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Abstract

We study the influence of unsecured debt (subdebt) and of bail-in debt on banks' risk-taking in a contingent claim model, while considering the bargaining between stockholders and debtholders. We show that replacing stock with subdebt: (1) leads to fewer risk-shifting events, but generates a higher level of risk when stockholders have strong bargaining power, and (2) does not affect asset risk when side-payments are possible. Further, severe regulatory corrective measures might have adverse effects on risk-shifting. Finally, in a bank with bail-inable debt, an increase in debt write-down increases the magnitude, yet decreases the likelihood, of risk-shifting events.

Keywords: Risk-taking, asset risk, financial institutions, stress test, leverage, bargaining, bail-in debt.
JEL Classification: G20, G21, C78

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1 Introduction

As the size and complexity of financial institutions has increased, regulators' ability to control banks' asset risk using traditional supervisory techniques, such as minimum capital requirements and supervisory review, has eroded. In response, regulators encourage banks to issue unsecured debt, which is subordinated to their deposits (hereafter, subdebt). It is believed that since the subdebtholders are sophisticated creditors they can increase banks' transparency (Hart and Zingales, 2011) and affect banks' behavior ("direct discipline") in a way that is aligned with the deposit insurer's incentive (Flannery, 2001; Chen, Goldstein, Huang, and Vashishtha, 2020). Further, subdebtholders can indirectly discipline banks by providing a signal of the banks' risk to the regulator (Gorton and Santomero, 1990; Dewatripont and Tirole, 1993).

Following the 2008 financial crisis, the use of debt as a monitoring tool has been questioned due to mixed evidence on its effectiveness. On the one hand, the empirical literature finds that subdebt reduced banks' risk-taking, both during the financial crisis and in the following period (Nguyen, 2013; Belkhir, 2013; Danisewicz, McGowan, Onali, and Schaeck, 2018; Francis, Hasan, Liu, and Wang, 2019). On the other hand, financial institutions with subdebt as part of their capital structure defaulted or were bailed out using taxpayers' money (Calomiris and Herring, 2013).[1]

The considerable amount of implicit guarantees and direct investment of taxpayers' money during the 2008 financial crisis led regulators to adopt "bail-in" tools for managing the failure of banks without the usage of taxpayer money. In a bail-in event, the claims of unsecured creditors of the failed bank are written down or converted into equity in order to absorb the losses and recapitalize the bank without causing the disruption associated with insolvency proceedings in financial institutions (Chennells and Wingfield, 2015). Crucially, a bail-in is not negotiated at the time of distress; instead, it is imposed upon the bank and its creditors by the authority responsible for bank resolution (Philippon and Salord, 2017).

Motivated by the inconsistent assessments of the ability of subdebt to mitigate risk-taking that led to the introduction of bail-inable debt as a mandatory capital instrument, and the adoption of reforms that can affect creditors' bargaining power such as the introduction of

[1] The pre-crisis literature on the informativeness of subdebt yields on the issuing banks' financial condition presented mixed results as well (Gorton and Santomero, 1990; Flannery and Sorescu, 1996; Evanoff and Wall, 2001).

banks' mandatory stress tests (Goldstein and Leitner, 2018; Gofman, 2017), we study how risk-taking is affected when replacing part of a bank's common equity with subordinated debt or with bail-inable debt, given the relative bargaining power of the debtholder. We consider both the extreme cases where all bargaining power is in the hands of either the stockholders or the debtholders, as well as the intermediate cases of intermediate levels of bargaining power.

The analysis in the paper is conducted in two main steps. First, we model the fair value of a bank's different liabilities using a framework in which the bank's assets are risky debt claims. Next, we apply a game-theoretic approach to the strategic bargaining interaction between the bank's claimholders and its borrowers, to find the equilibrium level of asset risk.

In a framework where bank assets are risky debt claims, a bank's asset is a loan to its borrower. Therefore, the bank's asset value and asset risk are derived from the borrower's asset value and asset risk (Dermine and Lajeri, 2001; Nagel and Purnanandam, 2020; Peleg Lazar and Raviv, 2017). We assume that since banks are efficient at monitoring and limiting the risk of their borrowers (Datta, Iskandar-Datta, and Patel, 1999; Ahn and Choi, 2009), the borrower cannot increase its level of asset risk without the bank's consent. Further, while the regulator conducts periodic audits, setting the bank's asset risk in accordance with its policy, these audits are sufficiently infrequent that risk-shifting might occur between audit events.[2] Thus, a change in the bank's asset risk might occur between audits if the bank and the borrower agree on a new level of risk.

Consistent with the recent literature that shows that debtholders have an active role in firms' decision making, especially when the firm is in or near financial distress (Chava and Roberts, 2008; Roberts and Sufi, 2009; Nini, Smith, and Sufi, 2012), we assume that a bank's preferred level of asset risk is the result of a bargaining process. The result of the bargaining process depends on the relative bargaining power of the bank's claimholders. This is done by applying the well-known concept of an asymmetric Nash bargaining solution (Nash, 1950; Kalai, 1977).[3] Specifically, we assume that risk-shifting occurs only if both the stockholders

[2] Several papers suggest that since the regulator conducts on-site examinations of banks, it is better than other claimants at uncovering negative information; however, the additional information that is revealed becomes stale within a few months (Berger and Davies, 1998; DeYoung, Flannery, Lang, and Sorescu, 1998), suggesting that risk-shifting is possible between audit events.

[3] The asymmetric Nash bargaining solution is commonly applied to study situations in which players have to make a joint decision, given a default outcome that is implemented if the players do not reach an agreement. Recent applications of Nash bargaining solution to joint decisions of creditors and stockholders are Hugonnier, Malamud, and Morellec (2015); Corbae and D'Erasmo (2017); see also Allen, Chapman, Echenique, and Shum (2016) for an interbank loan market bargaining power analysis based the game core.

and the debtholders are better off increasing asset risk.

We find that substituting a portion of a bank stock with subdebt decreases the range of asset values for which risk-shifting takes place, since subdebtholders have an outside option and therefore must be better off after the negotiation. When risk-shifting does occur in equilibrium, the equilibrium level of asset risk is between the level that maximizes the value of the stock and the level that maximizes the value of the subdebt, and this level of asset risk decreases with the subdebtholders' bargaining power. We show that the substitution of part of a bank's stocks with subdebt can increase the equilibrium level of asset risk if the subdebtholders' bargaining power is not sufficiently high. The intuition is that the increase in subdebt, on the one hand, increases bank leverage, which should lead to an increase in risk-taking, and, on the other hand, introduces monitoring efforts by the subdebtholders, which should lead to a decrease in risk-taking. The answer to the question of which of these two effects is stronger depends on the stockholders' bargaining power.

As discussed above, we assume that risk-shifting occurs only if both the stockholders and the subdebtholders of the bank are better off with it. This assumption implies that if there is no agreement regarding the level of asset risk, risk is set to the initial level of risk. The assumption can be motivated in two ways. First, the relationship between the claimholders fits the case of a repeated game. Second, in case of disagreement the information regarding risk-shifting is brought to the regulator who sets the level of asset risk back to its initial level. Interestingly, we show that as the initial level of asset risk decreases, i.e., as the regulator is stricter in audit periods, the threat of stricter corrective actions can have the adverse effect of increasing the equilibrium level of asset risk.

The comparison between a bank with subdebt in its capital structure and a bank with no such instrument, i.e., a bank financed with stock and deposits only, leads us to analyze the new capital instrument that was introduced following the crisis: bail-in debt. We compare a bank with bail-in debt in its capital structure with the previous two alternatives: (1) non-bail-inable subdebt, and (2) no debt (the debt is substituted by stock). In our model, bail-in debt is written down by a known percent at the time of financial distress. Therefore, a bail-in event transfers value from the debtholders to the stockholders. Following a bail-in event the regulator sets the bank's level of asset risk to its initial level. This regulatory behavior is in line with findings from Tsyplakov, Berger, Ongena, and Nistor (2020) who show that regulators do intervene in banks' decision-making following a bail-in event.[4]

[4]Another example of the regulator's complex role in a bail-in event discussed in Walther and White

We find that when bail-in debt is issued and there is risk-shifting, the equilibrium level of asset risk is (1) between the level that maximizes the value of debt and the level that maximizes the value of stock, and (2) increasing with the size of the write-down. The second property can be explained by the fact that as the write-down increases, the stockholders' position in case of no agreement improves. In addition, the range of asset values where risk-shifting occurs is decreasing with the size of the write-down, meaning that as the transfer from debtholders to stockholders increases, the range of asset values for which there is no risk-shifting and a bail-in event occurs increases as well.

We extend the framework of analysis to address a concern raised in previous literature, by allowing side payments between the stockholders and the subdebtholders.[5] We solve the model in this case in two steps. First, the stockholders and the subdebtholders jointly choose the level of asset risk that maximizes the sum of their payoffs. Next, the side payment is chosen as the unique Nash solution to the bargaining problem of dividing the joint payoff between the two claimholders. We find that both the asset value threshold for risk-shifting and the equilibrium level of asset risk, in the case of a bank with subdebt where side payments are possible, are identical to those of a bank funded by just stock and deposits, with no subdebt. In other words, if side payments are a concern, a mandatory requirement to issue subdebt would not affect the level of risk in equilibrium.

Since the 2008 financial crisis, the issue of bank transparency has been heavily debated. We contribute to the understanding of this issue by showing that more restrictive, yet infrequent, regulatory corrective measures in the form of a lower level of asset risk prescribed at the time of an audit may motivate claimholders to agree on a higher level of asset risk in the bargaining process. Thus, our analysis is complementary to Chen and Hasan (2011) who show that less frequent audits lead to more risk-shifting. We strengthen this result by showing that more restrictive measures taken at those infrequent audits lead to even more risk-shifting between audits.

Our paper is part of the growing literature that deals with loss-absorbing liabilities in banks. Studies (Raviv, 2004; Flannery, 2005; Chen, Glasserman, Nouri, and Pelger, 2017; Glasserman and Nouri, 2012) have suggested the use of contingent capital, a debt instrument

(2020) is the signaling effect of a regulator-triggered bail-in event.

[5] Furlong and Keeley (1987) show that stockholders can compensate uninsured debtholders for increased risk in the form of higher promised interest rates. Calomiris (1999) and Chen and Hasan (2011) discuss the need to regulate the design of subordinated debt, including its maturity and maximum allowable yield, in order to assure that subdebtholders are motivated to control stockholders' risk-taking.

that can be converted into stock in time of distress, as a means of recapitalizing banks while reducing reliance on taxpayers' money. A special case of contingent convertible is bail-in debt, which is known as "write-down debt", where some of the debt is forgiven in time of distress. Previous studies show that it can encourage risk-taking by banks (Pennacchi, 2010; Hilscher and Raviv, 2014; Martynova and Perotti, 2018). Moreover, it is shown by Avdjiev, Bogdanova, Bolton, Jiang, and Kartasheva (2020) that contingent capital with write-down is vastly used by banks.

Our paper differs from this literature from a conceptual standpoint since we do not assume that the stockholders of the bank determine the level of risk solely, but rather we assume a bargaining process between the stockholders and the bail-in debtholders that may be subject to regulatory intervention. Moreover, we assume that bank assets are risky debt claims and therefore the value of assets is capped from above. As we use these assumptions, the effect of bail-in debt on risk-taking and cost of deposit insurance is more subtle than observed in the literature. We show that as the size of the debt write-down increases there are fewer risk-shifting events but, when there is risk-shifting, it is to a higher level of asset risk.[6]

Lastly, the paper is also related to the strand of the literature that studies the question of whether mandatory disclosure of financial information can be welfare-improving (Goldstein and Leitner, 2018; Frenkel, Guttman, and Kremer, 2020). In our paper the disclosure of information by stockholders can be interpreted as an increase in debtholders' bargaining power.

The study of banking resolution in time of distress and its effect on risk-taking has been a high priority during the Covid-19 pandemic, when there is a need to assess the risk of many financial institutions negatively affected by the slowdown in business and the resulting economic state (IMF, 2020; De Vito and Gomez, 2020). The decrease in borrowers' asset value, in fact, leads to an increase in banks' leverage ratio and cost of default (Reinders, Schoenmaker, and Van Dijk, 2020).

The rest of the paper is organized as follows. Section 2 describes our model and the liability structures of the bank and its borrower and expresses the values of their different claims. Section 3 discusses the different claimholders' risk preferences. We present the

[6]By contrast, when a bail-in has a high conversion ratio, i.e., the stockholders are highly diluted, both empirical (Giuliana, 2019) and theoretical (Lambrecht and Tse, 2019) papers suggest that bail-in debt increases market discipline.

bargaining model and its solution in Section 4. In Section 5 we present two extensions of our model and analyze the effect of side payments and bail-in debt. Section 6 presents a numerical example of results, and Section 7 concludes.

2 The Model

A corporation is funded by stock with market value S_C and by a single loan with face value F_C and market value B_C. The loan is a zero-coupon loan maturing at time T and the bank is its sole creditor. The bank is funded by stock with a market value of S_B, deposits with a face value of F_{Dep} and a market value of B_{Dep}, and zero-coupon debt, which is subordinated to the deposits (subdebt) and has a face value of F_{Sub} and a market value of B_{Sub}. We define deposits as debt claims that mature at the time of a regulatory audit, T, following Marcus and Shaked (1984) and Ronn and Verma (1986).[7] Following a similar logic, we assume that the subdebt matures at time T as well.

The corporation's asset value follows a geometric Brownian motion. The bank's asset is the loan to the corporation and therefore the bank's asset value and the bank's level of asset risk depend on its borrower's asset value and its borrower's level of asset risk; i.e., the bank's asset risk is a function of the borrower's asset value and the volatility of the assets.

The bank can monitor and limit its borrower's risk-taking, so that the corporation can only increase the level of its asset risk with the consent of the bank. We assume that the bank's depositors are unable and unmotivated to monitor the bank and therefore they are not an active agent in the model (Cooper and Ross, 2002). The risk of the bank is determined in a bargaining process between its stockholders and subdebtholders as discussed in Section 4. For comparison, we also consider the case where risk is determined solely by the stockholders and the case where risk is determined solely by the subdebtholders with no bargaining (Section 3).

