Bank stability and market discipline: The effect of contingent capital on risk taking and default probability

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Abstract

This paper investigates the effects of financial institutions issuing contingent capital, a debt security that automatically converts into equity if assets fall below a predetermined threshold. We decompose bank liabilities into sets of barrier options and present closed-form solutions for their prices. We quantify the reduction in default probability associated with issuing contingent capital instead of subordinated debt. We then show that appropriate choice of contingent capital terms (in particular the conversion ratio) can virtually eliminate stockholders' incentives to risk-shift, a motivation that is present when bank liabilities instead include either subordinated debt or additional equity. Importantly, risk-taking incentives continue to be weak during times of financial distress. Our findings imply that contingent capital may be an effective tool for stabilizing financial institutions.

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1 Introduction

Bank capital, primarily in the form of common equity, provides banks with a buffer to absorb losses and protect creditors. However, severe negative shocks may result in a shortfall in capital. In the recent financial crisis financial institutions were not able to raise significant new capital in the market and had to rely instead on governments. The extensive amount of implicit guarantees and outright infusion of taxpayer money into large financial institutions has come under much scrutiny.

One of the most prominent suggested solutions for the shortfall of capital in bad times is the introduction of contingent convertible bonds (often simply referred to as "contingent capital" or "coco") into the capital structure of financial institutions. Contingent capital is subordinated debt that automatically converts into equity when a certain stress-related trigger is breached and thus can absorb losses on a going concern basis. Such an automatic debt-to-equity swap or "bail-in" is potentially valuable since it is executed in times of distress.

In recent years, there have been major developments both in the market for contingent capital and in regulations related to introducing it into capital structure requirements. For example, Lloyds, Rabobank, and Barclays have issued coco bonds that are converted or written off if there are specific reductions in consolidated core Tier 1 capital ratios.[1] Meanwhile, regulators and policymakers have advocated using contingent capital as a preferred tool for implementing prudential banking regulations. Swiss regulators have required additional capital for the country's systemically important institutions (Credit Suisse and UBS), stating that it can be issued in the form of contingent capital. In the U.S., the 2010 Dodd-Frank Act calls for a careful analysis of the introduction of contingent capital into the capital structure of systemically important financial institutions (Krainer, 2012). In order to meet higher national capital requirements, the Basel Committee under Basel III requires contingent capital instruments to convert prior to the point of 'non-viability' (distress).[2]

[1] The 2009 Lloyds issue converts into ordinary shares if the consolidated core Tier 1 ratio falls below 5%; the 2010 Rabobank issue is written down when regulatory capital falls below 7%; and in 2012 Barclays raised $3 billion that are written off if the Barclays Tier 1 capital drops below 7%.

[2] In this case, contingent capital qualifies as additional capital. Another guideline is the inclusion of a trigger to write off contingent capital at the point of 'non-viability.' See also Pennacchi, Vermaelen,

In this paper we analyze the effects of introducing contingent capital into the capital structure. We propose a model of contingent capital that reflects the structure of existing "real-world" issuances. We first derive closed-form solutions for the prices of contingent capital and equity by decomposing capital structure components into sets of barrier options. We then investigate the stabilizing abilities of contingent capital by comparing it to two alternatives: capital structures that instead either include subordinated debt, which does not convert into equity in times of distress, or additional equity.

We show that the inclusion and design of contingent capital can have important effects on banks' financial stability through two channels: bank default probability and incentives for managerial risk taking.[3] We demonstrate that a bank that issues coco will have a lower default probability than one that issues subordinated debt. However, it will have the same default probability as an equivalent volatility bank with additional equity.

The main focus of our paper is the second channel: the effect of coco on risk taking incentives. We show that appropriate choice of coco parameters can entirely eliminate any motivation to increase or decrease risk. The intuition is that appropriate choice of coco parameters can exactly offset costs and benefits to shareholders of increasing the likelihood of conversion. In contrast, incentives to increase risk are present under the two alternatives (subordinated debt or additional equity). Thus, stability is highest for a bank with well-designed coco.[4]

The central parameter governing the motivation to change risk is the conversion ratio, the percentage of the ownership in the post-conversion financial institution that coco holders receive (previous shareholders receive the remainder). If the conversion ratio is zero ("stock-friendly"), contingent capital holders receive nothing and equity holders are faced with a lower level of debt, while a level of one ("coco-friendly") means that previous equity holders receive nothing and coco holders become the post-conversion stockholders.[5] For stock-friendly conversion ratios

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and Wolff (2013), Sundaresan and Wang (2013), and Bailey et al. (2013).

