders are repaid in full. Otherwise, the firm defaults. In default, the bank's seniority and the absolute priority rule mean the bank receives

$$\min\left\{R_L, (1-\alpha_F)(1-\tau)F^i\right\}. \tag{27}$$

The firm's bondholders get the residual value, if any, that remains after the firm's bank debt is paid:

$$(1-\alpha_F)(1-\tau)F^i - \min\left\{R_L, (1-\alpha_F)(1-\tau)F^i\right\}. \tag{28}$$

The payoff to the bank from a single loan is derived in a similar way as in the base model, with Eq. (2) adjusted by taking into account the bank's added seniority:

$$B^i = R_L \mathbb{I}\left[F^i \geq C_F\right] + \min\left\{R_L, (1-\alpha_F)(1-\tau)F^i\right\} \mathbb{I}\left[F^i < C_F\right]. \tag{29}$$

The bank's equity and debt values are then as given by Eq. (10) and (11).

The value of the firm's bond issuance, V_M, is the discounted payoff of the residual debt claim:

$$V_M = e^{-Tr_f}(R_F - R_L)\mathbb{P}\left[F^i \geq C_F\right] + e^{-Tr_f}\mathbb{E}\left[\max\left\{0, (1-\alpha_F)(1-\tau)F^i - R_L\right\}\mathbb{I}\left[F^i < C_F\right]\right]. \tag{30}$$

The firm's total debt value V_{FD} is the sum of the proceeds of its bond issuance and the value its loan contributes to the bank:

$$V_{FD} = V_M + V_{BE} + V_{BD}. \tag{31}$$

Consider a firm that chooses its debt-to-equity ratio but maintains a fixed debt structure with a constant ratio of bond repayment to bank loan repayment. Fig. 6 shows how varying firm debt structure impacts the financial system, using a bank with 60% mortgage debt, 20% corporate debt, and 20% risk-free assets.

On the left of Fig. 6, a firm that relies solely on bank financing has 29% leverage and borrows from a bank with 85% leverage. Moving right, the firm's debt structure tilts more toward bonds, and the firm's leverage increases. Junior bondholders absorb the first round of the firm's losses and so adding junior creditors to the firm's capital structure reduces the cost firm bankruptcy imposes on the bank. This weakens the strategic substitution effect. The firms and the bank respond by taking on more debt. For example, if the firm has 50% of its debt coming from junior bonds, its leverage increases to 45%, and the bank's leverage increases to 87%. At the right of each panel, if the firm borrows entirely from the bond market, it takes on leverage of 55%. In this case, the strategic substitution effect is shut down completely, and firm leverage increases dramatically. Firm default rises with leverage, increasing from 4% to 14%.

Note that corporate debt represents only 20% of our bank's assets. This attenuates the effect of firm debt structure on bank leverage in Fig. 6, as only one-fifth of the bank's portfolio is being affected. The seniority effects here is extremely strong for a bank that lends only to firms,

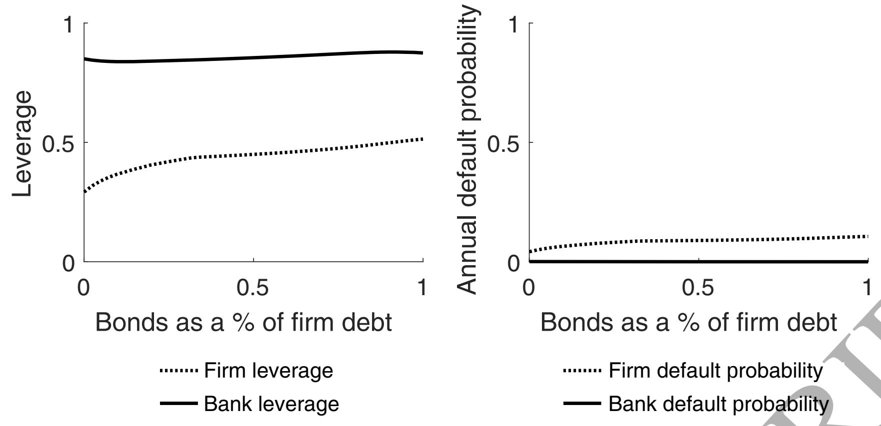


Fig. 6. Impact of firm debt financing mix on firm and bank leverage. Fig. 6 shows the capital structure of firms and banks in an economy where firms that raise debt financing must raise a given portion of it through banks. The bank is modeled using the parameters in Section 3.

as Fig. 2 shows. In fact, as the portion of bonds in a firms debt structure grows to 100%, bank leverage also goes to 100%.

6. Moral hazard

Due to the large social cost of bank failures, struggling banks often receive government assistance. This section considers two common forms of such assistance (deposit insurance and debt guarantees) and shows how these interventions can lead banks to increase their leverage and lend to riskier borrowers. Capital regulation can combat that; however, it can be difficult to properly target.

6.1. Deposit insurance

Government-backed deposit insurance protects bank depositors from the costs of bank failure. Most developed countries have schemes of this sort to help prevent bank failures. In the US, the FDIC is a deposit insurance program guaranteed by the federal government in which all deposit-taking institutions participate. Because we use a two period model, we cannot consider the effect of depositor runs. For example, Sundaresan and Wang (2016) provide an interesting analysis of bank financing decisions when depositors can run. However, we can analyse the effect of deposit insurance on leverage choices in a world without runs. We find that such interventions not only cause banks to increase their leverage but also change the way banks price risk in a way that pushes borrowers toward higher leverage.

Let D be the amount of insured depositors a bank has at date zero. These deposits are backstoped by the US government and pay the risk-free rate of r_f. We assume that the payments to insured depositors make up a constant portion of the bank's repayment, $De^{Tr_f} = \gamma R_B$.[23]

Consistent with US regulation, we assume insured deposits are senior to other creditors, and so the bank's other creditors are paid the residual, $R_B - De^{Tr_f}$ if the bank survives and $\max\left\{0, (1-\alpha_B)B - De^{Tr_f}\right\}$ if the bank defaults. Under these assumptions, the time-zero value of the bank's insured deposits is D, and the value of the bank's other debt is

$$V_{BD} - D \ = \left(R_B - De^{Tr_f}\right)\mathbb{P}\left[B \geq R_B\right] + e^{-Tr_f}\mathbb{E}\left[\max\left\{0, \left((1-\alpha_B)B - De^{Tr_f}\right)\right\}\mathbb{I}\left[B < R_B\right]\right]. \tag{32}$$

Fig. 7 shows the impact of varying the amount of insured deposits on the leverage and default likelihood of banks and firms. Strikingly, high levels of insured deposits cause the bank to pursue high-risk strategies by leveraging to the hilt and gambling on excessively risky loans. Our benchmark bank switches to a risk-seeking strategy that exploits the government guarantee when insured deposits make up more than 91% of its liabilities. Appendix A provides evidence that some banks are exposed to high levels of moral hazard and pursue risky strategies.