We assume a regulator that conducts periodic audits to assess and align the bank's level of asset risk with the regulatory policy.[8] However, at the time of an audit the regulator

[7]This is also consistent with the finding of Berger, Davies, and Flannery (2000) who show that supervisory assessments following an on-site inspection (audit) are more accurate than the market in predicting changes in bank performance.

[8]The question of what is the optimal level of asset risk that should be set at the time of a regulatory audit as well as the relation between the optimal level and the actual level that the regulator chooses is beyond the scope of our analysis.

can force some level of risk, which we call the initial level of risk, σ_0. We assume audits are sufficiently infrequent, such that the bank's claimholders have sufficient time to shift the bank's level of asset risk between audits by allowing the borrower to change its level of asset risk. In our model, we focus on such points in time and inquire into the conditions under which risk-shifting can occur.

Throughout the paper the objective of each claimholder is to maximize the market value of its claim. In what follows we study the preferences of the different claimholders at time $t \in (0, T)$ – after the loan contract is set but before the time of the next audit, i.e., before the time of debt maturity.

In the rest of this section we describe in detail the liability structures of the bank and of the borrower and express the value of their different claims. For convenience, all the notations are summarized in Appendix A.

2.1 The borrower's liability structure

The value of the corporation's assets, V_C, under the risk-neutral measure follows a geometric Brownian motion according to the following equation:

$$dV_{C,t} = rV_{C,t}dt + \sigma V_{C,t}dW,$$

where r is the instantaneous risk-free rate of return, σ is the instantaneous volatility of the corporation's assets, and dW is a standard Wiener process under the risk-neutral probability measure.

A default event occurs at debt maturity, T, if the corporation's asset value, $V_{C,T}$, is lower than the face value of its debt. If default occurs, the bank receives the residual assets of the borrowing corporation, $V_{C,T}$. Otherwise, debt is fully paid and the creditor receives the total face value of debt, F_C. Therefore, the payoff to the corporation's creditors at debt maturity is equal to $B_{C,T} = \min[V_{C,T}, F_C]$. This expression can be rearranged and expressed as

$$B_{C,T} = F_C - \max[F_C - V_{C,T}, 0]. \quad (1)$$

As suggested by Merton (1974), this payoff is equivalent to the payoff of a risk-free debt with a face value of F^C and a short position in a European put option. Therefore, the present value of the corporation's debt is given by

$$B_{C,t} = F_C \cdot e^{-r(T-t)} - Put_t(V_{C,t}, F_C, \sigma, T-t, r),$$

where $Put_t(V_{C,t}, F_C, \sigma, T-t, r)$ is the value at time t of a European put option on the corporation's asset value and the option's strike price is equal to the face value of it's debt F_C. Under the above-described geometric Brownian motion the value of the option can be found using the standard Black and Scholes (1973) equation.

Since the borrower's stock is the residual claim, its payoff at debt maturity is $S_{C,T} = \max[V_{C,T} - F_C, 0]$. This payoff can be replicated by a European call option on the value of the corporation's assets, with a strike price equal to the face value of its debt (Galai and Masulis, 1976). Therefore the value of stock at time t is

$$S_{C,t} = Call_t(V_{C,t}, F_C, \sigma, T-t, r),$$

where $Call_t(V_{C,t}, F_C, \sigma, T-t, r)$ is the value of a European call option according to the Black and Scholes (1973) equation.

2.2 The bank's liability structure

Since the bank's asset is the loan that funds the activity of the corporation, described in Eq. (1), we can express the payoff of the bank's assets at maturity as

$$V_{B,T} = B_{C,T} = F_C - \max[F_C - V_{C,T}, 0]. \tag{2}$$

Depositors The depositors are the senior claimholders of the bank and their payoff at time T is the minimum between the value of the bank's assets and the face value of its deposits: $B_{Dep,T} = \min[V_{B,T}, F_{Dep}]$. Rearranging under the assumption that the face value of the corporation's debt is higher than the face value of the bank's deposits,[9] $F_C > F_{Dep}$ we can express the depositor's payoff at maturity as $B_{Dep,T} = F_{Dep} - \max[F_{Dep} - V_{C,T}, 0]$. This payoff can be replicated by a long position in a risk-free debt with a face value of F_{Dep} and a short position in a European put option on the borrower's assets, with a strike price equal to

[9] As the bank funds the borrower's loan using both stock and debt, the face value of the borrower's debt, F_C, must be higher than the face value of the bank's own debt, $(F_{Dep} + F_{Sub})$, and, therefore, also higher than F_{Dep}.

the face value of the bank's deposits. Therefore, the value of the deposits at any time t prior to debt maturity can be expressed as $B_{Dep,t} = F_{Dep} \cdot e^{-r(T-t)} - Put_t(V_{C,t}, F_{Dep}, \sigma, T-t, r)$.

The bank's issued debt The subdebtholders receive at debt maturity a face value of F_{Sub} if the value of the borrower's assets is above the bank's total face value of debt. Otherwise, their payoff is the maximum between zero and the difference between the value of the borrower's assets and the face value of the bank's deposits. This payoff can be rearranged and expressed as

$$B_{Sub,T} = \max\left[V_{C,T} - F_{Dep}, 0\right] - \max\left[V_{C,T} - (F_{Dep} + F_{Sub}), 0\right],$$

which is equivalent to a long position in a European call option with a strike price equal to the face value of the bank's deposits, F_{Dep}, and a short position in a European call option with a strike price equal to the face value of the bank's total debt, $(F_{Dep} + F_{Sub})$. Therefore, the value of the subdebt prior to debt maturity is

$$B_{Sub,t} = Call_t(V_{C,t}, F_{Dep}, \sigma, T-t, r) - Call_t(V_{C,t}, F_{Dep} + F_{Sub}, \sigma, T-t, r). \quad (3)$$

Stock Since the bank's stockholders are the residual claimholders, their payoff at maturity is $S_{B,T} = \max\left[V_{B,T} - (F_{Dep} + F_{Sub}), 0\right]$. If the bank is solvent at maturity, the stockholders receive a payoff of $F_C - (F_{Dep} + F_{Sub})$, which is the maximum payoff that the bank's stockholders can receive. This differs from the basic contingent claims approach in which the stockholders' payoff is unbounded from above. When we expand this payoff it can be expressed as

$$S_{B,T} = \max[V_{C,T} - (F_{Dep} + F_{Sub}), 0] - \max[V_{C,T} - F_C, 0].$$

The payoff of the stock can be replicated by a long position in a European call option, with a strike price equal to the face value of the bank's total debt, $(F_{Dep} + F_{Sub})$, and a short position in a European call option, with a strike price equal to the face value of the corporation's debt, F_C. Therefore, the value of the bank's stock prior to debt maturity is

$$S_{B,t} = Call_t(V_{C,t}, F_{Dep} + F_{Sub}, \sigma, T-t, r) - Call_t(V_{C,t}, F_C, \sigma, T-t, r). \quad (4)$$

The value of the bank's assets and the payoff to each of the bank's claimholders at debt maturity is described in Figure 1.

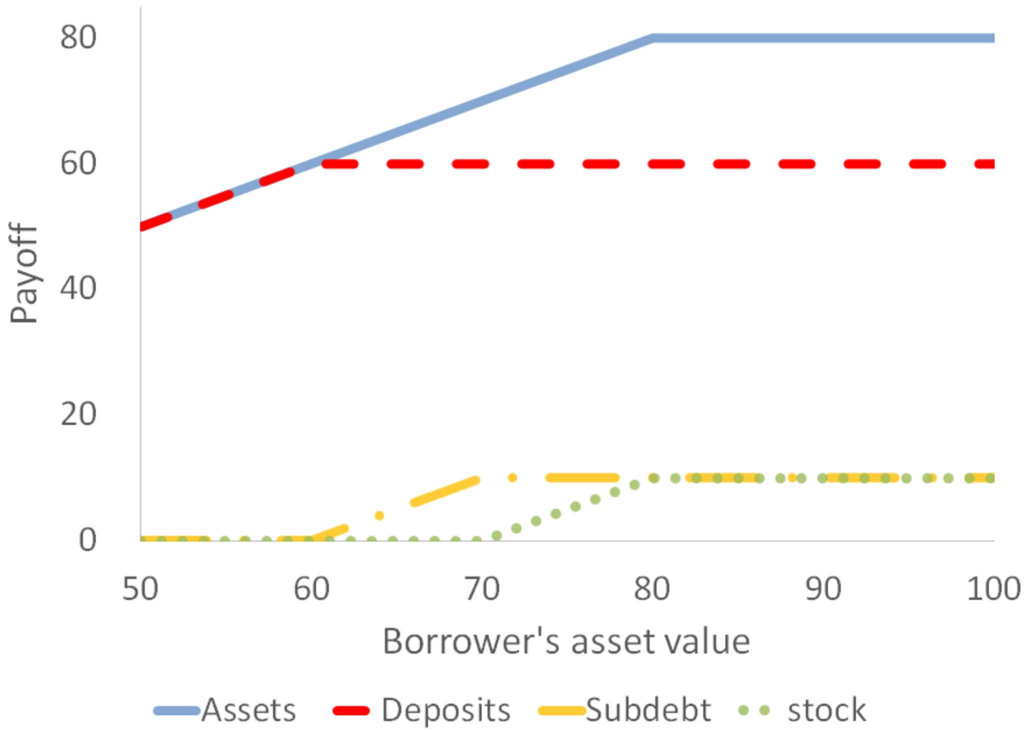


Figure 1: The bank's asset value and the payoffs to the bank's depositors, subdebtholders, and stockholders at debt maturity. The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subdebt is $F_{Sub} = 10$.

3 Sensitivity of the claimholders to asset risk

The main goal of our paper is to find the equilibrium level of asset risk under different levels of bargaining power of the bank's claimholders. This analysis enables us to find the cost of deposit insurance of banks with different capital structures and different levels of claimholders' bargaining power. Therefore, in this section we first study the sensitivity to asset risk of the stock of the borrower and of the liabilities issued by the bank (debt and equity). The analysis in this section is mostly not novel to our paper and is based on previous contributions. However, it is presented as it is essential for the understanding of our framework of analysis presented in Section 4. Further, the analysis in this chapter yields the benchmark results where there is no bargaining by the claimholders and one of them controls the level of asset risk. Moreover, since we study the equilibrium level of risk of a bank with subdebt as part of its capital structure, it is essential to make a comparison to the alternative benchmark case, which is a bank with no subdebt as part of its capital structure, and instead has only deposits and stock.

3.1 Risk preferences of the stockholders of the borrower

In line with the classic agency theory (Jensen and Meckling, 1976), the stockholders of the borrower (the borrowing corporation) are always better off increasing the level of asset risk. We omit the proof of this well-known standard result, which is implied by the fact that the value of a call option is strictly increasing with the level of risk of the underlying asset.

Claim 1. *The value of the stock of the bank's borrower is increasing with the level of asset risk.*

This claim implies that the borrower's stockholders always prefer the highest level of asset risk allowed by the bank and would never agree to decrease risk. Therefore, in the rest of our analysis we focus on the maximum allowed level of the borrower's asset risk as chosen by the agents controlling the bank's decision-making, which must be weakly higher than the initial level of asset risk in order for the stockholders of the borrower to agree. We assume that this maximum allowed level of risk is feasible given the technological limitations governing the borrower's assets, and that the borrower's shareholders always shift the level of asset risk to it.

3.2 Auxiliary result: Sensitivity to risk of bull spread

The payoffs to both the bank's stockholders (Eq. (4)) and its subdebtholders (Eq. (3)) are equivalent to a portfolio of two call options with the same maturity date on the value of the borrower's assets, where each payoff is defined by options with different strike prices. The value of such a position is known among options traders and investors as a "bull spread." Both payoffs can be represented, generally, as

$$P_t(V_t, F_1, F_2, \sigma, T-t, r) = Call_t(V_t, F_1, \sigma, T-t, r) - Call_t(V_t, F_2, \sigma, T-t, r),$$

where V_t is the asset value at time t, $F_1 < F_2$ denote the strike prices of the call options, $T-t$ is the time, and r is the instantaneous risk-free rate of return.

Define the following two threshold values $0 < H^{**} < H^*$ as

$$H^*(F_1, F_2, T-t, r) \equiv e^{-r(T-t)}\sqrt{F_1 \cdot F_2} \tag{5}$$

and

$$H^{**}(F_1, F_2, T-t, r, \sigma_0) \equiv e^{-\left(r+\frac{\sigma_0^2}{2}\right)(T-t)} \sqrt{F_1 \cdot F_2}, \tag{6}$$

and for each $V_t < H^*$ define the payoff-maximizing asset risk σ^{max} as

$$\sigma^{max}(F_1, F_2, T-t, r, V_t) \equiv \sqrt{\frac{1}{T-t} \ln\left(\frac{F_1 \cdot F_2}{(V_t)^2}\right) - 2r}. \tag{7}$$

The following auxiliary result characterizes the value P_t of a portfolio of two call options with strike prices $F_1 < F_2$ as a function of the asset risk. It exhibits four key properties. The portfolio value is (1) decreasing with the asset risk if $V_t > H^*$, and (2) hump-shaped in the asset risk if $V_t < H^*$. In this latter case, (3) the maximum of the portfolio value is obtained for the level of risk σ^{max}, and (4) the level of asset risk that maximizes the portfolio's value is higher than σ_0 if and only if $V_t > H^{**}$. Formally,

Proposition 1. *The value of the portfolio $P_t(V_t, F_1, F_2, \sigma, T-t, r)$ is (1) decreasing with the value of asset risk σ if $V_t > H^*(F_1, F_2, T-t, r,)$, and (2) hump-shaped (unimodal) in the asset risk if $V_t < H^*(F_1, F_2, T-t, r,)$. In this latter case the maximum is obtained for the level of asset risk $\sigma^{max}(F_1, F_2, T-t, r, V_t)$. Moreover, the maximizing level is higher than σ_0 (i.e., $\sigma^{max}(F_1, F_2, T-t, r, V_t) > \sigma_0$) if and only if $V_t < H^{**}(F_1, F_2, T-t, r, \sigma_0)$.*

The proof, which is presented in Appendix B.1, mostly summarizes existing results: the threshold of asset value is developed in Black and Cox (1976) and Gorton and Santomero (1990), and the level of asset risk is derived in Peleg Lazar and Raviv (2017).