[3] We assume that stockholders may be able to change the risk profile of the bank's assets in order to maximize the value of their own holding (Jensen and Meckling, 1976; Galai and Masulis, 1976).

[4] Admati, DeMarzo, Hellwig, and Pfleiderer (2011) discuss 'fallacies' surrounding the view that high bank leverage is socially desirable. They do not, however, analyze the continued incentives to increase risk that are present even in a bank with a larger equity cushion.

[5] Interestingly, the conversion ratio, even though it varies across recently issued instruments, has tended to be low ("stock-friendly"). The Rabobank and recent Barclays issues both have a conversion

stockholders have a motivation to increase asset risk, while they are motivated to decrease asset risk for coco-friendly conversion ratios. Importantly, we show that there is always an intermediate level of the conversion ratio for which the incentives for stockholders to change asset risk are eliminated.

Incentives to change risk remain low even if volatility changes or if leverage increases. This is not the case for both alternatives (subordinated debt or additional equity), where risk-shifting incentives increase noticeably with leverage. Furthermore, the presence of weak incentives is robust to changes in other important model parameters: weak incentives can be achieved both for different conversion thresholds and for different regulatory seizing policies.

Introducing contingent capital can thus achieve two goals: a reduction in financial institution default probability and a compensation structure that does not reward excessive risk-taking. It is these two aspects that French et al. (2010) highlight in "The Squam Lake Report."[6] Indeed, we show that it is possible to attribute the two effects of contingent capital introduction to its terms: An increase in face value is related to a reduction in default probability, while the conversion terms (ratio and threshold) are related to risk-taking incentives.[7]

There are several parameters that define a contingent capital contract: (1) conversion timing, (2) conversion trigger, (3) instruments that deliver contingent capital, (4) and assumptions about default.

Our setting is motivated by the structure of existing securities (e.g. the coco bonds issued by Lloyds, Rabobank, and Barclays). Thus we assume that contingent capital is converted into common equity if at any time before maturity the value of assets (or, bank capital) falls below a pre-specified conversion threshold. In practice, however, asset value may not be accurately observable and conversion and default may partly be based on accounting information that can be monitored only infrequently. We relax our assumption of accurate continuous monitoring in two ways. Following Glasserman and Nouri (2012a), we assume that asset value is observed

ratio of zero. The Lloyds and Credit Suisse issues are converted into the underlying stock at a relatively low or "stock-friendly" conversion ratio.

[6] In an update, Baily et al. (2013) suggest an important role of contingent capital to reduce the risk of costly bailouts.

[7] We consider the effect of issuing a 'reverse warrant' – a security with a zero face value that converts into a fraction of equity if a pre-determined trigger is touched.

with error, though shocks to the observed and actual asset value processes remain highly correlated (80% or 90%). We also assume that the audit frequency is discrete so that bank capital is observed only periodically. We find robustness of our main results – the effect of contract terms on the motivation to change risk. In both cases it is possible to choose contingent capital terms that result in weak incentives.

The conversion trigger is the second important coco parameter. Following Albul, Jaffee, and Tchistyi (2010), Pennacchi (2011), and Glasserman and Nouri (2012a), we assume an asset value (or capital) trigger. The alternative is a trigger that is based on the market price of equity ('market-based trigger'), first proposed by Flannery (2002, 2009). However, Sundaresan and Wang (2013) show that a market-based trigger may lead to a situation where no unique equilibrium exists.[8] The problem is a special case of the more general possibility – pointed out by Bond, Goldstein, and Prescott (2011) in theory and Davis, Prescott, and Korenok (2011) in an experimental setting – that a market-based variable may lose information if regulatory intervention is based on it. Our assumption reflects the design of existing securities that are based on capital ratios, and which can be modeled by assuming an asset value trigger.