6.2. Bailouts

Bailouts of financial institutions can take many forms. At their root is a transfer of taxpayer funds to the owners and creditors of a weakened financial institution.[24] While taxpayers often

[23]Additionally, we limit the bank's promised repayment to be equal to the value of its loans if those loans were held by a tax-free investor. This prevents banks from issuing a near-infinite amount of insured deposits.

[24]Some bailouts are accomplished through means other than an explicit transfer, or promise thereof, of taxpayer funds. Coercion of private companies (e.g., the Long-Term Capital Management hedge fund debacle), printing money to buy bank assets (one type of quantitative easing), or waiver of traditional competition laws (e.g., the

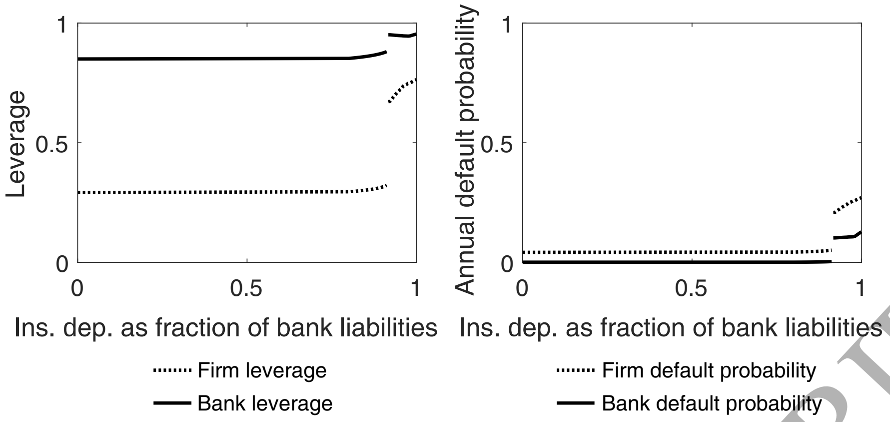


Fig. 7. Impact of insured deposits on leverage and default rates. Fig. 7 shows how insured deposits impact the leverage and annual default probabilities of banks (solid) and firms (dotted). The bank is modeled using the parameters in Section 3.

receive securities as compensation for this transfer, these securities are generally worth less than the transfer is, at least at the time of the bailout.

In this section, we consider a bailout where the government guarantees a financial institution's debt. In Appendix B, we consider a bailout where the government buys a financial institution's equity at an above-market valuation. Both types of intervention were used in the recent financial crisis. In either case, what matters for ex-ante capital structure decisions is the ex-ante expectation of such bailouts by private decision makers.

Market participants may expect that the government will step in and pay the debts of a distressed bank. This response can be contingent upon macroeconomic, macrofinancial, and political concerns. Further, what matters is not the government's present choice of action but the government's expected action in the future when the bank–or possibly the banking system–is near default. Because we consider only a single bank, we abstract beyond macro-prudential considerations. Suppose that the market's expectation is that with some probability, θ, the

Lloyds-HBOS merger) can also aid failing banks and have a similar effect on bank capital structure as they all subsidize poor performance.

government will step in and guarantee a failing bank's debt; otherwise that bank will be allowed to fail.

If the government intervenes, the government takes over the failing bank and pays the bank's creditors their promised repayment, R_B. The expectation of this type of bailout increases the bank's time-zero debt value:

$$V_{BD} = e^{-Tr_f} R_B \mathbb{P}\left[B \geq R_B\right] + e^{-Tr_f} \mathbb{E}\left[\theta R_B + (1-\theta)(1-\tau)(1-\alpha_B) B \mathbb{I}\left[B < R_B\right]\right]. \tag{33}$$

Expectations of such a debt guarantee create moral hazard for the bank at the time of a capital structure decision because the bank is subsidized in the states of the world where it defaults. This gives the bank an incentive to issue more debt to take advantage of that potential subsidy.

Fig. 8 illustrates how bank leverage increases as bailouts become more likely. If bailouts are seen as very likely (above about a 69% probability for our benchmark set of parameters), the bank experiences extreme moral hazard. At this point, as the gains from taxpayer-subsidized gambling overwhelm the gains from legitimate lending, the bank chooses to pursue extremely high leverage and lend to very risky firms. Bank default risk triples if the probability of a bailout is 50%. If the probability rises to 75%, the likelihood of bank default increases a hundredfold, and the bank shifts to a risk-seeking strategy with very frequent defaults. Firm leverage and default probabilities also change due to the bank mispricing firm default risk. As bailout probabilities increase, firm default rates increase by a factor of four, and firm leverage increases from 29% to 76%.[25]

6.3. Capital regulation

Capital regulation that restricts bank financing is a key weapon regulators use to combat bank risk-taking. Preventing a bank from issuing excessive debt reduces its incentive to risk-shift and insulates its creditors and depositors from loss. Capital regulation policies, as well

[25] Although firm leverage increases more than bank leverage in absolute terms, this is because bank leverage starts so much higher. If we instead look at debt-to-equity ratios, the firm's debt-to-equity ratio increases from 1.4 to 4, while the bank's debt-to-equity ratio increases from 7 to 22.

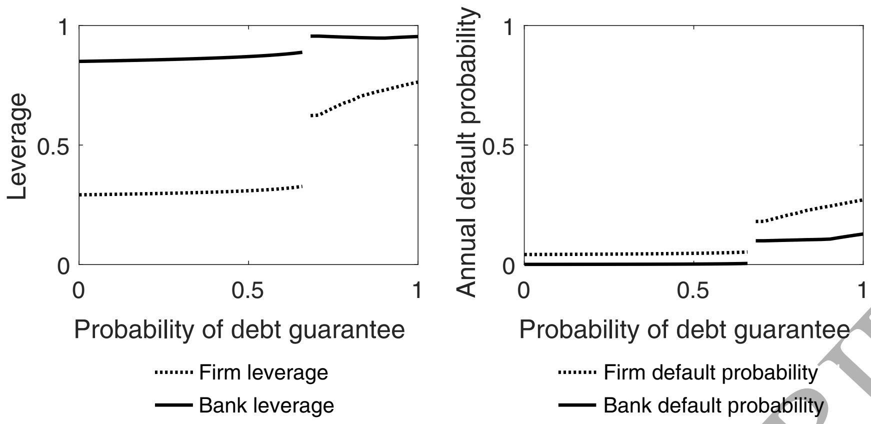


Fig. 8. Impact of debt guarantees on leverage and default rates. Fig. 8 shows how debt guarantees impact the leverage and annual default probabilities of banks (solid) and firms (dotted). The bank is modeled using the parameters in Section 3.

as their cost and impact, have been at the center of recent debates by both practitioners and academics. We find that while capital regulation reduces bank leverage, it can increase borrower leverage by changing the way banks price risk and thus lead to more borrower defaults.