3.3 Bank stockholders' risk preferences

Since the value of the bank's stock, as described in Eq. (4), is equal to the value of a portfolio composed of a call option with a strike price of $(F_{Dep} + F_{sub})$, minus the value of a call option with a strike price of F_C, Proposition 1 applies to it. Therefore, we define the thresholds as

$$H^*_{Stk} \equiv e^{-r(T-t)} \sqrt{(F_{Dep} + F_{Sub}) \cdot F_C} \tag{8}$$

and

$$H^{**}_{Stk} \equiv e^{-\left(r+\frac{\sigma_0^2}{2}\right)(T-t)} \sqrt{(F_{Dep} + F_{Sub}) \cdot F_C}, \tag{9}$$

and the level of asset risk that maximizes the value of the stock, σ_{Stk}^{max}, as

$$\sigma_{Stk}^{max} \equiv \arg\max_{\sigma} S_B = \sqrt{\frac{1}{T-t} \ln\left(\frac{(F_{Dep} + F_{sub}) \cdot F_C}{(V_{C,t})^2}\right) - 2r}. \tag{10}$$

Thus, we can summarize the relationship between the value of the stock and the borrower's asset value and risk in the following corollary.

Corollary 1. *The value of the bank's stock is (1) decreasing with the value of its borrower's asset risk if $H_{Stk}^{*} < V_{C,t}$, and (2) hump-shaped (unimodal) in the asset risk if $H_{Stk}^{*} > V_{C,t}$, and, in this case, its maximum is obtained for the level of asset risk σ_{Stk}^{max}. Moreover, the level of asset risk that maximizes the value of the bank's stock is higher than the initial level of asset risk (i.e., $\sigma_{Stk}^{max} > \sigma_0$) if and only if $V_{C,t} < H_{Stk}^{**}$.*

The proof is immediate from Eq. (4) and Proposition 1.

Since, when the value of the asset is below H_{Stk}^{**}, the value of the stock is hump-shaped with respect to asset risk and the maximum value is received with a level of asset risk greater than the initial level of asset risk, we can derive the following corollary.

Corollary 2. *When the bank's stockholders control the bank and therefore can enforce their choice of an upper bound on the borrower's asset risk, risk-shifting occurs if and only if $V_{C,t} < H_{Stk}^{**}$. When there is risk-shifting, the level of asset risk increases to σ_{Stk}^{max}.*

The level of asset risk preferred by the bank's stockholders, $\sigma_{S_B}^{max}$, is an increasing function of both the borrower's leverage, $F_C/V_{C,t}$, and the leverage of the bank, $(F_{Dep} + F_{sub})/V_{C,t}$. Thus, the level of asset risk preferred by the bank's stockholders depends on the financial risk of both the bank and of its borrower. In addition, since the face value of the bank's debt is lower than that of the borrower's debt, the threshold H_{Stk}^{**} is lower than the face value of the borrower's debt. Thus, risk-shifting is limited to states where the bank's borrower is in financial distress and the maximum level of asset risk is limited to σ_{Stk}^{max}, the level of asset risk that maximizes the value of the stock.[10]

[10] Since the bank's stockholders' payoff is limited from above, their utility from the level of asset risk is hump-shaped. This would not be the case if the bank's asset value was unbounded, in which case the equilibrium level of asset risk would be unbounded as well (see the related analysis in Heller, Peleg Lazar, and Raviv, 2019).

Remark 1. Throughout the analysis we assume that the value of the bank's asset is limited from above by the face value of the borrower's loan. However, our results can be adapted to a setup in which the value of the bank's asset is not capped, and follows a standard geometric Brownian motion. Specifically, an uncapped bank's asset value can be approximated in our model by assuming that the face value of the borrower's debt F_C is very large relative to the borrower's asset value (i.e., by assuming that $F_C >> V_C$). By looking at the limit in which $F_C \rightarrow \infty$ one can apply the formulas presented in the paper to obtain the equilibrium level of asset risk obtained when the bank's asset value is not capped.

3.4 Bank subdebtholders' risk preferences

Since, as shown in Black and Cox (1976) and formulated in Eq. (3), the value of the bank's subdebt is equal to a portfolio of a call option with a strike price of F_{Dep} minus the value of a call option with a strike price of $(F_{Dep} + F_{sub})$, Proposition 1 applies to it. Therefore we define the thresholds as

$$H^{*}_{Sub} \equiv e^{-r(T-t)}\sqrt{F_{Dep} \cdot (F_{Dep} + F_{sub})} \tag{11}$$

and

$$H^{**}_{Sub} \equiv e^{-\left(r+\frac{\sigma_0^2}{2}\right)(T-t)}\sqrt{(F_{Dep} + F_{Sub}) \cdot F_{Dep}}, \tag{12}$$

and the level of asset risk that maximizes the value of the subdebt, σ^{max}_{Sub}, as

$$\sigma^{max}_{Sub} \equiv \arg\max_{\sigma} B_{Sub,t}(\sigma) = \sqrt{\frac{1}{T-t}\ln\left(\frac{(F_{Dep} + F_{sub}) \cdot F_{Dep}}{(V_{C,t})^2}\right) - 2r}, \tag{13}$$

which allows us to apply Proposition 1 to the bank's subdebt in the following corollary.

Corollary 3. *The market value of the subdebt claim is (1) decreasing with the level of the borrower's asset risk if $H^{*}_{Sub} < V_{C,t}$, and (2) hump-shaped (unimodal) in the level of asset risk if $H^{*}_{Sub} > V_{C,t}$, and, in this case, its maximum is obtained for the level of asset risk σ^{max}_{Sub}. Moreover, the level of asset risk that maximizes the value of the subdebt is higher than the initial level of risk (i.e., $\sigma^{max}_{Sub} > \sigma_0$) if and only if $V_{C,t} < H^{**}_{Sub}$.*

The proof is immediate from Eq. (3) and Proposition 1.

Since, when the value of the asset is below H^{**}_{Sub}, the value of the subdebt is hump-shaped with respect to asset risk, and the maximum value of the subdebt is received when the value of risk is greater than the initial level of asset risk, we can derive the following corollary.

Corollary 4. *When the subdebtholders control the bank's decisions, risk-shifting occurs if and only if* $V_{C,t} < H^{**}_{Sub}$. *When there is risk-shifting, the level of asset risk increases to* σ^{max}_{Sub}.

Observe that even when the subdebtholders have full control of the bank's risk-taking, risk-shifting is not avoided completely. However, the subdebtholders' risk-taking motivation is less pronounced than the shareholders' in the following two ways: (1) when the borrower's asset value is between H^{**}_{Sub} and H^{**}_{Stk}, risk-shifting occurs only when the bank is controlled by the stockholders and does not occur when it is controlled by the subdebtholders and (2) when the corporation's asset value is below H^{**}_{Sub}, there is risk-shifting in both cases, but the risk-shifting is less pronounced when the bank is controlled by the subdebtholders, i.e., $\sigma^{max}_{Sub} < \sigma^{max}_{Stk}$. These differences are presented in Figure 2.

3.5 Bank with no subdebt

In this section we analyze a bank with no subdebt as part of its capital structure, where the level of asset risk between audit periods is set solely by the bank's stockholders (Peleg Lazar and Raviv, 2017). This case is an important benchmark that allows us to compare the equilibrium level of risk with the alternative capital structure that includes subdebt.

The bank is funded by deposits with a face value of F_{Dep} and stock. Since the stockholders are the residual claimholders, their payoff at maturity is $S^{NoSub}_{B,T} = \max[V_{B,T} - F_{Dep}, 0]$. When we expand this payoff it can be expressed as $S^{NoSub}_{B,T} = \max[V_{C,T} - F_{Dep}, 0] - \max[V_{C,T} - F_C, 0]$. This payoff can be replicated by a long position in a European call option, with a strike price equal to the face value of the bank's debt, F_{Dep}, and a short position in a European call option, with a strike price equal to the face value of the corporation's debt, F_C. Therefore, the value of the bank's stock prior to debt maturity is

$$S^{NoSub}_{B,t} = Call_t(V_{C,t}, F_{Dep}, \sigma, T-t, r) - Call_t(V_{C,t}, F_C, \sigma, T-t, r). \tag{14}$$

Proposition 1 applies to this case and therefore we define the thresholds as

$$H^{*}_{NoSub} \equiv e^{-r(T-t)}\sqrt{F_{Dep} \cdot F_C} \tag{15}$$

and

$$H^{**}_{NoSub} \equiv e^{-\left(r+\frac{\sigma_0^2}{2}\right)(T-t)}\sqrt{F_{Dep}\cdot F_C}, \tag{16}$$

and the level of risk that maximizes the value of the stock, σ^{max}_{NoSub}, as

$$\sigma^{max}_{NoSub} \equiv \arg\max_{\sigma} S^{NoSub}_{B,t}(\sigma) = \sqrt{\frac{1}{T-t}\ln\left(\frac{F_{Dep}\cdot F_C}{(V_{C,t})^2}\right) - 2r}, \tag{17}$$

which allows us to apply Proposition 1 to the bank's stockholders in the following corollary.

Corollary 5. *The market value of the stock claim in a bank with no subdebt is (1) decreasing with the borrower's level of asset risk if $H^{*}_{NoSub} < V_{C,t}$, and (2) hump-shaped (unimodal) in the level of asset risk if $H^{*}_{NoSub} > V_{C,t}$, and, in this case, its maximum is obtained for the level of asset risk σ^{max}_{NoSub}. Moreover, the level of asset risk that maximizes the value of the subdebt is higher than the initial level of risk (i.e., $\sigma^{max}_{NoSub} > \sigma_0$) if and only if $V_{C,t} < H^{**}_{NoSub}$.*

The proof is immediate from Eq. (14) and Proposition 1.

Since, when the value of the asset is below H^{**}_{NoSub}, the value of the stock is hump-shaped with respect to asset risk and maximized with a level of risk that is above the initial level of asset risk, we can derive the following corollary.

Corollary 6. *When a bank is funded by stock and deposits only, i.e., is not funded by subdebt, risk-shifting occurs if and only if $V_{C,t} < H^{**}_{NoSub}$. When there is risk-shifting, the level of asset risk increases to σ^{max}_{NoSub}.*

The analysis of the risk preferences of the stockholders of a bank with deposits and stock enables us to compare the degree of risk-shifting with an all-else-equal bank except for part of the stock being replaced with subdebt. When the level of risk is controlled by the stockholder, risk-taking in a bank with subdebt occurs whenever the value of assets is below the discounted geometric mean of the face value of the borrowers' debt and the face value of the bank's total debt, H^{**}_{Stk}. In a bank with no subdebt, risk-shifting occurs whenever the value of assets is below the discounted geometric mean of the face value of the borrower's debt and the face value of the deposits, H^{**}_{NoSub}. Since $H^{**}_{Stk} > H^{**}_{NoSub}$ there are less risk-shifting events in a bank with no subdebt than in a bank with subdebt where risk is determined solely by the stockholder. Moreover, when risk-shifting occurs, the chosen level of risk is lower since $\sigma^{max}_{NoSub} < \sigma^{max}_{Stk}$. The increased amount of risk-shifting in a bank with

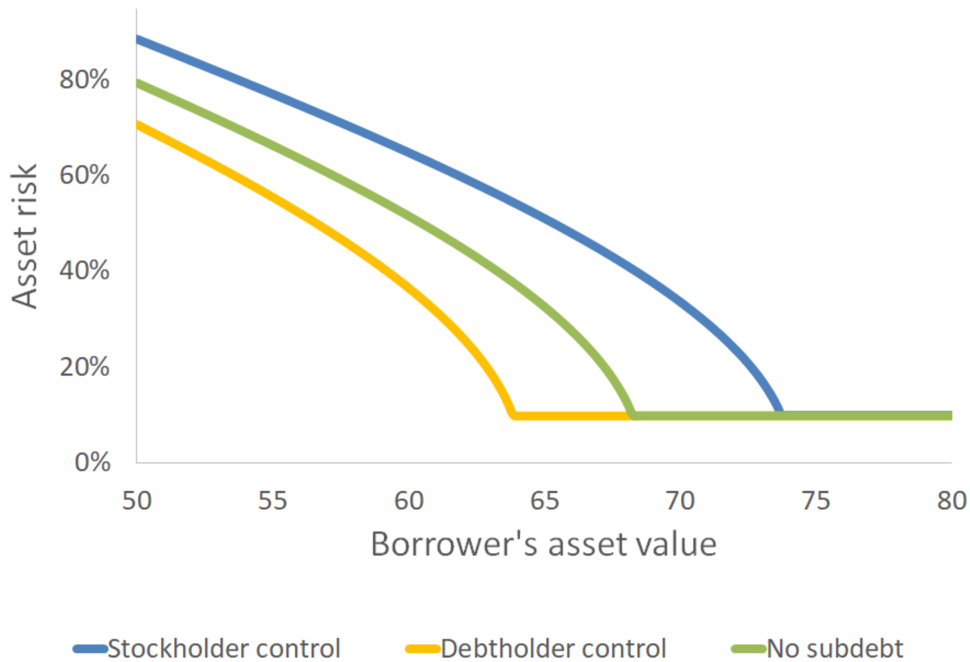


Figure 2: The equilibrium level of the borrower's asset risk. The figure depicts the equilibrium levels of asset risk in a bank with subdebt that is controlled by stockholders (Section 3.3), a bank with subdebt controlled by subdebtholders (Section 3.4), and a bank with no subdebt (Section 3.5). The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{sub} = 10$. The initial level of asset risk is $\sigma_0 = 10\%$. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$.

subdebt can be explained by the higher leverage of the bank in which stock is replaced by subdebt.