The third modeling assumption is the set of contingent capital instruments. Our focus is on the design of existing contracts on banks' financial stability. Thus we assume that the coco bond has a fixed payoff unless at any time before maturity the value of assets falls below a pre-specified conversion threshold. In such an event the debt contract is converted automatically into common equity according to a pre-determined conversion ratio. Other studies have instead proposed alternative securities to deliver contingent capital: Duffie (2009) proposes a mandatory offering of new equity by banks facing financial distress; Bolton and Samama (2012) propose 'capital access bonds;' Glasserman and Nouri (2012a) consider the effect of a gradual conversion trigger; and Pennacchi, Vermaelen and Wolff (2013) propose 'call

[8] One way to think about the intuition is as follows: A low stock value may lead to a belief that conversion will occur, but that may in turn increase equity value, resulting in no conversion. Sundaresan and Wang (2013) point out that either an absence of equilibrium or multiplicity may arise when basing conversion on the market price of equity. However, in a recent contribution, Glasserman and Nouri (2012b) argue that continuous trading may ensure that current market prices accurately reflect up-to-date expectations about the likelihood of future conversion, ensuring a single price at all times.

option enhanced reverse convertibles.'[9]

Fourth, default occurs as soon as asset value drops below a threshold related to the amount of deposits. This assumption reflects the policy of banks in distress being seized by the regulator (FDIC). Chen, Glasserman, Nouri, and Pelger (2013) and Albul, Jaffee, and Tchistyi (2010) base their analysis on the structural corporate bond pricing model of Leland (1994), where default is the result of an optimal decision made by equity holders.

A limited set of studies considers the effect of contingent capital on incentives to change risk, though using different settings to ours. Chen et al. (2013) base their analysis on Leland (1994) and Pennacchi (2011) considers a setting where there is continuous monitoring by depositors and thus no deposit insurance. Both of these settings may be less appropriate when analyzing the incentives to change asset risk faced by regulated banks that have dispersed depositors and that are seized by regulators in times of distress.[10] In an empirical contribution, Berg and Kaserer (2012) analyze the effect of changes in risk on observed contingent capital prices in the context of the Merton (1974) model, where default can only occur at maturity. We demonstrate that contingent capital can be designed to entirely eliminate any motivation to change risk and consider the robustness of this result to changes in bank fundamentals.

The rest of the paper is organized as follows. Section 2 presents the basic assumptions for the valuation of corporate liabilities. We provide closed-form solutions for the valuation of a bank's claims using option replication. Section 3 quantifies default probabilities. Section 4 investigates the effect of contingent capital terms and modeling assumptions on incentives to change risk. Section 5 concludes.

[9] There are also other proposed methods for capital provision in financial distress. See, for example, Kashyap, Rajan, and Stein (2008): capital provision during a systemic crisis; Caballero and Kurlat (2009): tradable insurance credits reflecting central bank guarantees; Hart and Zingales (2011): mandatory capital requirements based on credit default swap premia.

[10] Unlike firms in non-financial, unregulated industries, the primary creditors in a bank, the depositors, do not have sufficient incentives to monitor the bank, because of the implicit or explicit guarantees that are provided to commercial banks by national governments (see Saunders, Strock, and Travlos, 1990).

2 A model for pricing bank capital

2.1 Bank capital structure

We consider a hypothetical bank with asset value denoted by V.[11] To finance its assets, the bank issues three types of claims as part of its capital structure: a single zero-coupon deposit, either contingent convertible or subordinated debt, and a residual equity claim. All the claims mature at time T, unless there is a security specific event previous to time T.

2.1.1 Contingent convertible bonds

We first consider the capital structure of a bank that issues contingent convertible bonds so that the capital structure includes deposits, coco, and equity.

The most senior claims in the capital structure are secured deposits with face value F^D. We assume that the government regulator will either seize the bank or force liquidation in the event of bank insolvency. Both of these events represent default which means that default occurs either at debt maturity, T, if the value of assets lies below the face value of the deposits, F^D, or if at any time t previous to maturity T, that is $0 < t < T$, the value of bank assets touches the default threshold K^D. We refer to such an event as early default $\tau_D < T$ where the event is defined as:

$$\tau_D = \inf \left\{ t > 0 | V_t \leqslant K^D \right\}. \tag{1}$$

We assume that the default threshold K^D is equal to $F^D (1 - \gamma)$, where $0 \leqslant \gamma \leqslant 1$, which means that the threshold is located below the face value of deposits. This assumption follows Black and Cox (1976) and captures the fact that the regulator has limited ability to seize the bank at the moment it becomes insolvent either because of imperfect information due to discrete audit frequency (Duffie and Lando, 2001), or simply choosing a policy where banks are not immediately seized (Cetin, Jarrow, Protter, and Yildirim, 2004). We can think of the size of γ as being related to the ability and willingness of the regulator to closely monitor and

[11] To keep the notation as simple as possible, all variables without subscripts are present values.

enforce bank solvency.[12] Close monitoring may be costly and difficult in the case of complicated bank balance sheets, for example those holding complex or illiquid assets such as tranches of collateralized debt obligations (CDO) of pools of mortgage backed securities (MBS). Figure 1 presents all possible types of sample paths of asset value; default occurs either before maturity (1.C) or at maturity (1.B).