While capital regulation takes many forms, the international standards laid out in Basel II and those proposed in Basel III form widely accepted benchmarks. Basel II, and now Basel III, lays out different capital regulation guidelines for banks of different sizes. The capital requirements for smaller and less sophisticated banks are set using the standardized approach, which uses simple risk weights for different types of assets. Larger banks are subject to the IRB approach, where a bank's equity requirements are calculated using outputs from that bank's own models.[26] In the following sections, we apply these two regulatory approaches to our model and examine how effectively these regulations combat the incentive problems introduced by bailouts and deposit insurance. These regulatory structures are complicated, and thus we focus on equity standards and use simplified models; however, our results are very general.

[26]The US implementation of Basel III requires that the largest banks use the IRB approach in addition to the standardized approach. See the report by the Office of the Comptroller (2013) for more details on the US implementation of Basel III.

6.3.1. Basel capital regulation: standardized approach

Under the standardized approach of Basel II and III, banks need to hold equity capital equal to a constant fraction of their risk-weighted assets. We model this type of regulation by assuming a bank must have equity capital, V_{BE}, in excess of h portion of its risk-weighted assets, so that

$$V_{BE} \geq V_B \times w \times h, \tag{34}$$

where V_B is the bank's asset value, w is the bank's risk weight, and h is the capital requirement.

The BCBS (2013) sets out a so-called standardized approach that assigns a bank a risk weight based on the assets in its portfolio. For example, residential mortgages are placed into buckets based on loan-to-value ratio and loan properties and given risk weights of 35%–200%, and corporate debt is given a risk weight varying from 20%–150% depending on rating.[27] The total risk weight of the bank's assets determines how much capital it needs to hold. This type of capital regulation is simple, but the risk weights can do a poor job of capturing the real risk of the underlying assets. Banks faced with this form of capital regulation can try to game it by issuing riskier loans to more leveraged or less credit-worthy borrowers.

Our calculations ignore asset specific risk weights and instead fix the bank's risk weight w at 0.70 to match the regulatory environment of US banks in the pre-crisis period. (As shown in Le Leslé and Avramova (2012), this varies substantially by country.) We set h to 8% to match the key equity ratio used by the standardized approach in Basel II. The actual Basel II and Basel III frameworks are much more complicated. Banks face multiple capital requirements, ranging from Basel II's 4% tier one capital requirement to Basel III's 13% maximum mandate with full capital conservation and countercyclical capital buffers.

[27] Note that capital regulation is usually written in terms of the book value of assets and the book value of equity. Under our model, the time-zero book values and market values are equal for both equity and assets as the bank is zero profit.

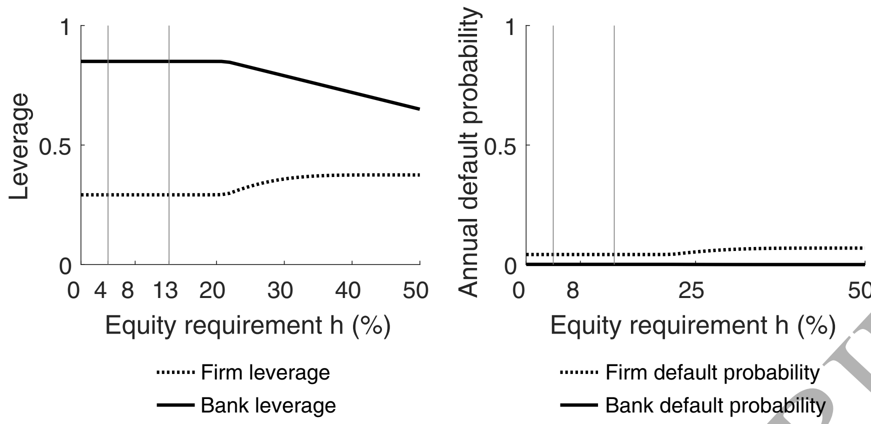


Fig. 9. Impact of bank leverage limits on leverage and default rates. Fig. 9 shows how capital regulation that mandates an equity capital-to-asset ratio above h impacts the leverage and annual default probabilities of banks (solid) and firms (dotted). The vertical lines denote bounds on the current Basel capital requirements, which range from $h = 4\%$ to $h = 13\%$. The bank is modeled using the parameters in Section 3.

Fig. 9 illustrates the impact of imposing bank leverage limits. The current range of Basel II and III capital requirements is denoted using vertical lines. We can see that such capital regulations do not bind for our base case bank. This matches the empirical reality where most banks hold capital significantly in excess of the regulatory minimums (e.g., Berger et al., 2008).

Stronger capital regulation would bind; however, as in Section 4.2, it would paradoxically increase borrower leverage and default risk. The strategic substitution effect means that stronger capital regulation pushes the real sector of the economy to borrow more.[28] This is shown in Fig. 9 by the increased firm default probability. The plausible analogue of this, which we can observe in practice, is that a bank subject to capital regulation can decide to circumvent the regulation by making riskier loans as a back door way to increase its leverage. These capital restrictions distort banks' lending preferences, which can cause spillover into the real economy.

Our capital requirement of $h = 8\%$ does not bind for a bank not subject to moral hazard. However, as the third and fourth columns of Table 5 show, it can reduce the risk-taking associated with deposit insurance and bailouts. Forcing a bank to maintain an equity buffer gives it more

[28]Harris, Opp and Opp (2015) use a different channel to show moderate capital regulation can increase risk-taking in the real economy.

"skin in the game" and means that bank investors lose more if the bank fails. This reduces the bank's ability to exploit government bailouts and limits the bank's default risk.

6.3.2. Basel capital regulation: internal ratings-based approach

Simple leverage limits can push banks toward risky lending. One countermeasure is to risk-weight assets. Basel II and III include this type of capital regulation as an option for banks. The risk-weighting formulas the regulatory framework employs are based on the Vasicek (2002) structure that underlies our analysis. Each bank is required to maintain equity capital in excess of a formula-imposed floor. This floor, $K \times V_{FD}$, is the value of the bank's assets multiplied by an exposure-based risk-weighting K, which is calculated as

$$K = \left[LGD \times \Phi \left(\sqrt{\frac{1}{1-\hat{\rho}}} \Phi^{-1}(PD) + \sqrt{\frac{\hat{\rho}}{1-\hat{\rho}}} \, \Phi^{-1}(0.999) \right) - LGD \times PD \right] \frac{1 + (T - 2.5)b}{1 - 1.5b}, \tag{35}$$

where PD is the default probability, LGD is loss given default, $\hat{\rho}$ is the imputed correlation given by Eq. (26), and b, the maturity adjustment, is calculated as

$$b = (0.11852 - 0.05478 \times \ln(PD))^2. \tag{36}$$

The formulas in Eq. (35) and (36) are copied from paragraph 102 in the current Basel III proposal from the BCBS (2013). We calculate PD and LGD from our model.[29]

As with the standardized approach, this form of capital regulation is not binding for our base case parameters—a bank that pays its own default costs chooses a capital structure that already satisfies this form of capital regulation. The real effect of this type of capital regulation is in preventing the moral hazard induced by government interventions. As the last two columns of Table 5 show, IRB-style regulation can dramatically reduce the impact of bailouts and deposit

[29]We follow the IRB advanced approach where these inputs are derived from the banks models. Similar results follow from the IRB foundation approach where these values are set to regulator determined constants.

insurance on bank risk-taking. Without capital regulation, the bank increases its leverage to benefit from the effective put option the government provides with deposit insurance or bailouts, sometimes dramatically so.