When the bank's subdebtholders solely determine the level of asset risk, risk-shifting occurs whenever the asset value is below the discounted geometric mean of the bank's total face value of debt and the face value of deposits, H^{**}_{Sub}. Since $H^{**}_{NoSub} > H^{**}_{Sub}$ there are fewer risk-shifting events in a bank with subdebt where risk is determined solely by the subdebtholders than in a bank with no subdebt. Moreover, when risk-shifting occurs the chosen level of risk is lower since $\sigma^{max}_{Sub} < \sigma^{max}_{NoSub}$. These results are presented in Figure 2.

4 Bargaining analysis

While in the previous section we show the risk preference of each claimholder, an analysis that fits the case where a single claimholder controls the level of risk of the bank's borrower, in this section we turn to the analysis of the bargaining game, where any change in the level of asset risk requires the mutual consent of both the stockholders and subdebtholders. Specifically, we assume that regardless of the bargaining power of each claimholder, an increase in the level of asset risk occurs only if the two claimholders are better off with it. Therefore, regardless of the bargaining power of each claimholder, an increase in the level of asset risk occurs only if the two claimholders are better off with it, i.e., when the value of each claim is greater than its value at the initial level of risk that was set at the time of the audit. Thus, an increase in the level of asset risk that leads to a higher stock and subdebt value must be at the expense of the other claimholders: the depositors or the deposit insurer.

A necessary condition for the described bargaining process is that subdebtholders can observe the level of asset risk. Thus, a regime shift from the case where only the stockholders determine the level of risk to the case with bargaining can be a result of a change in investor sophistication or an increase in asset transparency, such as the one brought about by the disclosure rules that followed Basel III (Chen, Goldstein, Huang, and Vashishtha, 2020).

4.1 Analysis of the bargaining game

As is common in the game-theoretic literature, we model the strategic interaction as a bargaining situation (see, e.g., Osborne and Rubinstein, 1990, Chapter 7, for a textbook introduction). Specifically, we assume that an exogenous parameter $\alpha \in [0, 1]$ describes the bargaining power of the stockholders relative to the subdebtholders. The case of $\alpha = 1$ ($\alpha = 0$) corresponds to a state in which the stockholders (subdebtholders) hold all the bargaining power; i.e., the stockholders (subdebtholders) present a "take-it-or-leave-it" offer regarding the maximal allowed level of asset risk, and the subdebtholders (stockholders) can either accept or reject this offer, without an opportunity to present a counteroffer. The case where $\alpha = 0.5$ corresponds to a symmetric state, where both claimholders possess the same bargaining power.

The solution concept we apply to capture the joint decision of the stockholders and the subdebtholders is the asymmetric Nash bargaining solution (Nash, 1950; Kalai, 1977; see Footnote 3 for recent applications of the Nash bargaining solution in related setups), according to which the maximal level of asset risk that is chosen at the end of the bargaining process is

$$\sigma_\alpha^{max} = \arg\max_{\substack{\sigma \geq \sigma_0 \\ S_{B,t}(\sigma) \geq S_{B,t}(\sigma_0) \\ B_{Sub,t}(\sigma) \geq B_{Sub,t}(\sigma_0)}} \left(\left(S_{B,t}(\sigma) - S_{B,t}(\sigma_0) \right)^{\alpha} \cdot \left(B_{Sub,t}(\sigma) - B_{Sub,t}(\sigma_0) \right)^{1-\alpha} \right). \tag{18}$$

4.2 Solution of the bargaining game

The following proposition characterizes the maximal level of asset risk σ_α^{max} jointly chosen by the stockholders and the subdebtholders. Specifically, it shows that (1) the condition for risk-shifting is the same as in the case where the bank is controlled by the subdebtholder, and (2) if there is risk-shifting, the level of asset risk is increasing with α, and it is between the level of risk chosen by the stockholders and the level of risk chosen by the subdebtholders (a comparison of the solution of this case with those of the two previous cases is presented in Table 1 below).

Proposition 2. *When the bank is jointly controlled by subdebtholders and stockholders, risk-shifting occurs if and only if $V_{C,t} < H_{Sub}^{**}$. When there is risk-shifting, the level of asset risk σ_α^{max} is (1) increasing with α, and (2) between the level of asset risk decided upon in the case of sole control by the subdebtholders and the level decided upon in the case of sole control by the stockholders (i.e., $\sigma_{Sub}^{max} \leq \sigma_\alpha^{max} \leq \sigma_{Stk}^{max}$).*

The proof of Proposition 2 is presented in Appendix B.2.

Introducing subdebt in a bank financed by just stock and deposits, i.e., substituting a portion of stock with subdebt, decreases the range of asset values for which risk-shifting takes place from the range $V_{C,t} < H_{NoSub}^{**}$ to the range $V_{C,t} < H_{Sub}^{**}$. This result is demonstrated in Figure 3.

Introducing subdebt in a bank financed by just stock and deposits, i.e., substituting a portion of stock with subdebt, may increase the equilibrium level of asset risk if the subdebtholders' bargaining power is not sufficiently high. The increase in subdebt on the one hand increases bank leverage, which should increase risk-taking, and on the other hand, introduces supervision by the subdebtholders, which should decrease risk-taking. The answer to the question of which of these two effects is stronger depends on the stockholders' bargaining power.

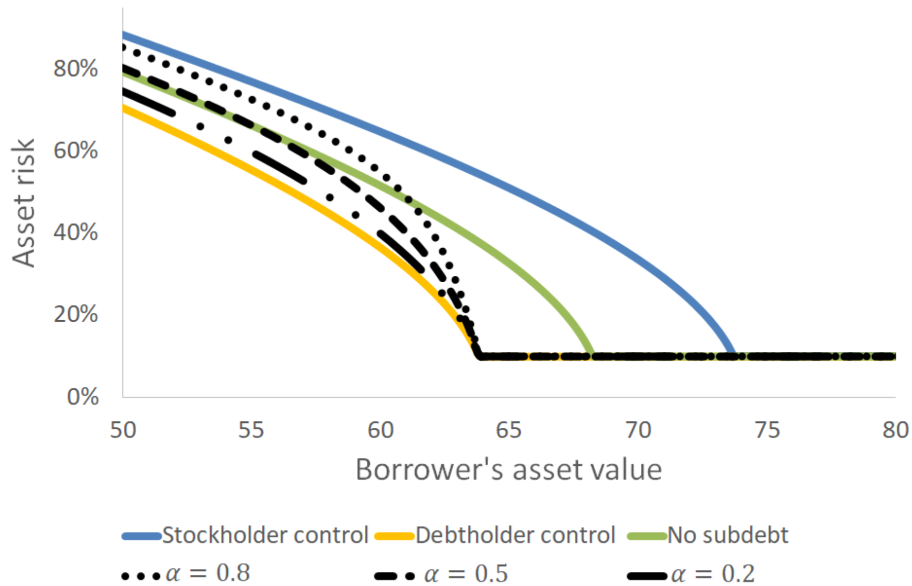


Figure 3: The equilibrium level of the borrower's asset risk with bargaining. The figure depicts the equilibrium levels of the borrower's asset risk in a bank with subdebt where the level of asset risk is determined in a bargaining process between the bank's claimholders (as defined in Eq. (18)) for three different values of the stockholders' bargaining power relative to that of the subdebtholders: (1) $\alpha = 0.8$, (2) $\alpha = 0.5$, and (3) $\alpha = 0.2$. In addition, the figure depicts the equilibrium levels of asset risk in a bank with subdebt that is controlled by stockholders (Section 3.3), a bank with subdebt controlled by subdebtholders (Section 3.4), and a bank with no subdebt (Section 3.5). The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{sub} = 10$. The initial level of asset risk is $\sigma_0 = 10\%$. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$.

4.3 Illustration

We demonstrate the motivation of the bank's subdebtholders and stockholders in Figure 4. In our base-case analysis, the face value of the borrower's loan is 80, the face value of the subdebt is 10, and the face value of the deposits is 60. The risk-free rate is 1% and the time to maturity is one year.

When the borrower's asset value is above the subdebtholders' threshold, $V_{C,t} > H^{**}_{Sub}$, for example, when $V_{C,t} = 70$, as depicted in Figure 4a, the subdebtholders will not agree to any increase in the level of asset risk above its initial level since such an increase would decrease the value of their claim.

By contrast, as depicted in Figure 4b, when the borrower's asset value is low, $V_{C,t} = 62$, the relationship between the subdebt value and the asset risk is hump-shaped. Therefore,

Table 1: Summary of Risk-shifting Analysis

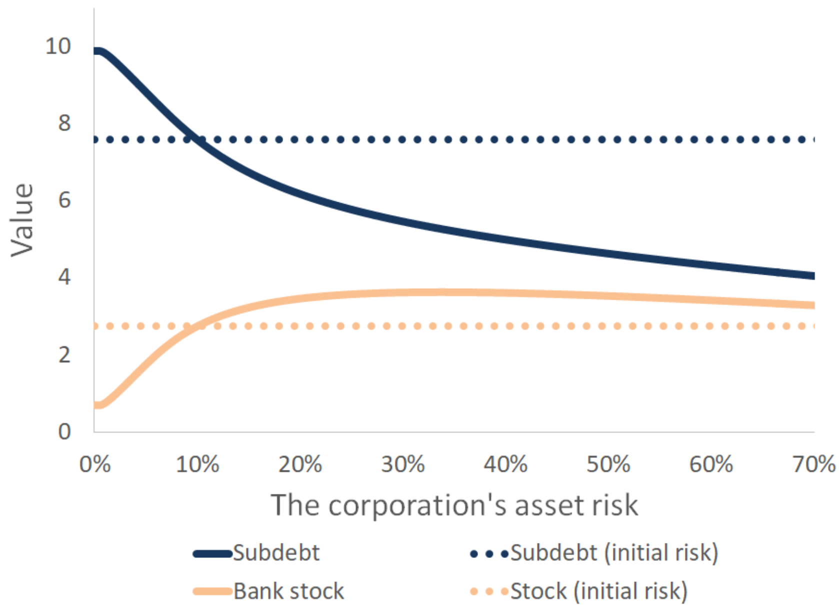
<table>
<tr><th rowspan="2">Control & bargaining framework</th><th colspan="4">Corporation's asset value (V_C)</th></tr>
<tr><th>$V_C > H^{**}_{Stk}$</th><th>$V_C \in (H^{**}_{NoSub}, H^{**}_{Stk})$</th><th>$V_C \in (H^{**}_{Sub}, H^{**}_{NoSub})$</th><th>$V_C < H^{**}_{Sub}$</th></tr>
<tr><td>Stockholders control the bank</td><td rowspan="4">No risk-shifting</td><td colspan="3">Risk-shifting to σ^{max}_{Stk}</td></tr>
<tr><td>No subdebt</td><td rowspan="3">No risk-shifting</td><td colspan="2">Risk-shifting to $\sigma^{max}_{NoSub} \in (\sigma^{max}_{Sub}, \sigma^{max}_{Stk})$</td></tr>
<tr><td>Joint control</td><td rowspan="2">No risk-shifting</td><td>Risk-shifting to $\sigma^{max}_{\alpha} \in (\sigma^{max}_{Sub}, \sigma^{max}_{Stk})$</td></tr>
<tr><td>Subdebtholders control the bank</td><td>Risk-shifting to σ^{max}_{Sub}</td></tr>
</table>

when the initial level of asset risk is below the level that maximizes the value of subdebt, the subdebtholders are better off increasing the level of asset risk to a level between the initial level of asset risk and the level of asset risk for which the value of the subdebt is identical to its value at the initial level of asset risk. This level is defined as $\overline{\sigma_0}$ and equals 64% in this specific example.

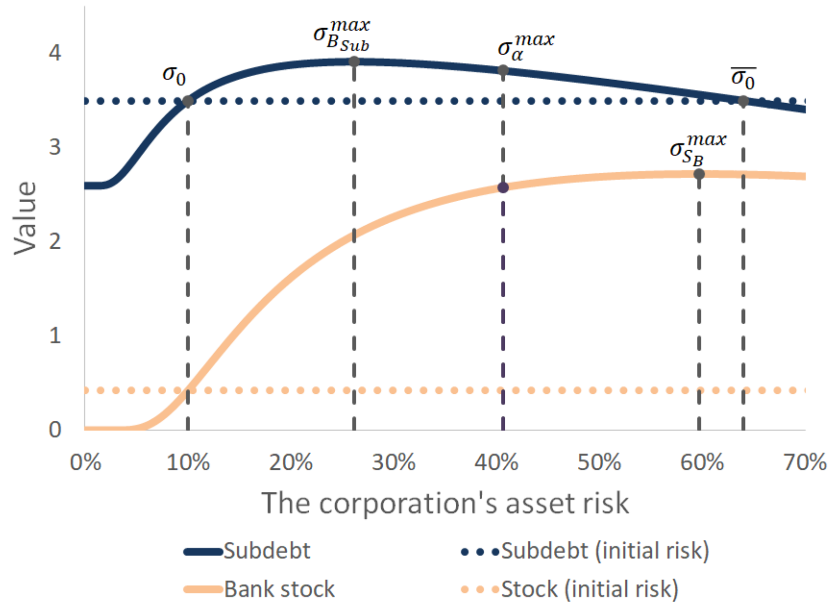
Since usually both stock and subdebt are traded financial instruments, one might assume that the regulator can use these instruments' market value to indicate a risk-shifting event between two audit periods ("indirect market discipline"). However, this is not a straightforward task, since risk-shifting is expected to increase the market value of both the stock and the subdebt, making it indistinguishable from an increase in the borrower's asset value. For example, when $\alpha = 0.8$ the equilibrium level of risk is $\sigma^{max}_{\alpha=0.8}(10\%) = 40.6\%$, which is between the risk preferred by the stockholders, 59.7%, and the risk preferred by the subdebtholders, 26.2%, and both the value of stock and subdebt increases relative to their value at the initial level of risk. Note that a decrease in the market value of deposits coinciding with an increase in the market values of stock and subdebt would be an indication of risk-shifting, if the bank's deposits or deposit insurance were traded securities with an observed market value.