We note that through a change in the regulatory seizing policy parameter (γ) it is possible to relate our model to one where default is only possible at maturity (e.g. Merton(1974)). If the default threshold lies much below the face value of deposits (γ is large), default in our model will in general only occur at maturity. In addition, as we point out in Section 4.1.2, assuming $\gamma = 0$, represents a perfect ability of the regulator to seize the bank immediately when insolvency is reached and results in an inability of shareholders to transfer wealth from depositors by changing asset volatility. In addition, varying the seizing policy is also similar to changing the audit frequency (discussed in Section 4.4.1).

The second debt security in the capital structure is the contingent convertible bond with face value F^C and market value C. It pays F^C at maturity if there is no prior conversion event (Figure 1.A). In this case the stockholder is the residual claimant and receives $\left(V_T - F^C - F^D\right)$. Conversion occurs if at any time previous to maturity the value of the financial institution drops below the conversion threshold K^C, defined as:

$$K^C = (1+\beta)\left(F^C + F^D\right) \tag{2}$$

where β ($\beta \geqslant 0$) measures the distance between the conversion threshold and the bank's book value of debt. A larger β implies conversion at times of lower leverage and lower probability of financial distress.

If $V < K^C$ at any time before maturity, the coco is converted into equity (Figure 1.B). In this event the coco holder receives a share α ($0 \leqslant \alpha \leqslant 1$) of the equity and the previous

[12] The depletion of the FDIC's Deposit Insurance Fund (DIF) during the financial crisis is likely a consequence of the difficulty faced by the regulator in shutting down banks exactly at the moment when asset value reaches the value of liabilities. See also Prescott (2011), who points out that, despite the policy of 'prompt corrective action' by the FDIC, during the crisis losses to the deposit insurance fund were substantial.

shareholders receive the remaining $(1-\alpha)$. At maturity, the payoff to the coco holder is therefore equal to $\alpha\left(V_T - F^D\right)$ and the original stockholder receives $(1-\alpha)\left(V_T - F^D\right)$ unless default occurs, in which case both claimholders receive nothing (Figure 1.C). The time of conversion is defined as

$$\tau_C = \inf\left\{t > 0 | V_t \leqslant K^C\right\}. \tag{3}$$

We note that $\beta \geqslant 0$ implies that the event of conversion will always occur before the event of default, i.e. $\tau_C \leqslant \tau_D$. The payoff at maturity to the coco holders and to equity holders can be written as:

$$\begin{aligned} C_T &= F^C 1_{\{\tau_C > T\}} + \alpha \max\left\{\left(V_T - F^D\right), 0\right\} 1_{\{\tau_C < T < \tau_D\}} \\ E_T &= \left(V_T - F^C - F^D\right) 1_{\{\tau_C > T\}} + (1-\alpha) \max\left\{\left(V_T - F^D\right), 0\right\} 1_{\{\tau_C < T < \tau_D\}} \end{aligned} \tag{4}$$

where 1_ψ is an indicator function of the event ψ. Table 1 Panel A summarizes the payoffs to claimholders in the different possible cases.

2.1.2 Subordinated debt

Next, we define a capital structure that includes subordinated debt instead of coco. and thus consists of deposits, subordinated debt, and equity. Defining this capital structure allows us to compare the effects on default probability and risk-taking motivation of the stockholders for cases where the capital structure contains coco instead of subordinated debt.