6.3.3. Stronger capital regulation

The previous sections have shown that capital regulation can reduce bank risk-taking; however, current levels of capital regulation may not be effective. This section explores the impact of stronger capital regulation.

Table 5 shows how bank default rates are impacted by doubling the equity requirements prescribed by current capital regulation. Increasing the core capital requirement of the Basel standardized approach from $h = 8\%$ to $h = 16\%$ leads to a dramatic decrease in the default rates of banks exposed to moral hazard. With $h = 8\%$, banks that expect to be subsidized if they perform poorly can game the capital regulation by making riskier loans. With $h = 16\%$, bank investors have enough skin in the game that the incentive to make risky loans disappears. Overall, the maximum bank default rate decreases by 90%, from 9.92% to 0.76%. Strengthening the Basel IRB approach leads to a similar reduction in risk. Doubling the equity requirement prescribed by the IRB approach reduces the bank's maximal default likelihood from 2.72% to just 0.36%.

6.4. Systematic risk as a choice variable

The Basel IRB approach is effective at preventing bank failure in our model partially because the bank's portfolio is modeled using the very assumptions that underlie the IRB approach. In the real world, substantial model risk exists. A bank faced with binding capital regulation can try to find backdoors to increase its risk.[30] Under our base model, a bank that is subject to leverage limits accomplishes this by lending to riskier firms. In this section, we examine the

[30] Acharya and Richardson (2009) suggest the pursuit of such backdoors was one of the causes of the recent financial crisis.

impact of allowing the bank to increase the risk of its underlying portfolio by manipulating its systematic exposure.

So far, the level of systematic risk, ρ, has been kept exogenous. In reality, a bank can choose not only the riskiness of its individual loans but also its exposure to systematic risk. A bank could achieve this by increasing its exposure to borrowers with high systematic risk or similar borrowers. The Basel IRB approach uses a correlation based on default probability rather than true correlation, as in Eq. (26) and so would not prevent this type of manipulation. Increasing systematic risk increases the bank's asset volatility. Outside of our model, a bank could similarly increase the volatility of its portfolio using financial derivatives, off-balance-sheet exposures, or other risk exposures. Increasing the bank's risk makes the bank more likely to fail and the financial system somewhat more fragile, but it also increases the attractiveness of the gambling strategy by allowing the bank to exploit government subsidies, such as deposit insurance and bailouts, more effectively.

To consider an important example, suppose a bank can choose between two types of portfolio risk. It can either make well-diversified residential mortgage loans with $\rho = 0.2$, a "safe strategy", or make perfectly correlated residential mortgage loans with $\rho = 1$, a "gambling strategy". If the bank chooses $\rho = 0.2$, it can pursue high leverage with little risk of default. If the bank chooses $\rho = 1$ instead, it will face high default risk but be better able to take advantage of deposit insurance or any bailouts. We focus on this rather extreme case, but in the absence of readily available empirical data, it illustrates the type of behavior and risks that can be modeled using our framework. Anecdotal evidence from the recent financial crisis indicates that financial institutions can easily become overexposed to systematic risk if they wish to.

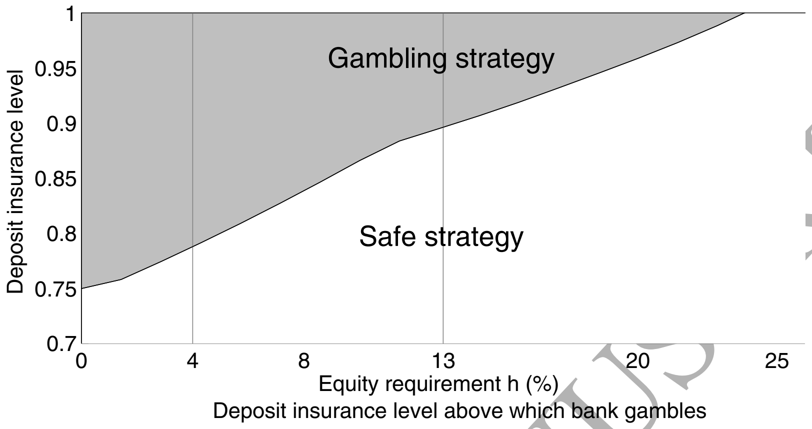
Giving a bank the option to increase its systematic risk dramatically increases the moral hazard posed by bailouts or deposit insurance, which makes capital regulation much more important. Fig. 10a and 10b show how capital regulation impacts a bank's choice between the safe strategy and the gambling strategy. Without capital regulation, a bank expecting generous bailouts or deposit insurance will choose a gambling strategy to maximize its private benefit from such interventions.

Tight capital regulation (high h) makes a gambling strategy less attractive, which helps mitigate the additional moral hazard a choice of ρ creates. Capital regulation increases tax costs and reduces the value of the bank, regardless of which strategy it pursues. However, it reduces the payoff of the gambling strategy by much more because high equity requirements increase the skin in the game of bank investors by increasing the amount they lose in default. This makes the gambling strategy relatively less attractive, which makes the bank more likely to choose the safe strategy. A bank financed almost entirely by equity would not pursue the gambling strategy even if all of its liabilities were insured. Easing capital regulation means banks pursue the gambling strategy more often. In the extreme case, when there is no capital regulation, a bank chooses the gambling strategy if more than 75% of its liabilities are insured deposits or it has a 34% chance of receiving a debt guarantee in the event of failure.

An equity capital requirement of $h = 8\%$, as in our model of the Basel standardized approach, means that the bank gambles if insured deposits make up more than 84% of liabilities or the chance of a bank debt guarantee is greater than 50%. Given that the average level of deposit insurance is well above that and many banks are almost certain to receive bailouts if they fail, current capital regulation may be insufficient. Fig. 10 shows that strengthening capital regulation in this manner curbs a bank's incentive to gamble. Unreported, we get similar results when we implement the same approach using the Vasicek-style IRB capital regulation.