4.4 The effect of the initial level of asset risk

One can interpret the initial level of the borrower's asset risk σ_0 as the maximal level of risk approved by the regulator when monitoring the bank. That is, at the time of each audit event the regulator ensures that the level of asset risk is not higher than σ_0. Thus, a lower σ_0



(a) The corporation's asset value: $V_C = 70$



(b) The corporation's asset value: $V_C = 62$

Figure 4: The values of the bank's stock and subordinated debt as a function of the level of the asset risk of the borrower. The dashed lines represent the value of the bank's subdebt and the value of its stock at the initial level of asset risk of $\sigma_0 = 10\%$. The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{Sub} = 10$. These face values yield for the bank a leverage of 87.5%. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$ and $\alpha = 0.8$.

is consistent with a regulator that is more intolerant of high levels of risk, and who applies more severe regulatory corrective measures.

Proposition 3 below shows that severe regulatory corrective actions can have the adverse effect of increasing the equilibrium level of asset risk chosen in a bargaining process. This occurs when the following three conditions are satisfied: (1) subdebtholders are willing to increase asset risk above its initial level, i.e., $V_{C,t} < H^{**}_{Sub}$, (2) yet, the subdebtholders do not agree to increase asset risk to the level that maximizes the value of the bank's stock, i.e., $B_{Sub,t}(\sigma^{max}_{Stk}) < B_{Sub,t}(\sigma_0)$, and (3) the stockholders' bargaining power α is sufficiently high.

The intuition behind this result is that when the stockholders' bargaining power is sufficiently high, what restricts the equilibrium level of asset risk is that it must make subdebtholders better off relative to the initial level of risk (which is used as the threat point in the bargaining process). Decreasing the initial level of asset risk decreases the value of the subdebt when bargaining fails, allowing the stockholders to persuade the subdebtholders to agree to a higher equilibrium level of asset risk that produces a lower value of subdebt. Formally:

Proposition 3. *Assume that the bank is jointly controlled by the subdebtholders and the stockholders and that $V_{C,t} < H^{**}_{Sub}$. Further assume that $B_{sub,t}(\sigma^{max}_{Stk}) < B_{sub,t}(\sigma_0)$. Then for each $\sigma' < \sigma_0$, there exists $\overline{\alpha} < 1$ such that the equilibrium level of asset risk is higher when the initial level of asset risk decreases from σ_0 to σ', i.e., $\sigma^{max}_{\alpha}(\sigma_0) < \sigma^{max}_{\alpha}(\sigma')$, for each $\alpha > \overline{\alpha}$.*

The proof of Proposition 3 is presented in Appendix B.3.

In the example in Section 4.3 we show that when $\sigma' = 10\%$, the equilibrium level of asset risk is $\sigma^{max}_{\alpha=0.8}(10\%) = 40.6\%$. If the initial level of asset risk increases to $\sigma_0 = 15\%$, the equilibrium level of asset risk decreases to $\sigma^{max}_{\alpha=0.8}(15\%) = 35.3\%$, as illustrated in Figure 5.

The result in Proposition 3, that equilibrium risk is decreasing at the initial level of asset risk, is further demonstrated in Figure 6, which presents the equilibrium level of asset risk when the initial level of risk is 10% (in dark blue) versus when the initial level of risk is 20% (in light pink) and for $\alpha = 0.8$ (dotted) and $\alpha = 0.2$ (dashed). The figure demonstrates that our result may be relevant under more circumstances than the ones for which it is proven in Proposition 3. In particular, given the values of the parameters in Figure 5, numeric analysis shows that the result holds for any value of the stockholders' bargaining power, α. The intuition behind the result presented in the figure for the case

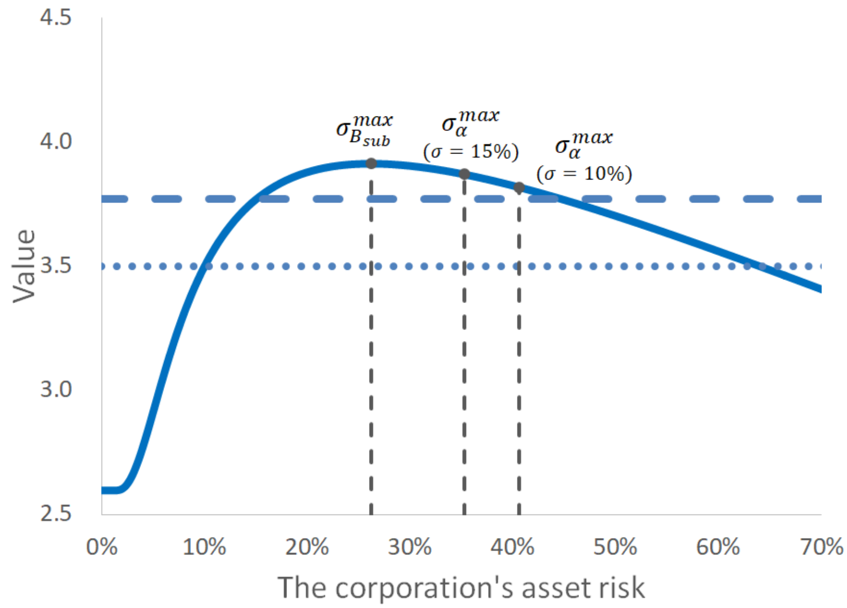


Figure 5: The value of the bank's subdebt versus the borrower's level of asset risk for different initial levels of asset risk. The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{Sub} = 10$. In addition, the time to maturity is one year, the risk free-rate is $r = 1\%$, and $\alpha = 0.8$. The dotted and dashed lines represent the value of subdebt with levels of asset risk of 10% and 15%, respectively.

where $\alpha = 0.2$ is as follows. When the level of risk is 20% the subdebtholders' payoff is very close to their maximal payoff, i.e., their payoff using their optimal level of risk. Thus, the subdebtholders can credibly threaten the bargaining process, in a way that stockholders are unable to do since their loss from abandoning the bargaining process would be great. This yields subdebtholders a better bargaining outcome at a lower equilibrium level of risk that is closer to the subdebtholders' ideal risk level, and further from the stockholders' ideal risk level.

5 Extensions: Side payments and bail-inable debt

In this section we present two extensions of our model. In the first we analyze the effect of requiring a bank to issue subdebt when side payments between stockholders and subdebtholders are possible. In the second extension we analyze the effect of bail-inable debt.

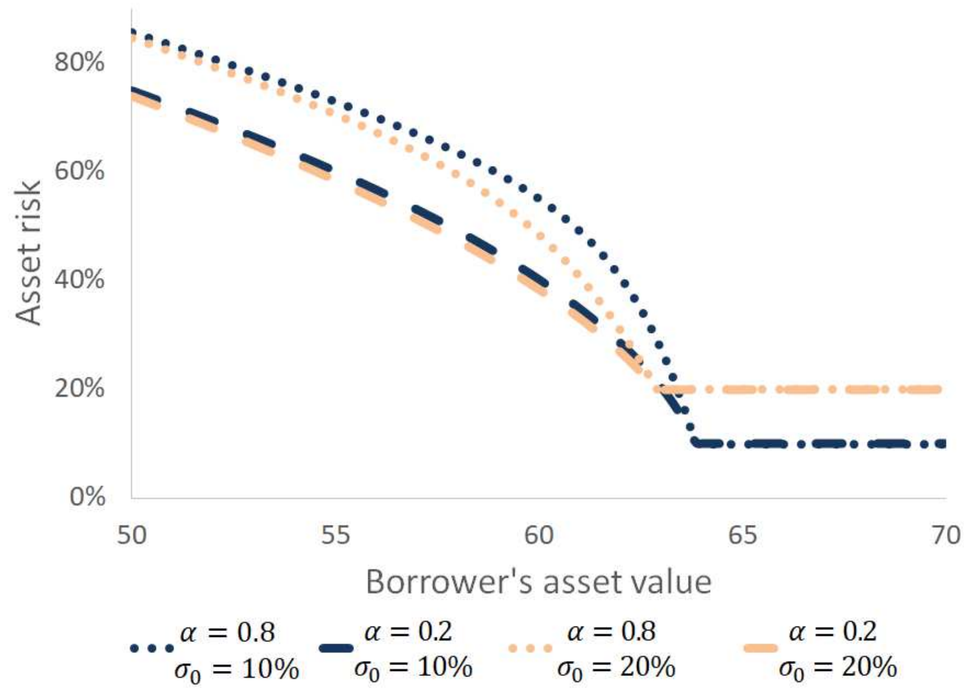


Figure 6: The borrower's level of asset risk for different initial levels of asset risk and alphas. The initial risk, σ_0, is 10% for the darker lines and 20% for the lighter lines. The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{Sub} = 10$. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$.

5.1 Joint control with side payments

In this section, we consider an extension where the stockholders and subdebtholders jointly control the bank and the stockholders' relative bargaining power is $\alpha \in (0, 1)$, but now we introduce the option of side payments paid by the stockholders to the subdebtholders or vice versa. Side payments allow the paying side to directly influence the receiving side's risk preferences by altering their payoff function.

Payments from stockholders to subdebtholders can be implemented by increasing the interest rate of the subdebt claim above the rate that the subdebtholders would request without the side payments. Several papers have expressed concerns about this possibility and suggested that regulators cap the interest payments on subdebt (Furlong and Keeley, 1987; Calomiris, 1999; Chen and Hasan, 2011). Payments from subdebtholders to stockholders can be implemented through deviation or threat of deviation from the absolute priority rule (Weiss, 1990).

In this case, the two sides have to jointly decide on (1) how much to allow the borrower to increase the level of asset risk (if at all) and (2) how much to require the stockholders to pay to the subdebtholders in a side payment of X_α dollars (which might be either positive or negative). The following simple lemma shows that the Nash bargaining solution of the two joint decisions can be solved by a two-step solution as follows: the two sides jointly choose (1) the level of asset risk that maximizes the sum of their claims, and (2) the side payment that is the unique Nash solution to the bargaining problem of dividing the joint value of the claims between the two parties.

Lemma 1. *The level of asset risk induced by the Nash solution of the bargaining between the bank's stockholders and subdebtholders with side payments is the one that maximizes the sum of the stock and the subdebt values. Therefore, the equilibrium level of risk with side payments is identical to the level of risk in a bank with only stock and deposits.*

Proof. Consider a case in which the two sides agree on asset risk σ and a side payment of x. This case induces a payoff of $(S_B(\sigma) - x)$ to the stockholders and a payoff of $(B_{Sub}(\sigma) + x)$ to the subdebtholders. Therefore, the set of all feasible payoff profiles induced by asset risk σ and an arbitrary side payment is the 45-degree line of all payoff profiles (u_{stk}, u_{sub}) that sum to $S_B(\sigma)+B_{Sub}(\sigma)$ (i.e., $u_{stk} + u_{sub} = S_B(\sigma) + B_{Sub}(\sigma)$). This, in turn, implies that the Pareto frontier of the set of feasible payoff profiles is the one induced by the level of asset risk that maximizes $S_B(\sigma) + B_{Sub}(\sigma)$. Since the Nash bargaining solution always chooses a point in the Pareto frontier of the set of feasible payoff profiles, the bargaining Nash solution chooses the level of asset risk that maximizes the sum of values of the stockholders' claim and subdebtholders' claim. □

Lemma 1 implies that the analysis of bargaining with side payments requires first a characterization of how the total value of both the subdebt and the stock depends on the level of risk, which is done in Section 5.1.1, and then an application of this analysis to the solution of the bargaining situation with side payments, which is shown in Section 5.1.2.

5.1.1 Analysis of the sum of claims: Stock and subdebt

The joint payoff of stockholders and subdebtholders is the sum of payoffs from Eq. (3) and Eq. (4):

$$S_{B,t} + B_{Sub,t} = Call_t(V_{C,t}, F_{Dep}, \sigma, T - t, r) - Call_t(V_{C,t}, F_C, \sigma, T - t, r). \quad (19)$$

This payoff is identical to the payoff of the stockholders in the case of a bank funded solely by deposits and stock, discussed in Section 3.5. In both cases, the party in control can increase its payoff by extracting value only from the depositors. This means that if side payments are possible, the depositors and the deposit insurer will not benefit from regulation requiring banks to issue subdebt to replace stock; in fact, the state of the depositors and the deposit insurer will not change at all.

Our entire analysis in Section 3.5 applies to a bank with subordinated debt where risk-taking is chosen in a bargaining process between the stockholders and subdebtholders and where side payments are possible. Therefore, the threshold below which there is risk-shifting is between the thresholds for risk-shifting for the subdebt and for the stock, i.e., $H^{**}_{Sub} < H^{**}_{S_B+B_{sub}} < H^{**}_{Stk}$. In addition, the level of asset risk that maximizes the total value of the two claims is between the level that maximizes the value of the subdebt and the level that maximizes the value of the stock, $\sigma^{max}_{sub} < \sigma^{max}_{S_B+B_{sub}} < \sigma^{max}_{Stk}$. It is interesting to observe that the thresholds in this case, $H^{*}_{S_B+B_{sub}}$ and $H^{**}_{S_B+B_{sub}}$, and the risk level that maximizes the payoff, $\sigma^{max}_{S_B+B_{sub}}$, do not depend on the size of the subdebt or on the relative bargaining power, α.

5.1.2 Bargaining solution with side payments

Corollary 5 immediately implies the following characterization of risk-shifting in the Nash bargaining solution in the case of joint control of the bank with side payments.

Corollary 7. *When the bank is jointly controlled by the subdebtholders and the stockholders and side payments are feasible, risk-shifting occurs if and only if* $V_{C,t} < H^{**}_{S_B+B_{sub}}$. *When there is risk-shifting, the level of risk-shifting (that is independent of* α*) is* $\sigma^{max}_{S_B+B_{sub}} \in (\sigma^{max}_{B_{sub}}, \sigma^{max}_{S_B})$.