The subordinated debt has face value F^B and market value B. As in the previous case of coco in the capital structure, default occurs if the value of the bank's assets falls below the threshold K^D at any time before maturity T. If this event occurs, the subordinated debt holder receives nothing. Default can also occur if at maturity the asset value lies below the face value of total debt $\left(V_T < F^D + F^B\right)$. There is no mandatory conversion or increase in capital as a result of low asset value; instead, the subordinated debt holders have the ability to take legal action if at maturity the value of the financial institution is smaller than the sum of the face values of deposits and subordinated debt. This means that default can occur either if before maturity asset value falls below the threshold K^D or if at maturity asset value is below the total face value of debt instruments $\left(F^D + F^B\right)$. Therefore, as long as F^B is larger than zero, the default probability in the case of subordinated debt is, ceteris paribus, larger than in the case of coco.

The payoff to subordinated debt holders is equal to zero if the bank is taken over by the regulator before maturity $(\tau_D < T)$ or if at maturity the residual value of assets is below the value of deposits and there is no surplus to be paid to the subordinated debt holders $\left(V_T < F^D\right)$. If at maturity asset value lies between the total face value of debt and the face value of the deposits $\left(F^D < V_T < F^D + F^B\right)$, subordinated debt holders receive the residual assets of the financial institution after the deposit holders are paid in full. Otherwise, if there is no default, subordinated debt is paid in full $\left(F^B\right)$. The payoff can be summarized as:

$$B_T = \left(\max\left\{V_T - F^D, 0\right\} - \max\left\{V_T - F^D - F^B, 0\right\}\right) 1_{\{\tau_D > T\}}. \tag{5}$$

Finally, the equity holders' payoff at maturity, in the case that default has not occurred before that time $(\tau_D > T)$, is equal to the residual value of assets:

$$E_T = \max\left\{V_T - F^D - F^B, 0\right\} 1_{\{\tau_D > T\}}. \tag{6}$$

If default occurs previous to maturity equity holders receive nothing. Table 1 Panel B reports the payoffs for the different states of the world.

2.1.3 Capital ratio triggers

We assume that default events (early default or default on subordinated debt) as well as conversion are based on asset value. Instead, as is done in practice, one could assume that default and conversion triggers are based on capital ratios (ratios of assets and liabilities). In the context of our model, default and conversion, respectively, occur if $\frac{V_t}{K^D} \leqslant 1$ and $\frac{V_t}{K^C} \leqslant 1$ and default at maturity occurs if $\frac{V_T}{F^D+F^B} < 1$. It is thus possible to recast a capital ratio trigger as an asset value trigger. This is possible since we assume that there is no change to bank liabilities (F^D, F^C, F^B) or issuance or buyback of stock. This assumption may be reasonable over a one-year horizon, which is what we choose as the basis of our analysis in Sections 3 and 4. We leave to future research the analysis of a more complex setting that, in addition to changes of bank asset value, allows for changes in liabilities over the maturity of the debt contract.

2.2 Valuation of bank liabilities with contingent capital or subordinated debt

2.2.1 Valuation of claims when capital structure includes contingent capital

We price each claim by replicating its payoff using a combination of different barrier options that all have closed form solutions. Section A of the online appendix describes the payoffs and the pricing equations for all of the options that are used to replicate the different payoff functions.

We first consider the case of a capital structure with contingent capital. The value of the deposits derives from future cash flows that may be received in the events of no default, early default, and default at maturity. Intuitively, the payoff to deposit holders at maturity is equal to the payoff of a zero coupon bond and a European put option, as pointed out by the seminal paper of Merton (1974). The difference in our case is that, since early default can occur, both options are path dependent.

The value in the case of early default is equal to $(1-\gamma)\,F^D$ units of a *down-and-in* digital barrier option, defined as $DB^{din}\left(K^D\right)$. This option pays \$1 the first time before maturity that asset value hits the default threshold (K^D) and nothing otherwise. The value in the case of no early default is replicated by using two *down-and-out* barrier options. If default does not occur at maturity, the payoff to the deposit holder is equal to the face value of the deposits F^D, and therefore the payoff can be replicated by F^D units of a long position in a *down-and-out* digital barrier option, defined as $DB^{dout}\left(K^D\right)$. If default occurs at maturity, the deposit holder receives the residual assets of the financial institution and therefore the loss can be replicated by using a *down-and-out* put option $PB^{dout}\left(K^D, F^D\right)$ with a strike price equal to the face value of the deposits F^D and a barrier level equal to the default threshold K^D. Both options have *down-and-out* features since early default can occur. Assuming a constant interest rate r the value of deposits can be expressed as:[13]

$$\begin{aligned} D &= E^Q \left[\begin{array}{c} e^{-rT} \left(F^D 1_{\{V_T > F^D\}} + V_T 1_{\{F^D > V_T\}} \right) 1_{\{\tau^D > T\}} \\ + e^{-r\tau_D} F^D \left(1-\gamma\right) 1_{\{\tau^D < T\}} \end{array} \right] \\ D &= F^D \left[DB^{dout}\left(K^D\right) + \left(1-\gamma\right) DB^{din}\left(K^D\right) \right] - PB^{dout}\left(K^D, F^D\right) \end{aligned} \tag{7}$$

where $E^Q[.]$ denotes the expectation under the risk-neutral measure Q.