Beyond the level of capital regulation, Fig. 10 shows that moral hazard increases with the degree of bailouts and deposit insurance. To prevent misbehavior, a bank that faces higher moral hazard needs tighter capital regulation. In particular, banks funded primarily with insured deposits and banks that are too big to fail need stricter regulation. These banks have stronger incentives to misbehave, and capital regulation that takes this into account could increase efficiency. Basel III includes additional capital requirements for systemically important

(a) Impact of deposit insurance on bank gambling



(b) Impact of debt guarantee expectations on bank gambling

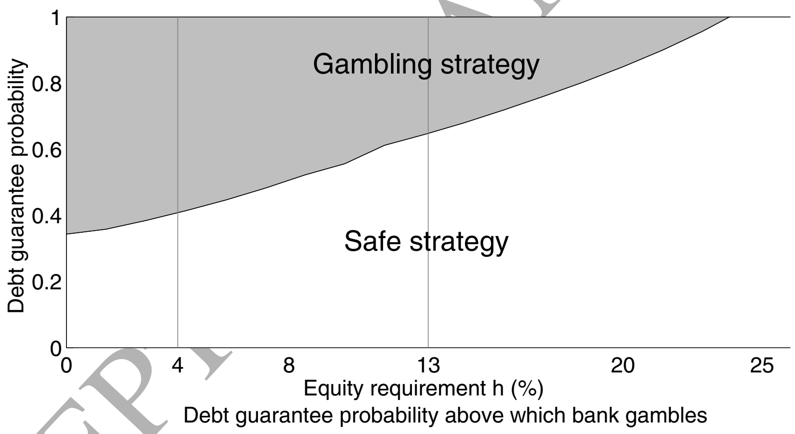


Fig. 10. Bank gambling and deposit insurance or debt guarantees. Fig. 10a and 10b show how capital regulation impacts a bank's choice to gamble in response to deposit insurance and bailout expectations, respectively. The line marks the level of deposit insurance (or bailout expectations) that makes a bank indifferent between the safe and gambling strategies. For levels of deposit insurance (or bailout expectations) in the shaded region above the line, the bank chooses a gambling strategy with $\rho = 1$. For lower levels, the bank chooses a safe strategy with $\rho = 0.2$. The vertical lines denote bounds on the current Basel capital requirements, which range from $h = 4\%$ to $h = 13\%$. The bank is modeled as holding only mortgages. Excluding the choice of ρ, these mortgages are modeled using the parameters in Section 3.2.

financial institutions, and we suggest that subjecting banks funded primarily by deposits to similar regulation can improve efficiency.[31]

Our structure can be used to explore the quantitative impact of government interventions, such as deposit insurance, bailouts, and capital regulation. Banks funded primarily with insured deposits or banks that are likely to be bailed out face strong incentives to take on risk. We quantify these effects and find that moderate levels of deposit insurance or small probabilities of bailouts increase bank risk-taking only marginally. However, larger interventions create extreme moral hazard that can push banks into a risk-seeking strategy. Many banks have enough insured deposits to face such extreme moral hazard.

Strong, targeted capital regulation combats this moral hazard and reduces bank failure. The proposed Basel III capital requirements can be insufficient for banks that are too big to fail or have large amounts of insured deposits, especially if banks can manipulate loan characteristics. Increasing capital requirements to 16% significantly reduces bank risk and only slightly increases borrowing costs. We calculate that increasing bank equity requirement by 1% increases borrower cost by only half of a basis point, suggesting that capital regulation could be substantially strengthened.

7. Extensions

In this section and the accompanying appendices, we discuss three extensions to our framework. First, we consider a Geske (1977) style model of intermediate periods. Second, we discuss debt benefits other than taxes. Third, we introduce imperfect bank competition and analyze the consequences of bank bargaining power. The main results are robust to these extensions.

Intermediate default points. Appendix C implements our model under a Geske (1977, 1979) style framework where default is possible at intermediate points. We consider a bank

[31]Refer to the BCBC (2011) for more detail on the additional capital requirements for systemically important financial institutions.

with a portfolio of mortgages that mature at different times, financed by debt that matures at different times. Extending our framework to multiple maturities has little impact on leverage, provided the average maturity is held constant.

Alternative debt benefits. Tax benefits drive the debt decisions of banks and firms in the preceding sections. Appendix D considers other debt benefits. Namely, we consider a liquidity provision benefit as developed by DeAngelo and Stulz (2015) and a reduced discount rate for debt as articulated by Baker and Wurgler (2015). Replacing the tax benefit of debt with either of these frictions produces similar results. Again, we see banks with high leverage because even a small benefit to debt will cause banks to pursue high leverage. Applying the aforementioned frictions, we see bank leverage that ranges from 82% to 100%.

Bank bargaining power. The main paper assumes competitive banks; Appendix E exogenously varies bank profitability. Higher bank bargaining power increases bank leverage through two channels. First, higher interest expenses drive firm leverage down as firms can get more tax benefits from less borrowing. This drives bank leverage up through the strategic substitution effect. Second, higher interest income for banks means banks pay more tax and choose higher leverage in response to that increased tax cost. This suggests that our competitive bank's assumption leads us to underestimate bank leverage.

8. Conclusion

In this paper, we propose a novel framework to model the joint debt decisions of banks and their borrowers. This framework combines the model regulators use to assess bank risk with an academic model of capital structure decisions. Our structure can quantitatively model bank and firm capital structure decisions in a realistic fashion.

Banks are diversified senior creditors, which reduces their risk and allows them to take on high leverage. The banks' borrowers respond to this high leverage by reducing own their borrowing, partially explaining low corporate leverage. Our benchmark parameters give rise to banks with leverage of 85% and firms with leverage of 30%, not dissimilar to what we observe empirically. These results have resolved two standing puzzles at the same time: why banks are so highly levered and why nonfinancial firms dislike financing themselves with debt.

Obviously, we have just scratched the surface of these issues. The mechanisms that we uncover are generic and can be used, for example, to study the impact of government regulation on the financial decisions of private agents. Regulators, academics, and practitioners continue to have a discussion on bank capital structure, systemic risk, and capital regulation. The framework we present is rich and flexible enough to address many of their unanswered questions.

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References

Acharya[, V. V.], Mehran[, H.], Schuermann[, T.], Thakor[, A.], 2012. Robust capital regulation. Current Issues in Economics and Finance 18 (4), 1–9.

Acharya[, V. V.], Mehran[, H.], Thakor[, A. V.], 2015. Caught between Scylla and Charybdis? Regulating bank leverage when there is rent-seeking and risk-shifting. Review of Corporate Finance Studies 5 (1), 36–75.

Acharya[, V. V.], Richardson[, M.], 2009. Causes of the financial crisis. Critical Review 21 (2-3), 195–210.

Admati[, A. R.], DeMarzo[, P. M.], Hellwig[, M. F.], Pfleiderer[, P.], 2013a. Fallacies, irrelevant facts, and myths in the discussion of capital regulation: why bank equity is not socially expensive. Unpublished working paper. Stanford University.