Observe that the introduction of side payments increases the range of market values of the asset for which risk-shifting occurs. Specifically, without side payments risk-shifting occurs if and only if $V_{C,t} < H^{**}_{Sub}$, but with side payments risk-shifting also occurs in the interval $H^{**}_{Sub} < V_{C,t} < H^{**}_{S_B+B_{sub}}$.

Finally, we briefly analyze the side payments between the two sides. The side payments are used if and only if there is risk-shifting (i.e., if $V_{C,t} < H^{**}_{S_B+B_{sub}}$). In this case, the (possibly negative) amount x_α that the stockholders pay to the subdebtholders is equal to

$$\arg\max_{x\in R}\left(\left(S_{B,t}\left(\sigma^{max}_{S_B+B_{sub}}\right) - S_{B,t}\left(\sigma_0\right) - x_\alpha\right)^{\alpha} \cdot \left(B_{Sub,t}\left(\sigma^{max}_{S_B+B_{sub}}\right) - B_{Sub,t}\left(\sigma_0\right) + x_\alpha\right)^{1-\alpha}\right).$$

Observe that the side payment x_α is decreasing with α; i.e., the lower the stockholders' bargaining power α, the higher their side payment to the subdebtholders.

5.2 Bail-in debt and risk-taking

In this section we replace the standard debt discussed in the previous sections with a bail-inable debt. Bail-in debt is a tool available to regulators who are dealing with a bank in financial distress and responsible for managing the failure in an orderly fashion, i.e., preserving financial stability and continuity of bank operation while protecting insured deposits and public funds (Chennells and Wingfield, 2015). In a bail-in event the claims of shareholders and unsecured creditors of the distressed bank are written down or converted into equity and consequently losses are absorbed and the bank is recapitalized. The bail-in debt is not negotiated at the time of distress; instead, it is imposed by the regulator. Under the new resolution arrangements in the European Union, a resolution that involves a bail-in of a bank must be accompanied by a restructuring plan (Chennells and Wingfield, 2015).

In our model, consistent with existing works (e.g., **?**), we refer to bail-inable debt as a debt claim that at the time of distress can be decreased in size, i.e., written down, at the discretion of the regulator. As discussed above, the regulator is informed of the state of the bank only at the time of an audit event. Therefore, a bail-in event can occur between audits only following a voluntary disclosure of information by one of the bank's claimholders, whether the debtholder or the stockholder. Claimholders will only disclose such information if they are made better off by it.

Once the regulator is informed of the state of the bank, a write-down of debt is enforced, decreasing the face value of debt by Δ percent. In addition, the level of asset risk is fixed to its initial level, σ_0. Both the new level of asset risk set by the regulator and the new face value of debt in the case of a bail-in event are known in advance. After regulatory intervention it is no longer possible to shift risk in the time remaining until the next audit, T. We assume that an informed regulator decides to bail in a bank whenever the borrower's asset value is below the face value of the borrower's debt $V_{C,t} < F_C$. This means that a bail-in event can occur for any asset value in which either the debtholder or the stockholder is motivated to increase risk. The value of the bank's stock following a bail-in event is

$$S^{\Delta}_{B,t}(\sigma_0) = Call_t(V_{C,t}, F_{Dep} + F_{Sub}(1-\Delta), \sigma_o, T-t, r) - Call_t(V_{C,t}, F_C, \sigma_0, T-t, r),$$

and the value of subdebt following a bail-in event is

$$B^{\Delta}_{Sub,t}\left(\sigma_0\right) = Call_t(V_{C,t}, F_{Dep}, \sigma_0, T-t, r) - Call_t(V_{C,t}, F_{Dep} + F_{Sub}(1-\Delta), \sigma_o, T-t, r).$$

Applying the same solution concept used in Section 4 (namely, an asymmetric Nash bargaining solution), we find that the maximal level of asset risk that is chosen at the end of the bargaining process is

$$\sigma^{max}_{(\alpha,\Delta)} = \arg\max_{\substack{\sigma\geq\sigma_0 \\ S_{B,t}(\sigma)\geq S^{\Delta}_{B,t}(\sigma_0) \\ B_{Sub,t}(\sigma)\geq B^{\Delta}_{Sub,t}(\sigma_0)}} \left(S_{B,t}\left(\sigma\right) - S^{\Delta}_{B,t}\left(\sigma_0\right)\right)^{\alpha} \cdot \left(B_{Sub,t}\left(\sigma\right) - B^{\Delta}_{Sub,t}\left(\sigma_0\right)\right)^{1-\alpha}. \quad (20)$$

Since the bail-in event makes the debtholders worse off relative to the simple bargaining scenario, the range of levels of asset risk that are not worse than the debtholders' outside option increases. This means that the debtholders may agree to higher levels of asset risk with bail-in than without it.

Proposition 4. *When a bank is jointly controlled by bail-inable debtholders and stockholders, risk-shifting occurs for a range of asset values that is decreasing with* Δ*. When there is risk-shifting (1) the level of asset risk* $\sigma^{max}_{(\alpha,\Delta)}$ *is between the level of asset risk that maximizes the value of debt and the level of asset risk that maximizes the value of stock, i.e.,* $\sigma^{max}_{B_{Sub}} \leq \sigma^{max}_{(\alpha,\Delta)} \leq \sigma^{max}_{S_B}$*, and (2) the level of asset risk* $\sigma^{max}_{(\alpha,\Delta)}$ *is increasing with* Δ*.*

The proof of Proposition 4 is presented in Appendix B.4.

Figure 7 presents an example of the equilibrium levels of asset risk for different size of write-downs, Δ. The bargaining power of the stockholders relative to the debtholders is $\alpha = 0.5$. In line with Proposition 4, for all values of Δ presented in the figure, when there is risk-shifting, the equilibrium level of asset risk is (1) between the level that maximizes the value of debt and the level that maximizes the value of stock (the dotted and dashed gray lines, respectively) and (2) increasing with Δ. The second property can be explained by the fact that as Δ increases the stockholders' position in case of no agreement improves, thus strengthening their position against the subdebtholders in the bargaining game.

In addition, Figure 7 shows that the range of asset values where risk-shifting occurs is decreasing with the size of the write-down, Δ. In other words, as the transfer from the debtholders to the stockholders increases, there is a corresponding increase in the range of asset values for which a bail-in event is triggered and therefore there is no risk-shifting. In such a case, the transfer from bailing in the debt compensates the stockholders for the lower equilibrium level of asset risk.

Figure 8 demonstrates this point for the case where the borrower's asset value is $V = 65$. When the level of the write-down is relatively high, say $\Delta = 66.6\%$, the value of the stock following a bail-in event is higher than with no bail-in event, including the no-bail-in case where the level of asset risk equals the stockholders' preferred level of risk, σ_{stk}^{max}. Therefore, when $\Delta = 66.6\%$ there is no risk-shifting and a bail-in event is triggered. By contrast, when the size of the write-down is lower, say $\Delta = 33.3\%$, there is a range of levels of asset risk that are exceptionable to both the stockholders and the subdebtholders and therefore an agreement can be reached and risk-shifting will occur. In the case depicted in Figure 8, the stockholders agree to any level of risk above $\sigma = 18\%$ while the subdebtholders agree to any level of risk below $\sigma = 49.1\%$ and so the equilibrium level of risk is $\sigma_{(\alpha,\Delta)}^{max} = 28.7\%$.

Figure 7 presents the borrower's level of asset risk for different bail-in levels. It may be noted that the equilibrium level of asset risk isn't necessarily monotonically decreasing with asset value. Instead, equilibrium risk is an increasing function for higher asset values and a decreasing function for lower asset values. This differs from the cases discussed so far in the paper in which $\Delta = 0$, where equilibrium risk is a decreasing function for all asset values where risk-shifting takes place. To understand this result we look first to the case where there is no bail-in event. When there is no bail-in event ($\Delta = 0$), the equilibrium level of asset risk is a compromise between the level of asset risk preferred by the stockholders and the level of asset risk preferred by the subdebtholders. Since both claimholders' preferred level of asset risk is a decreasing function, so is the equilibrium level of asset risk. By contrast, when there is a bail-in event ($\Delta > 0$), a second element comes into play: the result in case of disagreement is a transfer of wealth from the subdebtholders to the stockholders. When asset value is very low, the value of the bail-in event is low and therefore the first element dominates. This is why for very low asset values the equilibrium levels of asset risk converge to the equilibrium level of asset risk with no bail-in event. By contrast, for higher asset values, closer to $F_{Dep} + F_{Sub}(1 - \Delta)$, the second element begins to dominate.

Lastly, as described in Figure 7, when the bank is in severe financial distress, the equilibrium level of asset risk is higher than the equilibrium level of asset risk with no subdebt (solid gray line). By contrast, when the bank is in mild distress, i.e., with asset values closer to $F_{Dep} + F_{Sub}$, the equilibrium level of asset risk with bail-inable debt is lower than the equilibrium risk in a bank with no subdebt. Therefore, if the regulator can credibly

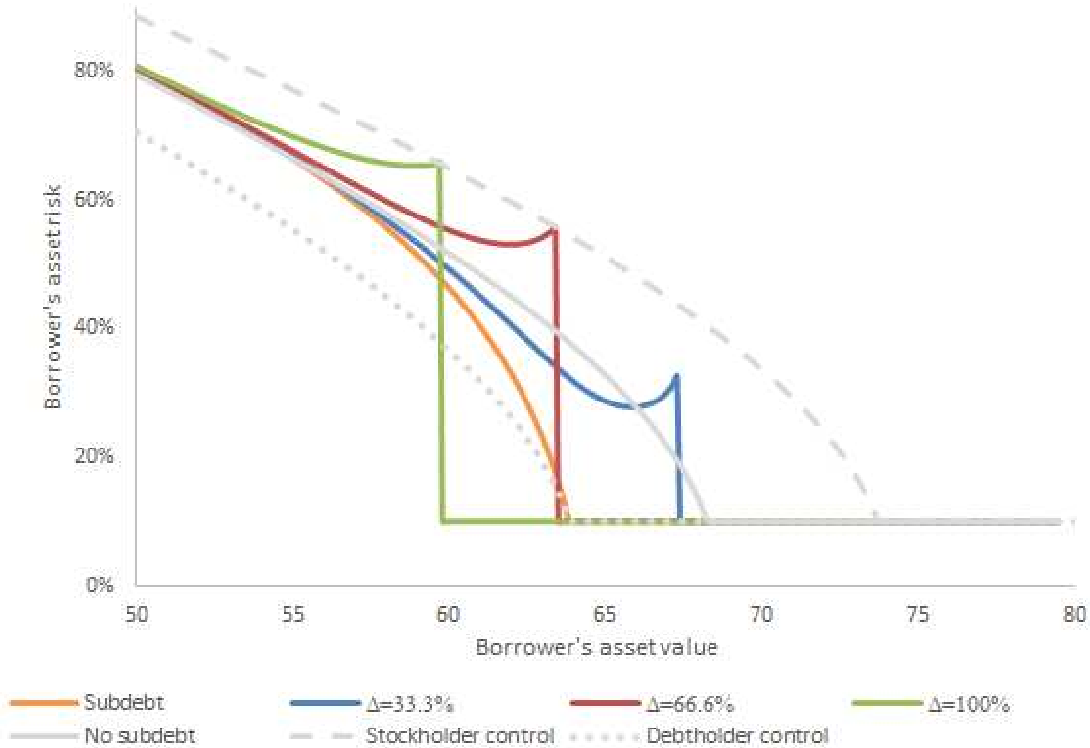


Figure 7: The borrower's level of asset risk for different bail-in levels. The dashed and dotted gray lines represent the preferred levels of asset risk of the stockholders and the subdebtholders, respectively. The initial risk, σ_0, is 10% and $\alpha = 0.5$. The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{Sub} = 10$. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$.

find out that a bank is distressed before it is in severe financial distress, bail-inable debt is a good regulatory tool for limiting risk-shifting, even though it transfers wealth from the debtholders to the stockholders. The regulator is more likely to find out that a bank is in mild distress if the regulator's audits are relatively frequent. Therefore, for bail-in debt to be an effective tool for restricting a bank's risk-taking it must be accompanied by frequent regulatory audits.

6 A numerical analysis: Changes in capital structure and in regulatory policy

In this section we present a comprehensive assessment of the effect of different capital structures and different levels of bargaining power on the equilibrium level of asset risk and on

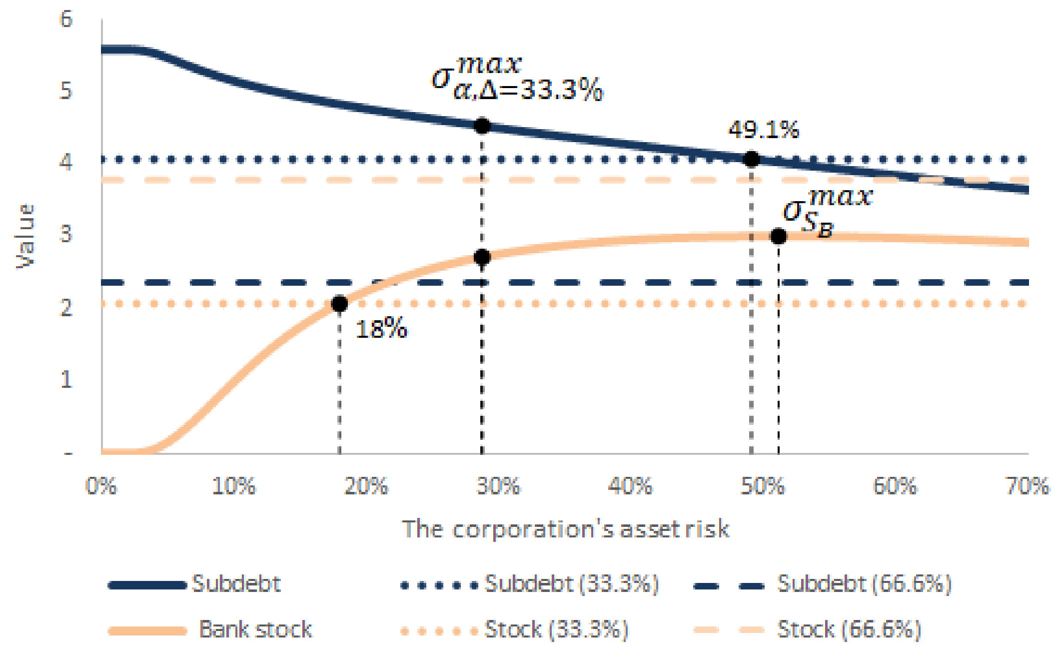


Figure 8: The value of the bank's stock and subdebt for different levels of the borrower's asset risk. The dashed and dotted blue lines represent the value of bail-in debt with asset risk $\sigma = 10\%$ and a write-down of $\Delta = 66.6\%$ and $\Delta = 33.3\%$, respectively. The dashed and dotted pink lines represent the stock value with asset risk $\sigma = 10\%$ and a write-down of $\Delta = 66.6\%$ and $\Delta = 33.3\%$, respectively. The borrower's asset value is $V = 65$. The initial risk, σ_0, is 10% and $\alpha = 0.5$. The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{Sub} = 10$. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$.

the value of deposit insurance. Deposit insurance, a measure implemented to protect bank depositors from losses caused by a bank's inability to repay its debt, is formally defined in Section 6.1, before we begin our numerical analysis in Section 6.2.