To price the coco we need to take into account three mutually exclusive events that affect its payoff. First, the value from the case of no conversion before maturity T, which is equal to F^C units of a *down-and-out* digital barrier option with a barrier of K^C. The value contributed to the second possible event (conversion and no default) and to the third possible event (default where the coco holder receives nothing) are replicated by a spread position in two *down-and-in* barrier call options with the same strike, but with different barriers. The coco holder has a long position in α units of a *down-and-in* call option on the value of assets $CB^{din}\left(K^C, F^D\right)$, with a strike price equal to the face value of deposits F^D and a threshold level of K^C. However, if asset value falls further and touches the default threshold the equity becomes worthless and the coco holder receives nothing. To capture this payoff structure we add a similar but short position in a *down-and-in* call option $CB^{din}\left(K^D, F^D\right)$ with the same terms except having a barrier at the default threshold. This means that if asset value touches K^D the two option payoffs cancel each other. We can write the coco value as:

$$\begin{aligned} C &= E^Q \left[e^{-rT} \left(F^C 1_{\{\tau^C > T\}} + \alpha \left(V_T - F^D\right) 1_{\{\tau^C < T < \tau^D, V_T > F^D\}} \right) \right] \\ C &= F^C DB^{dout}\left(K^C\right) + \alpha \left(CB^{din}\left(K^C, F^D\right) - CB^{din}\left(K^D, F^D\right) \right). \end{aligned} \tag{8}$$

[13] We calculate here the market value of (risky) deposits, which is strictly smaller than the present value of (insured) deposits. The difference is equal to the value of deposit insurance.

The stock price is affected by the outcome of the same three mutually exclusive events as in the case of the coco: no early default and no conversion, no early default and conversion, and early default. The value of the stock can be expressed as follows:

$$\begin{aligned} E &= E^{Q}\left[e^{-rT}\left(\begin{array}{c} \left(V_T - F^C - F^D\right) 1_{\{\tau^C > T\}} \\ +\left(1-\alpha\right)\left(V_T - F^D\right) 1_{\{\tau^C < T < \tau^D, V_T > F^D\}} \end{array}\right)\right] \\ E &= CB^{dout}\left(K^C, F^D + F^C\right) + \left(1-\alpha\right)\left(CB^{din}\left(K^C, F^D\right) - CB^{din}\left(K^D, F^D\right)\right) \end{aligned} \tag{9}$$

where $CB^{dout}\left(K^C, F^D + F^C\right)$ is a *down-and-out* call option. This option is a European call option on the underlying bank asset value that pays off at maturity only if the asset value does not touch the conversion threshold K^C before maturity. In case of conversion, equity value is divided between the original stockholders, who receive $(1-\alpha)$, and the coco holders, who receive a fraction α. Therefore, as in the case of the coco we use a position in a *down-and-in* call option to take into account the stream of cash flows at the event of early conversion; the number of option units is equal to $(1-\alpha)$.

2.2.2 Capital structure with subordinated debt

We next price the securities if the capital structure includes equity, deposits and subordinated debt. The pricing of deposits is the same as before since the event of conversion does not affect the payoff of the deposit holders.