Admati[, A. R.], DeMarzo[, P. M.], Hellwig[, M. F.], Pfleiderer[, P.], 2013b. The leverage ratchet effect. Unpublished working paper. Stanford University.

Adrian[, T.], Shin[, H. S.], 2010. Liquidity and leverage. Journal of Financial Intermediation 19 (3), 418–437.

Allen[, F.], Carletti[, E.], Marquez[, R.], 2015. Deposits and bank capital structure. Journal of Financial Economics 118 (3), 601–619.

Amromin[, G.], Paulson[, A.], 2010. Default rates on prime and subprime mortgages: differences and similarities. Federal Reserve Bank of Chicago (Sep), 1–10.

Baker[, M.], Wurgler[, J.], 2015. Do strict capital requirements raise the cost of capital? Banking regulation and the low risk anomaly. American Economic Review 105 (5), 315–320.

Basel Committee on Banking Supervision[], 2002. Quantitative impact study 3: technical guidance. Bank for International Settlements.

Basel Committee on Banking Supervision[], 2004. Basel II: international convergence of capital measurement and capital standards: a revised framework. Bank for International Settlements.

Basel Committee on Banking Supervision[], 2010. An assessment of the long-term economic impact of stronger capital and liquidity requirements. Bank for International Settlements.

Basel Committee on Banking Supervision[], 2011. Basel III: a global regulatory framework for more resilient banks and banking systems. Bank for International Settlements.

Basel Committee on Banking Supervision[], 2013. Global systemically important banks: updated assessment methodology and the higher loss absorbency requirement. Bank for International Settlements.

Bennett[, R. L.], Unal[, H.], 2015. Understanding the components of bank failure resolution costs. Financial Markets, Institutions and Instruments 24 (5), 349–389.

Berger[, A. N.], Bouwman[, C. H.], 2013. How does capital affect bank performance during financial crises? Journal of Financial Economics 109, 146–176.

Berger[, A. N.], DeYoung[, R.], Flannery[, M. J.], Lee[, D.], Öztekin[, Ö.], 2008. How do large banking organizations manage their capital ratios? Journal of Financial Services Research 34 (2-3), 123–149.

Bhattacharya[, S.], Purnanandam[, A.], 2011. Risk-taking by banks: what did we know and when did we know it? Unpublished working paper. University of Michigan.

Black[, F.], Cox[, J. C.], 1976. Valuing corporate securities: some effects of bond indenture provisions. The Journal of Finance 31 (2), 351–367.

Bokhari[, S.], Torous[, W.], Wheaton[, W.], 2013. Why did household mortgage leverage rise from the mid-1980s until the great recession? American Economic Association 2013 Annual Meeting.

Bruno[, V.], Shin[, H. S.], 2015. Cross-border banking and global liquidity. Review of Economic Studies 82 (2), 535–564.

Bullard[, J.], 2012. The aftermath of the housing bubble. Speech, Federal Reserve Bank of St. Louis.

Bulow[, J.], Klemperer[, P.], 2013. Market-based bank capital regulation. Unpublished working paper. Stanford University.

Campbell[, J. Y.], Cocco[, J. F.], 2015. A model of mortgage default. Journal of Finance 70 (4), 1495–1554.

Choi[, J.], Richardson[, M.], 2016. The volatility of firm's assets and the leverage effect. Journal of Financial Economics 121 (2), 254–277.

Congressional Budget Office[], 2010. Fannie Mae, Freddie Mac, and the federal role in the secondary mortgage market. The Congress of the United States.

Cotter[, J.], Gabriel[, S.], Roll[, R.], 2011. Integration and contagion in US housing markets. Unpublished working paper. UCLA.

Davydenko[, S.], Strebulaev[, I. A.], Zhao[, X.], 2012. A market-based study of the cost of default. Review of Financial Studies 25 (10), 2959–2999.

DeAngelo[, H.], Masulis[, R. W.], 1980. Optimal capital structure under corporate and personal taxation. Journal of Financial Economics 8 (1), 3–29.

DeAngelo[, H.], Stulz[, R. M.], 2015. Liquid-claim production, risk management, and bank capital structure: why high leverage is optimal for banks. Journal of Financial Economics 116 (2), 219–236.

Della Seta[, M.], Morellec[, E.], Zucchi[, F.], 2015. Debt structure, rollover traps, and default risk. Unpublished working paper. Swiss Finance Institute.

Diamond[, D. W.], 1984. Financial intermediation and delegated monitoring. Review of Economic Studies 51 (3), 393–414.

Diamond[, D. W.], Dybvig[, P. H.], 1983. Bank runs, deposit insurance, and liquidity. Journal of Political Economy 91 (3), 401–419.

Diamond[, D. W.], Rajan[, R. G.], 2000. A theory of bank capital. Journal of Finance 55, 2431–2465.

Dietsch[, M.], Petey[, J.], 2004. Should SME exposures be treated as retail or corporate exposures? A comparative analysis of default probabilities and asset correlations in French and German SMEs. Journal of Banking and Finance 28 (4), 773–788.

Djankov[, S.], Ganser[, T.], McLiesh[, C.], Ramalho[, R.], Shleifer[, A.], 2010. The effect of corporate taxes on investment and entrepreneurship. American Economic Journal: Macroeconomics 2 (3), 31–64.

Elliott[, D.], Salloy[, S.], Santos[, A.], 2012. Assessing the cost of financial regulation. Unpublished working paper. International Monetary Fund.

Faulkender[, M.], Wang[, R.], 2006. Corporate financial policy and the value of cash. Journal of Finance 61 (4), 1957–1990.

Geske[, R.], 1977. The valuation of corporate liabilities as compound options. Journal of Financial and Quantitative Analysis 12 (04), 541–552.

Geske[, R.], 1979. The valuation of compound options. Journal of Financial Economics 7 (1), 63–81.

Glover[, B.], 2016. The expected cost of default. Journal of Financial Economics 119 (2), 284–299.

Goldstein[, R.], Ju[, N.], Leland[, H.], 2001. An EBIT-based model of dynamic capital structure. Journal of Business 74 (4), 483–512.

Graham[, J. R.], 1996. Debt and the marginal tax rate. Journal of Financial Economics 41 (1), 41–73.

Graham[, J. R.], 2000. How big are the tax benefits of debt? Journal of Finance 55, 1901–1941.

Graham[, J. R.], Tucker[, A. L.], 2006. Tax shelters and corporate debt policy. Journal of Financial Economics 81 (3), 563–594.

Hackbarth[, D.], Hennessy[, C. A.], Leland[, H. E.], 2007. Can the trade-off theory explain debt structure? Review of Financial Studies 20 (5), 1389–1428.