6.1 The cost of deposit insurance

In the case of deposit insurance, if a bank cannot repay its depositors, i.e., the value of the bank's assets is below the face value of its deposit at maturity, the government compensates the depositors with the difference between the two. Thus, the cost of deposit insurance equals the maximum between zero and the difference between the face value of the secured deposits and the value of the bank's assets: $DI_T = \max[F_{Dep} - V_{B,T}, 0]$. Replacing $V_{B,T}$ above by Eq. (2) we find that $DI_T = \max[F_{Dep} - V_{C,T}, 0]$. As discussed in Merton (1977) and Crouhy and Galai (1991), this payoff is equivalent to a long put option on the corporation's assets with a strike price equal to the face value of the bank's deposits. Following convention, we normalize and use the value of deposit insurance per dollar (DIPD) of insured deposits, which is defined as

$$DIPD_t = \frac{Put_t(V_{C,t}, F_{Dep}, \sigma, T-t, r)}{F_{Dep}}. \tag{21}$$

As expected, the value of deposit insurance increases with the borrower's asset risk, and decreases with its asset value.

6.2 Comparative statics

The analysis is conducted using the base-case parameters discussed in Section 4.3. The face value of the corporation's loan is 80, the face value of the subdebt is 10, and the face value of the deposits is 60. These face values yield an accounting-based leverage of 87.5% for the bank. In addition, the time to maturity is one year and the risk-free rate is 1%. We consider an initial level of asset volatility of 10%, similar to the level of risk of investment grade bonds (Huang and Huang, 2012).

When the bank's assets are risky debt claims, as in our framework, the highest asset value for which risk-shifting occurs is the discounted geometric average of the face value of the borrower's debt and the total face value of the bank's debt, which is equal to 73.7. However, as seen in Table 2, risk-shifting below this threshold occurs only if the bank's stockholders possess the control rights. For example, if the corporation's asset value is 70, risk-shifting will occur only if stockholders control the bank, in which case the equilibrium level of asset risk is 33.7% and the value of deposit insurance per dollar of insured deposits is 7.3%.

If the bank is jointly controlled and side payments are possible, risk-shifting can occur for any asset value below the discounted geometric average of the face value of the borrower's debt and the face value of the bank's deposits, which is equal to 68.3. For example, if the borrower's asset value decreases to 65, risk-shifting takes place either when the stockholders control the bank or when both claimholders jointly control the bank. However, in the first case, the equilibrium level of asset risk is 51.2%, and the cost of deposit insurance per dollar of insured deposits (DIPD) is 16.6%. When the bank is jointly controlled and side payments are possible, the subdebtholders are able to restrict the increase in the equilibrium level of asset risk to 32.8%, and the cost of deposit insurance is 9.3%.

The case of bargaining with side payments is important, since a capital structure with subdebt where side payments are possible yields identical results to the case where subdebt is swapped out by stock. Thus, if the subdebtholders cannot affect the level of risk as in the first case, a capital structure with stock only is superior. However, side payments clearly decrease market monitoring, since if side payments were restricted, subdebtholders would not agree to an increase in risk at all. As discussed above, while the equilibrium level of asset risk is unaffected by stockholders' relative bargaining power, the side payment that the stockholders must make to the subdebtholders is decreasing with the stockholders' relative bargaining power.

The last threshold that effects risk-shifting is the discounted geometric average between the face value of the deposits and the total face value of the bank's debt. Below this threshold risk-shifting occurs even if the subdebtholders have complete control over the level of asset risk. For example, if the borrower's asset value is very low ($V = 62$), risk-shifting can take place under any level of the claimholders' bargaining power, but the degree of risk-shifting increases with the stockholders' relative bargaining power. The equilibrium level of asset risk is highest when stockholders have full control, 59.7%, in which case DIPD receives its highest value of 21.6%. The lowest level of asset risk is observed when subdebtholders have full control, 26.2% (similarly the cost of DIPD is the lowest at 8.5%). If claimholders have joint control and side payments are not possible, the equilibrium level of asset risk is between 26.2% and 59.7%, depending on the relative bargaining power. In the case where claimholders have joint control and side payments are possible, or if the bank has no subdebt and is funded by stock and deposits, the equilibrium level of asset risk is 45% and the cost of DIPD is 15.9%.

A similar picture emerges from Figure 3, which presents the equilibrium level of the borrower's asset risk for different levels of bargaining power. We observe the maximum equilibrium level of asset risk when the bank is controlled by the stockholders, the minimum equilibrium level of asset risk when the bank is controlled by the subdebtholders, and intermediate levels when the bank is jointly controlled. In addition, when the bank is jointly controlled risk-shifting occurs only for asset values for which the subdebtholders would increase the level of asset risk if they controlled the bank. The effect of side payments on the equilibrium level of asset risk is ambiguous and depends on the stockholders' relative bargaining power. Since the case of side payments is identical to the case of a bank with no subdebt, it is also true that the effect of replacing subdebt with stock on the equilibrium level of asset risk is ambiguous and depends on the stockholders' relative bargaining power. Specifically, we find that when α is less than 0.45, the introduction of subdebt to replace stock leads to a decrease in the equilibrium level of asset risk for all asset values. However,

Table 2: Numerical Analysis: Equilibrium level of asset risk and cost of deposit insurance

<table>
<tr><th rowspan="2">Control and bargaining framework</th><th colspan="4">Corporation's asset value (V_C)</th></tr>
<tr><th>$V_C > 73.7$</th><th>$V_C = 70$</th><th>$V_C = 65$</th><th>$V_C = 62$</th></tr>
<tr><td>Stockholder control</td><td rowspan="4">No risk-shifting</td><td>Risk-shifting to 33.7%
DIPD=7.3%</td><td>Risk-shifting to 51.2%
DIPD=16.6%</td><td>Risk-shifting to 59.7%
DIPD=21.6%</td></tr>
<tr><td>No subdebt - Joint control with side payments
$\alpha = 0.2/\alpha = 0.5/\alpha = 0.8$</td><td rowspan="3">No risk-shifting</td><td>Risk-shifting to 32.8%
Side payment: 1.62/1.28/0.95
DIPD=9.3%</td><td>Risk-shifting to 45.0%
Side payment: 1.72/0.98/0.23
DIPD=15.9%</td></tr>
<tr><td>Joint control
$\alpha = 0.2/\alpha = 0.5/\alpha = 0.8$</td><td rowspan="2">No risk-shifting</td><td>Risk-shifting to
28.5%/32.9%/40.6%
DIPD: 9.4%/11.2%/14.2%</td></tr>
<tr><td>Subdebtholder control</td><td>Risk-shifting to 26.2%
DIPD=8.5%</td></tr>
</table>

The numerical analysis refers to the case where the face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{sub} = 10$. The initial level of asset risk is $\sigma_0 = 10\%$. The risk-free rate is $r = 1\%$ and the time to maturity is one year. The table presents the equilibrium level of asset risk as well as the cost of deposit insurance, in terms of the percentage of the face value of deposits, for different levels of asset value and subdebtholders' bargaining power.

when α is greater than 0.45, the equilibrium level of asset risk with subdebt is higher than in a bank with no subdebt for low enough asset values. For example, when $\alpha = 0.8$, the introduction of subdebt leads to a lower equilibrium level of asset risk for asset values above 61.1.

Figure 9 presents the bank's cost of deposit insurance per dollar of insured deposits. A higher level of equilibrium risk translates into a higher cost of deposit insurance.

7 Conclusion

The common belief among policymakers and regulators before the financial crisis of 2007–2009 was that subordinated debt can effectively reduce financial institutions' risk-taking. However, the crisis called into question the effectiveness of such debt instruments as many financial institutions with subdebt were bailed out using taxpayers' money. Still, the empirical literature shows that during the crisis period subordinated debt reduced banks' risk-taking. As a response to the crisis and the usage of taxpayer money to bail out banks, regulators began developing "bail-in" tools – unsecured debt that is written down or converted into equity in time of financial distress. Motivated by these events and reforms we study how

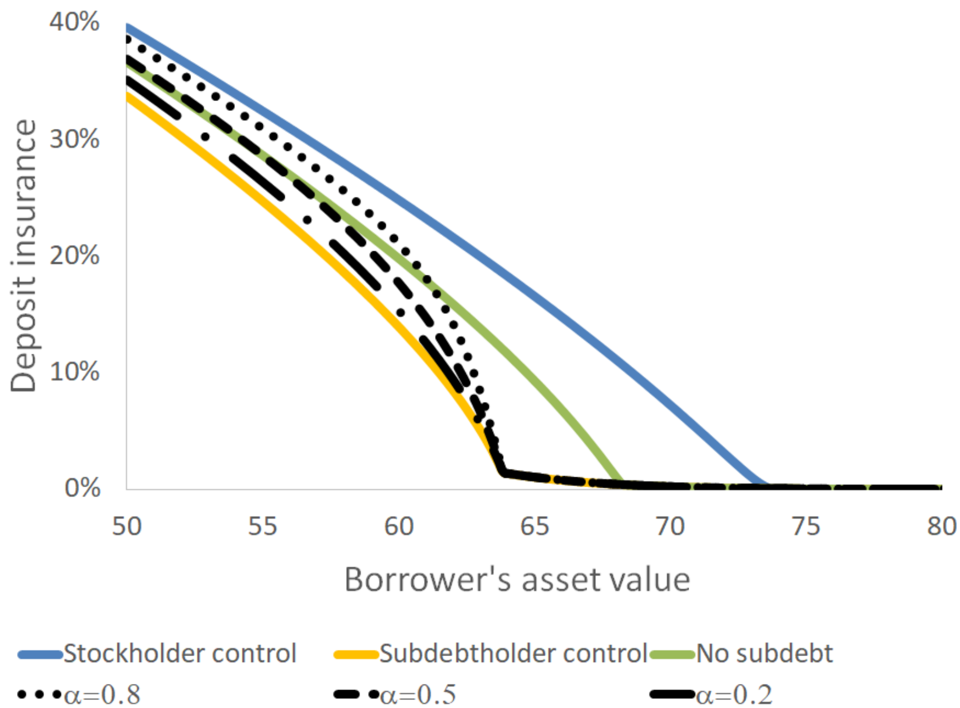


Figure 9: Value of deposit insurance per dollar of insured deposits. The figure depicts the value of a bank's deposit insurance per dollar of insured deposits in a bank with subdebt where the level of asset risk is determined in a bargaining process between the bank's claimholders (as defined in Eq. (18)) for three different values of the stockholders' bargaining power relative to the subdebtholders': (1) $\alpha = 0.8$, (2) $\alpha = 0.5$, and (3) $\alpha = 0.2$. In addition, the figure depicts the equilibrium levels of asset risk in a bank with subdebt that is controlled by stockholders (Section 3.3), a bank with subdebt controlled by subdebtholders (Section 3.4), and a bank with no subdebt (Section 3.5). The face value of the borrower's debt is $F_C = 80$. The face value of the bank's deposits is $F_{Dep} = 60$ and the face value of its subordinated debt is $F_{sub} = 10$. The initial level of risk is $\sigma_0 = 10\%$. In addition, the time to maturity is one year and the risk-free rate is $r = 1\%$.

risk-taking is affected when part of a bank's common equity is replaced with subordinated debt or with bail-inable debt, given the relative bargaining power of the subdebtholder.

We find that substituting a portion of a bank's stock with subdebt decreases the range of asset values for which risk-shifting takes place, since subdebtholders must be better off after the negotiation. When risk-shifting does occur, the equilibrium level of asset risk is between the level that maximizes the value of the stock and the level that maximizes the value of the subdebt, and this equilibrium level of asset risk is decreasing with the subdebtholders' bargaining power. In addition, we show that substituting part of a bank's stock with subdebt can increase the equilibrium level of asset risk if the subdebtholders' bargaining power is not sufficiently high.

Next we extended the model to the case of bail-inable debt, i.e., debt that is written down by a known percent at the time of financial distress. We find that when there is risk-shifting, the equilibrium level of asset risk is between the level that maximizes the value of debt and the level that maximizes the value of stock. Moreover, asset risk is increasing with the size of the write-down. In addition, the range of asset values where risk-shifting occurs is decreasing with the size of the write-down, so that as the transfer from debtholders to stockholders increases, the range of assets for which there is no risk-shifting and a bail-in event occurs increases as well.

We address a concern raised in previous literature, by allowing side payments between the stockholders and the subdebtholders. We find that with side payments, both the asset value threshold for risk-shifting and the equilibrium level of asset risk are identical to those of a bank funded by just stock and deposits. Thus, if side payments are a concern, requesting that banks issue subdebt does not affect their risk-taking.