The potential future cash flows to the subordinated debt holder depend on two mutually exclusive events: no default until maturity (events 1.A, 1.B, or 1.C in Table 1 Panel B) and early default (event 2). As in the case of coco, in the event of early default, when the value of assets is equal to the default threshold K^D, the subordinated debt holder receives nothing. In the case that default does not occur until debt maturity the payoff to the subordinated debt holders can be replicated by two options – a long position in a *down-and-out* call option with a strike price equal to the face value of the deposits and a short position in a similar option, but with a higher strike which is equal to the total face value of the debt instruments, $\left(F^D + F^B\right)$. If the value of assets touches the default threshold before maturity the subordinated debt holders receive nothing, which means that both options are *down-and-out* barrier options with the same barrier of K^D. The replicating options are identical to the Black and Cox (1976) framework for pricing subordinated debt and can be expressed as follows:

$$\begin{aligned} B &= e^{-rT} E_t^Q \left[\left(\begin{array}{c} F^B 1_{\{\tau^D > T, V_T \geqslant F^B + F^D\}} \\ + \max\left(V_T - F^D, 0\right) \end{array} \right) 1_{\{\tau^D > T, (F^B + F^D) > V_T \geqslant F^D\}} \right] \\ B &= CB^{dout}\left(K^D, F^D\right) - CB^{dout}\left(K^D, F^D + F^B\right). \end{aligned} \tag{10}$$

The value of equity can be replicated by a *down-and-out* call option. While in the case of coco a similar option is used for replicating the payoff in the event of no early conversion, in the case of subordinated debt the barrier is equal to the default threshold and not to the conversion threshold. The present value of the payoff can be written as:

$$\begin{aligned} E &= e^{-rT} E_t^Q \left[\max\left(V_T - F^D - F^B, 0\right) 1_{\{\tau^D > T\}} \right] \\ E &= CB^{dout}\left(K^D, F^B + F^D\right). \end{aligned} \tag{11}$$

2.3 Pricing the options

To price the options we follow standard option pricing theory as developed by Black, Scholes, and Merton (1973, 1974), and Black and Cox (1976) and assume that the dynamics of the bank's assets follow a simple Geometric Brownian Motion. In addition, we follow the Black and Cox model in which exercise can happen at any time before maturity. This setting is appropriate since banks' liabilities (deposits) will most likely have staggered maturities (Ericsson and Reneby, 1998), and therefore monitoring occurs not only at maturity. Chen, Glasserman, Nouri, and Pelger (2013) stress the need to introduce jumps (e.g. Duffie and Lando, 2001). However, our model setting can incorporate effects similar to those of jumps by assuming delayed bank seizing by the regulator (Section 2.1), as well as an extension of our model in which the audit frequency is discrete (Section 4.4.1).

This assumption is consistent with most existing structural models (Merton, 1974; Black and Cox, 1976; Brennan and Schwartz, 1978; Longstaff and Schwartz, 1995; Leland, 1994; Ericsson and Reneby, 1998) and with models for pricing a bank's claims (Albul, Jaffee, and Tchistyi, 2010; Glasserman and Nouri, 2010; and Sundaresan and Wang, 2013).[14] The assumption also has the advantage of having closed form solutions, which allows us to analyze in a straightforward way the sensitivity of the bank's stock price to changes in the value of asset risk. The closed form solutions for the barrier options we use are developed by Merton (1973) and Rubinstein and Reiner (1991).

3 Default probability

Policymakers and regulators are interested in monitoring the default probability of a financial institution due to the potentially harmful effect of default on the real economy. Indeed, an important motivation for the introduction of contingent capital is its ability to absorb losses and the resulting reduction in bank default probability.

We next quantify this reduction by comparing the case of contingent capital to two alternatives. In addition to deposits, we assume that the capital structure includes one of the following:

1. Equity and contingent capital
2. Equity and subordinated debt
3. Equity only

That is, we assume that contingent capital is replaced with either subordinated debt (2.) or additional equity (3.). These two alternatives are natural given the main features of contingent capital – it is both a debt security and it can absorb losses. When making the comparisons, we assume that all the underlying parameters are the same. Specifically, the face value of contingent capital and subordinated debt are the same ($F^C = F^B$) and asset value is constant,

[14] Pennacchi (2010) instead considers a jump-diffusion formulation for the firm's underlying asset.

meaning that, when compared to the other two cases, additional equity (3.) replaces either the coco or subordinated debt. We initially assume that asset risk is constant, though we relax that assumption in Section 4.