Hackbarth[, D.], Mauer[, D. C.], 2012. Optimal priority structure, capital structure, and investment. Review of Financial Studies 25 (3), 747–796.

Hanson[, S. G.], Kashyap[, A. K.], Stein[, J. C.], 2011. A macroprudential approach to financial regulation. Journal of Economic Perspectives 25, 3–28.

Harding[, J. P.], Liang[, X.], Ross[, S. L.], 2007. The optimal capital structure of banks: balancing deposit insurance, capital requirements and tax-advantaged debt. Unpublished working paper. University of Connecticut.

Harris[, M.], Opp[, C. C.], Opp[, M. M.], 2015. The system-wide effects of bank capital regulation on credit supply and risk-taking. Unpublished working paper. University of Chicago.

Hassan[, M. K.], Karels[, G. V.], Peterson[, M. O.], 1994. Deposit insurance, market discipline and off-balance sheet banking risk of large US commercial banks. Journal of Banking and Finance 18 (3), 575–593.

Hugonnier[, J.], Morellec[, E.], 2017. Bank capital, liquid reserves, and insolvency risk. Journal of Financial Economics 125 (2), 266–285.

International Monetary Fund[], 2008. Global financial stability report. International Monetary Fund.

James[, C.], 1991. The losses realized in bank failures. Journal of Finance 46 (4), 1223–1242.

Ju[, N.], Parrino[, R.], Poteshman[, A. M.], Weisbach[, M. S.], 2005. Horses and rabbits? Trade-off theory and optimal capital structure. Journal of Financial and Quantitative Analysis 40 (2), 259–281.

Kisin[, R.], Manela[, A.], 2016. The shadow cost of bank capital requirements. Review of Financial Studies 29 (7), 1780–1820.

Krainer[, J.], LeRoy[, S.], 2010. Underwater mortgages. Economic Letter. Federal Reserve Bank of San Francisco.

Kraus[, A.], Litzenberger[, R. H.], 1973. A state-preference model of optimal financial leverage. Journal of Finance 28 (4), 911–922.

Le Leslé[, V.], Avramova[, S.], 2012. Revisiting risk-weighted assets. Unpublished working paper. International Monetary Fund.

Leland[, H. E.], 1994. Corporate debt value, bond covenants, and optimal capital structure. Journal of Finance 49, 1213–1252.

Leland[, H. E.], 1998. Agency costs, risk management, and capital structure. Journal of Finance 53 (4), 1213–1243.

Lopez[, J. A.], 2004. The empirical relationship between average asset correlation, firm probability of default, and asset size. Journal of Financial Intermediation 13 (2), 265–283.

Merton[, R. C.], 1974. On the pricing of corporate debt: the risk structure of interest rates. Journal of Finance 29 (2), 449–470.

Miller[, M. H.], 1977. Debt and taxes. Journal of Finance 32 (2), 261–275.

Modica[, G.], Poggiolini[, L.], 2012. A First Course in Probability and Markov Chains. Wiley, Hoboken.

Morellec[, E.], 2004. Can managerial discretion explain observed leverage ratios? Review of Financial Studies 17, 257–294.

Office of the Comptroller of the Currency and the Board of Governors of the Federal Reserve System[], 2013. Basel III implementation: final rule. Department of the Treasury and the Federal Reserve System.

Qi[, M.], Yang[, X.], 2009. Loss given default of high loan-to-value residential mortgages. Journal of Banking and Finance 33 (5), 788–799.

Roberts[, M. R.], Sufi[, A.], 2009. Renegotiation of financial contracts: evidence from private credit agreements. Journal of Financial Economics 93 (2), 159–184.

Ronn[, E. I.], Verma[, A. K.], 1986. Pricing risk-adjusted deposit insurance: an option-based model. Journal of Finance 41 (4), 871–896.

Schaefer[, S. M.], Strebulaev[, I. A.], 2008. Structural models of credit risk are useful: Evidence from hedge ratios on corporate bonds. Journal of Financial Economics 90 (1), 1–19.

Schandlbauer[, A.], 2017. How do financial institutions react to a tax increase? Journal of Financial Intermediation 30, 86–106.

Schepens[, G.], 2016. Taxes and bank capital structure. Journal of Financial Economics 120 (3), 585–600.

Shleifer[, A.], Vishny[, R. W.], 2010. Unstable banking. Journal of Financial Economics 97 (3), 306–318.

Strebulaev[, I. A.], 2007. Do tests of capital structure theory mean what they say? Journal of Finance 62 (4), 1747–1787.

Strebulaev[, I. A.], Yang[, B.], 2013. The mystery of zero-leverage firms. Journal of Financial Economics 109 (1), 1–23.

Sundaresan[, S.], Wang[, Z.], 2016. The effects of tax on bank liability structure. Unpublished working paper. Columbia University.

Thakor[, A. V.], 2014. Bank capital and financial stability: an economic trade-off or a Faustian bargain? Annual Review of Financial Economics 6 (1), 185–223.

Vasicek[, O.], 2002. The distribution of loan portfolio value. Risk 15 (12), 160–162.

Westerback[, D.], Okuyama[, K.], Venkatachalam[, V.], Tiwary[, A.], Burbage[, T.], Warner[, E.], 2011. US residential mortgage performance index. Standard & Poor's.

Zhou[, Y.], Haurin[, D. R.], 2010. On the determinants of house value volatility. Journal of Real Estate Research 32 (4), 377–395.

Table 1
Impact of seniority and diversification on asset volatility.
Table 1 reports how diversification and seniority impact the annualized standard deviation of logreturns. Table 1a looks at how these forces affect loans to firms; Table 1b looks at how these forces affect mortgages. The columns correspond to four types of exposure: a single asset, a diversified pool of assets, a loan collateralized by a single asset, and a diversified portfolio of such loans, respectively. Redundant values are omitted.

(a) Impact of seniority and diversification on corporate debt volatility.
This table plots the impact of diversification and seniority on the volatility of corporate claims. Our base case sets borrower leverage at 25% and correlation between borrowers at $\rho = 0.2$. Firms are modeled using the parameters in Section 3.1.

	Single firm	Pool of firms	Single loan	Pool of loans
Diversified	No	Yes	No	Yes
Senior	No	No	Yes	Yes
Base Case	40.00%	17.89%	11.48%	2.57%
$\rho = 0.1$		12.65%		1.69%
$\rho = 0.4$		25.30%		4.24%
Leverage of 15%			5.69%	0.96%
Leverage of 35%			17.23%	4.49%

(b) Impact of seniority and diversification on mortgage volatility.
This table plots the impact of diversification and seniority on the volatility of mortgage claims. Our base case sets the mortgage loan-to-value (LTV) ratio at 80% and correlation between house prices at $\rho = 0.2$. House prices and mortgage defaults are modeled using the parameters in Section 3.2.