Following the 2008 financial crisis, the issue of bank transparency was debated. The Basel III international regulatory framework calls for financial institutions to increase transparency by conducting stress tests involving an unprecedented amount of disclosure. On the one hand, transparency can prevent excessive risk-shifting by banks. On the other hand, it is often argued that transparency has significant disadvantages in banking, given the role of banks in liquidity provision and risk-sharing. We contribute to this debate by showing that as the level of asset risk determined at a regulatory audit decreases, the equilibrium level of asset risk increases (when the bargaining power of the stockholders is sufficiently high). As a result, a more restrictive corrective measure imposed by the regulator can motivate claimholders to agree on a higher level of asset risk in the bargaining process. Thus, the efficiency of subdebt as a disciplinary tool may decline with the enforcement of traditional regulatory tools such as on-site supervision.

Appendix A: Notation

The bank's borrower (the corporation)	
S_C	Value of borrower's stock.
F_C	Face value of borrower's debt.
B_C	Value of borrower's debt.
T	Time of next regulatory audit.
V_C	Value of borrower's assets.
μ	Instantaneous expected return on borrower's assets.
σ	Instantaneous volatility of borrower's assets (asset risk).
σ_0	Initial level of asset risk.
The bank	
V_B	Value of bank's assets.
S_B	Value of bank's stock.
F_{Dep}	Face value of deposits.
B_{Dep}	Value of deposits.
F_{Sub}	Face value of subdebt.
B_{Sub}	Market value of subdebt.
H^*_{Stk}	Threshold below which the bank's stockholders prefer risk higher than zero.
H^{**}_{Stk}	Threshold below which the bank's stockholders prefer risk higher than the initial risk.
σ^{max}_{Stk}	Stockholders' preferred level of asset risk when $V_C < H^*_{Stk}$.
H^*_{Sub}	Threshold below which the subdebtholders prefer risk higher than zero.
H^{**}_{Sub}	Threshold below which the subdebtholders prefer risk higher than the initial risk.
σ^{max}_{Sub}	Subdebtholders' preferred level of asset risk when $H^*_{Sub} < V_{C,t}$.
α	Bargaining power of the stockholders relative to the subdebtholders.
σ^{max}_{α}	Preferred asset risk when stockholders and subdebtholders have joint control.
X_α	Side payment.
$H^*_{S_B+B_{sub}}$	Threshold below which the bank's claimholders prefer risk higher than zero.
$H^{**}_{S_B+B_{sub}}$	Threshold below which the bank's claimholders prefer risk higher than the initial risk.
$\sigma^{max}_{S_B+B_{sub}}$	Preferred risk with side payments.
Δ	Debt write-down (%).
$S^{\Delta}_{B,t}(\sigma_0)$	Value of bank's stock following a bail-in event.
$B^{\Delta}_{Sub,t}(\sigma_0)$	Market value of subdebt following a bail-in event.
$\sigma^{max}_{(\alpha,\Delta)}$	Preferred asset risk with joint control and bail-in.

Appendix B: Proofs

B.1 Proposition 1: Auxiliary Result

Recall that the portfolio of two call options is given by

$$P_t(V_t, F_1, F_2, \sigma, T-t, r) = Call_t(V_t, F_1, \sigma, T-t, r) - Call_t(V_t, F_2, \sigma, T-t, r).$$

To find the level of asset risk that maximizes the portfolio's value we use the derivative of the value of each call option with respect to asset risk:

$$\frac{\partial call_t}{\partial \sigma} = \frac{\sqrt{T}}{\sqrt{2\pi}} \cdot V \cdot e^{-\frac{1}{2}\cdot(d_1(F_i))^2},$$

where $d_1 = \frac{1}{\sigma\sqrt{T-t}} \cdot \left[\ln\left(\frac{V_t}{F_i}\right) + \left(r + \frac{1}{2}\sigma^2\right) \cdot (T-t)\right]$, to get

$$\frac{\partial P_t}{\partial \sigma} = \frac{\sqrt{T}}{\sqrt{2\pi}} \cdot V . e^{-\frac{1}{2}\cdot(d_1(F_1))^2} - \frac{\sqrt{T}}{\sqrt{2\pi}} \cdot V_t \cdot e^{-\frac{1}{2}\cdot(d_1(F_2))^2}.$$

After rearranging it can be shown that the derivative is equal to

$$\frac{\partial P_t}{\partial \sigma} = \frac{\sqrt{T-t}}{\sqrt{2\pi}} \cdot V_t \cdot e^{-\frac{1}{2\cdot T\cdot\sigma^2}} \left[e^a - e^b\right],$$

where a and b are defined as

$$a = -2 \cdot \ln V_t \cdot \ln F_1 + (\ln(F_1))^2 - 2 \cdot \ln(F_1) \cdot \left(r + \frac{\sigma^2}{2}\right) \cdot (T-t)$$

$$b = -2 \cdot \ln V_t \cdot \ln F_2 + (\ln(F_2))^2 - 2 \cdot \ln(F_2) \cdot \left(r + \frac{\sigma^2}{2}\right) \cdot (T-t).$$

The payoff is maximized with respect to the level of asset risk in cases where the first derivative equals zero. This happens when either $V_t = 0$ or $a = b$. Since the first option is of no interest economically we focus on the second option. We find that $a = b$ when

$$V_t = e^{-\left(r+\frac{1}{2}\sigma^2\right)\cdot(T-t)} \cdot \sqrt{F_1 \cdot F_2}. \tag{B.1}$$

Observe that Eq. (B.1) has a solution if and only if $V_t < H^*(F_1, F_2, T-t, r) \equiv e^{-r(T-t)}\sqrt{F_1 \cdot F_2}$. It is simple to verify that (1) when Eq. (B.1) has a solution, the derivative is positive for lower levels of risk and it is negative for higher level of risks, which implies that the portfolio's value is hump-shaped and (2) in the opposite case (i.e., $V_t > H^*(F_1, F_2, T-t, r,))$, the derivative is always negative, and the portfolio's value is decreasing with asset risk (which proves part (1) of Prop. 1). Further observe that the level of asset risk σ that solves Eq. (B.1) is greater than σ_0 iff

$$V_t > H^{**}(F_1, F_2, T-t, r, \sigma_0) \equiv e^{-\left(r+\frac{\sigma_0^2}{2}\right)(T-t)}\sqrt{F_1 \cdot F_2}. \tag{B.2}$$

Next, we isolate σ in Eq. (B.1) (in the case in which $H^*(F_1, F_2, T-t, r) > V_t$), and we obtain the following equation for the level of asset risk that maximizes the portfolio's value:

$$argmax_{\sigma}(P_t) = \sigma^{max}(V_t, F_1, F_2, T-t, r) = \sqrt{\frac{1}{T-t}\ln\left(\frac{F_1 \cdot F_2}{(V_t)^2}\right) - 2r}, \tag{B.3}$$

which proves part (3) of Proposition 1.

B.2 Proposition 2: Solution of the bargaining game

We begin by showing that risk-shifting occurs if and only if $V_{C,t} < H^{**}_{Sub}$. Corollary 3 implies that there exists a higher level of asset risk $\sigma > \sigma_0$ that induces a higher value for the subdebt relative to the initial level of risk, if and only if $V_{C,t} < H^{**}_{Sub}$. Moreover, by Corollary 1 and inequality $H^{**}_{Sub} < H^{**}_{Stk}$, if the subdebtholders achieve a higher value for the subdebt (relative to its value given the initial risk), so do the stockholders. Thus, by Eq. (18), which defines the equilibrium level of risk, there exists a higher level of risk $\sigma > \sigma_0$ that induces a higher value for both the stock and the subdebt than the value induced for them by the initial risk, if and only if $V_{C,t} < H^{**}_{Sub}$.

Next, we focus on the case where risk-shifting occurs (i.e., $V_{C,t} < H^{**}_{Sub}$). We can conclude from Corollaries 1 and 3 that (1) both the expressions $(S_{B,t}(\sigma) - S_{B,t}(\sigma_0))$ and $(B_{Sub,t}(\sigma) - B_{Sub,t}(\sigma_0))$ are increasing with σ for low levels of asset risk satisfying $\sigma < \sigma^{max}_{Sub}$, (2) $(S_{B,t}(\sigma) - S_{B,t}(\sigma_0))$ is increasing with σ, while $(B_{Sub,t}(\sigma) - B_{Sub,t}(\sigma_0))$ is decreasing with σ, for intermediate levels of asset risk satisfying $\sigma^{max}_{Sub} < \sigma < \sigma^{max}_{Stk}$, and (3) both expressions are decreasing with σ for high levels of asset risk satisfying $\sigma > \sigma^{max}_{Stk}$. These observations and the definition of σ_{α}^{max} in Eq. (18) imply that σ_{α}^{max} is increasing with α, and that $\sigma_{Sub}^{max} \leq \sigma_{\alpha}^{max} \leq \sigma_{Stk}^{max}$.

B.3 Proposition 3: Impact of initial level of asset risk

The assumption that $V_{C,t} < H_{Sub}^{**}$ implies by Proposition 2 that there is risk-shifting, since the payoff functions of both the stockholders and the subdebtholders are hump-shaped, and that the levels of asset risk that maximize the values of the stock and the subdebt satisfy $\sigma_0 < \sigma_{Sub}^{max} < \sigma_{Stk}^{max}$. Let $\overline{\sigma_0} > \sigma_0$ (resp., $\overline{\sigma'} > \sigma'$) be the level of asset risk that induces the same payoff for the subdebtholders as the one induced by the initial risk level, i.e., $B_{sub,t}(\overline{\sigma_0}) = B_{sub,t}(\sigma_0)$ (resp., $B_{sub,t}\left(\overline{\sigma'}\right) = B_{sub,t}(\sigma'))$. The inequality $B_{sub,t}(\sigma_{Stk}^{max}) < B_{sub,t}(\sigma_0)$ and the definition of the Nash bargaining solution imply that $\sigma_{\alpha}^{max}(\sigma_0) < \overline{\sigma_0} < \sigma_{Stk}^{max}$ for each level of bargaining power α. Next, observe that $\sigma_{\alpha}^{max}(\sigma')$ converges to $min(\overline{\sigma'}, \sigma_{Stk}^{max}) > \overline{\sigma_0}$ as α converges to 1. This implies that there exists $\overline{\alpha} < 1$ such that $\sigma_{\alpha}^{max}(\sigma_0) < \overline{\sigma_0} < \sigma_{\alpha}^{max}(\sigma')$ for each $\alpha > \overline{\alpha}$.

B.4 Proposition 4: Bail-in debt

We begin by showing that the range of asset values for which risk-shifting occurs is decreasing with $\Delta > 0$. Define $RS(\Delta)$ as the interval of asset values for which there is risk-shifting. We show that for $\Delta' < \Delta$ if $V_C \in RS(\Delta)$ it must also be that $V_C \in RS(\Delta')$. Since $V_C \in RS(\Delta)$ there must be a $\sigma > \sigma_0$ such that $S_{B,t}(\sigma) \geq S_{B,t}^{\Delta}(\sigma_0)$ and $B_{Sub,t}(\sigma) \geq B_{Sub,t}^{\Delta}(\sigma_0)$; i.e., there is a level of asset risk such that both the stockholders and the subdebtholders are better off than with the initial level of asset risk and a bail-in event. In particular, it implies that $S_{B,t}(\sigma) + B_{Sub,t}(\sigma) \geq S_{B,t}(\sigma_0) + B_{Sub,t}(\sigma_0)$.

Observe that $B_{Sub,t}(\sigma_0) \geq B_{Sub,t}^{\Delta'}(\sigma_0)$, i.e., the subdebtholders weakly prefer not having a bail-in event. Let $\sigma' \in (\sigma_0, \sigma]$ be the maximal level of risk such that $B_{Sub,t}(\sigma') \geq B_{Sub,t}^{\Delta'}(\sigma_0)$. If $\sigma' = \sigma$, then it is immediate that both claimholders gain from a risk-shifting to σ with a bail-in level of Δ' (the subdebtholders' gain is implied by substituting $\sigma' = \sigma$ in the previous inequality, and the stockholders' gain is implied by the fact that $\Delta' < \Delta$), which implies that $V_C \in RS(\Delta')$. We are left with the case of $\sigma' < \sigma$. From the continuity of $B_{Sub,t}$ we know that $B_{Sub,t}(\sigma') = B_{Sub,t}^{\Delta'}(\sigma_0)$.

By Proposition 1 the inequality $S_{B,t}(\sigma) + B_{Sub,t}(\sigma) \geq S_{B,t}(\sigma_0) + B_{Sub,t}(\sigma_0)$ implies that the shape of $S_{B,t}(\sigma) + B_{Sub,t}(\sigma)$ is hump-shaped in the asset risk σ (i.e., $V_C < H_{Stk+Sub}^{**}$)

and that the initial risk is smaller than the risk inducing the maximal sum of values of the two claimholders (i.e., $\sigma_0 < \sigma^{max}_{Stk+Sub}$). This implies that for any $\sigma' \in (\sigma_0, \sigma]$ it is true that $S_{B,t}(\sigma') + B_{Sub,t}(\sigma') \geq S_{B,t}(\sigma_0) + B_{Sub,t}(\sigma_0) = S^{\Delta'}_{B,t}(\sigma_0) + B^{\Delta'}_{Sub,t}(\sigma_0)$. This implies that $S_{B,t}(\sigma') \geq S^{\Delta'}_{B,t}(\sigma_0)$, which, in turn, implies that both claimholders gain from risk-shifting to σ with a bail-in level of Δ', and thus $V_C \in RS(\Delta')$.

Next, we focus on the equilibrium level of asset risk. Following the same logic described in the proof of Proposition 2, we find that the level of asset risk $\sigma^{max}_{(\alpha,\Delta)}$ is between the level of asset risk that maximizes the value of debt and the level of asset risk that maximizes the value of stock. Lastly, we show that the level of asset risk $\sigma^{max}_{(\alpha,\Delta)}$ is increasing with Δ. Since $S^{\Delta}_{B,t}(\sigma_0)$ is increasing with Δ, the compensation that the stockholder will demand for increasing risk increases. This means that the equilibrium level of asset risk must increase with Δ as well.

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