	Single house	Pool of houses	Single mortgage	Pool of mortgages
Diversified	No	Yes	No	Yes
Senior	No	No	Yes	Yes
Base Case	25.00%	11.18%	12.98%	2.32%
$\rho = 0.1$		7.91%		1.60%
$\rho = 0.4$		15.81%		3.42%
LTV of 60%			8.74%	1.48%
LTV of 100%			16.61%	2.89%

Table 2
Benchmark parameter values.
Table 2 summarizes the parameter assumptions listed and explained in Section 3.

Model		
Risk-free rate	r_f	0.025
Time to loan maturity	T	5
Linear tax rate	τ	0.25
Bank		
Portfolio value	B	Loans
Bank's debt repayment	R_B	endogenous
Bankruptcy cost	α_B	0.2
Loan mix		60% residential mortgages, 20% corporate debt, 20% risk-free assets
Corporate loan		
Loan collateral	F	Firm assets
Asset volatility	σ_F	0.4
Correlation	ρ_F	0.2
Loan repayment	R_F	endogenous
Bankruptcy cost	α_F	0.1
Residential mortgage		
Loan collateral	A	Residential property
Asset volatility	σ_A	0.25
Correlation	ρ_A	0.2
Loan repayment	R_A	$0.8e^{-Tr_F}$
Bankruptcy cost	α_A	0.25

Table 3
Capital structure of banks and firms.
Table 3 reports the bank and firm leverage and default rates for varying parameters. The bank is modeled as described in Section 3.

	Firms borrow through bank (Section 2.3)				Firms issue bonds (Section 2.2)	
	Firm		Bank		Firm	
	Leverage	Def. rate	Leverage	Def. rate	Leverage	Def. rate
Base Case	29.18%	4.20%	85.01%	0.08%	55.42%	14.23%
$\rho = 0.1$	37.27%	6.78%	87.66%	0.05%		
$\rho = 0.4$	20.32%	1.95%	81.54%	0.10%		
$\sigma = 0.2$	62.09%	0.40%	95.47%	0.03%	65.92%	0.76%
$\sigma = 0.8$	27.39%	7.38%	78.93%	0.08%	53.28%	19.18%
$\tau = 0.1$	13.96%	0.82%	85.07%	0.02%	18.91%	1.69%
$\tau = 0.35$	43.42%	8.99%	81.49%	0.14%	66.72%	20.05%
$r_f = 0.01$	25.20%	3.16%	83.62%	0.02%	56.44%	14.85%
$r_f = 0.05$	31.04%	4.65%	86.70%	0.18%	54.25%	13.48%
$T = 1$	46.96%	4.40%	93.74%	0.22%	55.72%	10.65%
$T = 2.5$	35.19%	3.84%	89.37%	0.12%	54.97%	13.92%
$\alpha_F = 0.05$	47.41%	10.68%	81.18%	0.10%	68.40%	21.29%
$\alpha_F = 0.2$	17.27%	1.34%	87.68%	0.06%	29.09%	4.16%
$\alpha_B = 0.1$	30.34%	4.54%	86.63%	0.17%		
$\alpha_B = 0.4$	28.14%	3.91%	83.61%	0.04%		
$\gamma = 0.85$	30.19%	4.50%	86.04%	0.14%		
$\gamma = 0.9$	31.53%	4.90%	87.47%	0.27%		
$\gamma = 0.95$	71.93%	23.65%	94.77%	10.50%		
$\theta = 0.25$	29.78%	4.38%	85.75%	0.11%		
$\theta = 0.5$	30.89%	4.71%	87.03%	0.21%		
$\theta = 0.75$	65.54%	19.69%	95.34%	10.10%		

Table 4
Bank leverage for banks with varying portfolios.
Table 4 reports how bank leverage and default rates vary with differing bank portfolios. The first row is our benchmark bank as described in Section 3. The later rows consider banks that hold only loans to firms (with varying leverage) or only mortgages (with varying loan-to-value (LTV) ratios). The first pair of columns uses our benchmark parameter assumptions. The second set of columns uses $T = 2.5$ as the maturity assumption.

	Base case		$T = 2.5$	
	Leverage	Default rate	Leverage	Default rate
Diversified bank	85.01%	0.08%	89.37%	0.12%
Bank lending only to firms				
Leverage of 15%	90.24%	0.11%	98.20%	0.05%
Leverage of 25%	81.17%	0.19%	93.44%	0.14%
Leverage of 35%	73.06%	0.26%	86.54%	0.26%
Leverage of 55%	59.51%	0.35%	73.81%	0.43%
Leverage of 75%	48.82%	0.37%	61.52%	0.52%
Bank lending only via mortgages				
LTV of 60%	87.72%	0.07%	92.85%	0.10%
LTV of 70%	85.61%	0.07%	90.09%	0.12%
LTV of 80%	84.08%	0.07%	87.78%	0.12%
LTV of 90%	83.04%	0.06%	86.10%	0.12%
LTV of 100%	82.41%	0.06%	85.05%	0.10%

Table 5
Bank risk taking with moral hazard and capital regulation.
Table 5 reports the leverage and default probability of a bank with insured deposits or with the possibility of a debt guarantees under various capital regulation schemes (no regulation, Basel standardized approach, Basel standardized approach with a doubled equity requirement, Basel IRB approach, and Basel IRB approach with a doubled equity requirement, respectively). The bank is modeled using the parameters in Section 3.

	No regulation		Basel: Standardized				Basel: IRB			
			Current ($h = 8\%$)		Doubled ($h = 16\%$)		Current		Doubled	
	Leverage	Def. rate	Leverage	Def. rate	Leverage	Def. rate	Leverage	Def. rate	Leverage	Def. rate
Base case	85.01%	0.08%	85.01%	0.08%	85.01%	0.08%	85.01%	0.08%	85.01%	0.08%
Section 6.1: Insured deposits of amount γV_{BD}										
$\gamma = 0.85$	86.04%	0.13%	86.04%	0.13%	86.04%	0.13%	86.04%	0.13%	86.04%	0.13%
$\gamma = 0.9$	87.47%	0.27%	87.47%	0.27%	87.47%	0.27%	87.47%	0.27%	87.47%	0.27%
$\gamma = 0.95$	94.77%	10.50%	89.50%	1.10%	88.80%	0.80%	89.50%	1.10%	88.05%	0.34%
Section 6.2: Bailout of debtholders with probability θ										
$\theta = 0.25$	85.75%	0.11%	85.75%	0.11%	85.75%	0.11%	85.75%	0.11%	85.75%	0.11%
$\theta = 0.5$	87.03%	0.21%	87.03%	0.21%	87.03%	0.21%	87.03%	0.21%	87.03%	0.21%
$\theta = 0.75$	95.34%	10.10%	89.49%	0.84%	88.80%	0.66%	89.49%	0.84%	88.09%	0.34%