The default probability of a bank with subordinated debt (2.) is composed of two mutually exclusive events. Either before maturity asset value falls below the default threshold K^D, or at maturity the value of assets is below the total face value of debt $\left(F^D + F^B\right)$. In this case either subordinated debt holders or depositors force default if their claims are not fully met. Thus, the probability of default (PD) can be expressed as follows:

$$PD(B) = \Pr\left(\tau^D < T\right) + \Pr(V_T < (F^D + F^B)|\tau^D > T)\Pr\left(\tau^D > T\right). \tag{12}$$

The default probability of a bank with coco (1.) or equity only (3.) is also composed of two mutually exclusive events. Default either occurs before maturity if asset value touches the default threshold K^D or at maturity if assets value lies below the face value of deposits F^D. The probability of default is:

$$PD(C) = PD\,(E) = \Pr\left(\tau^D < T\right) + \Pr(V_T < F^D|\tau^D > T)\Pr\left(\tau^D > T\right). \tag{13}$$

As long as there is subordinated debt in the capital structure (F^B is positive), and assuming a constant level of asset volatility, the default probability in the case of subordinated debt is strictly larger than in the case of coco or equity only and the difference is equal to $\Pr\left(\left(F^D + F^B\right) > V_T > F^D|\tau^D > T\right)$.

3.1 Base case parameters

In order to quantify the effect of introducing contingent capital into a bank's capital structure we choose the following base case parameter values and then perform sensitivity analysis around these values.

3.1.1 Claim parameters

- **Maturity** (T): We choose a 1-year maturity following Marcus and Shaked (1984) and Ronn and Verma (1986). This maturity is also reasonable given that major audits are scheduled once a year. At such a time the regulator may ask the financial institution to change its capital structure.

- **Principal amounts**: We assume that the bank has a capital structure composed of deposits with face value $F^D = 100$, and either contingent capital or subordinated debt with a face value $F^C = F^B = 3$. The coco face value of 3% of deposits is similar to the ratio in the case of Lloyds' contingent capital.

- **Conversion ratio:** $\alpha = 0.5$.[15]

- **Conversion threshold** (β): We choose a conversion threshold $K^C = \left(F^D + F^C\right)(1+\beta)$ that is located $\beta = 1\%$ above the total face value of the two debt instruments. Thus conversion occurs before debt maturity the first time that the value of the bank's assets is equal to $(1+\beta)$ times the total face value of the debt.

3.1.2 Market parameters

- **Leverage ratio** (LR): We define the quasi leverage ratio as the present discounted value of book liabilities divided by current asset value, $LR = \frac{\left(F^D+F^C\right)e^{-rT}}{V_t}$. We choose a base case value for leverage of 0.93 and a range from 0.91 to 0.95. This range is typical for commercial and investment banks (John, Mehran, and Qian, 2010). To achieve variation in leverage we change firm asset value (while holding the face value of debt constant).

- **Interest rate** (r): We choose a continuously compounded constant rate of 2.5%. This is on par with average annual returns on 3-month Treasury bills between 2000 and 2007.

- **Bank assets** (V): The resulting bank asset value implied by a leverage ratio of 0.93 is $V = 108.02$.

[15] In Section 4 we consider the effect of varying the contingent claim parameters. In particular, we consider the effects of changing the conversion ratio and threshold.

- **Asset risk** (σ): Asset risk is set equal to 5%, similar to the average asset risk of banks found in a large sample studied by Mehran and Rosenberg (2008).

3.1.3 Regulatory parameters

- **Regulatory seizing policy** (γ): We assume that the regulator seizes the bank the first time that the value of assets is 3% below the face value of the deposits ($K^D = F^D(1-\gamma)$). Prescott (2011) discusses losses to the deposit insurance fund during the crisis.

- **Minimum and maximum asset risk** (σ): We assume that asset risk lies between 1% and 9%. These levels are consistent with Mehran and Rosenberg (2008), who find that the average asset risk of banks in a large sample is equal to 5.3% and that the size of the cross-sectional standard deviation around this average is equal to 2.2%.

3.2 Base case default probabilities

For the base case parameter values the 1-year risk neutral default probability for a bank with coco or equity only is 2.3% and for a bank with subordinated debt is 7.7%, an increase of 5.4%. The substantially higher default probability of a bank with subordinated debt is a reflection of the stabilizing effect that coco or additional equity financing has on the capital structure. In the case of a deterioration in asset value instead of default there is an automatic provision of capital or such capital is already available.[16] For a leverage ratio of 0.91, the default probabilities are equal to $PD(C) = PD(E) = 0.7\%$ and $PD(B) = 3.1\%$, while a leverage ratio of 0.95 results in respective default probabilities of 6.2% and 16%.

[16] A couple of observations are useful when interpreting the base case default probabilities. First, we report risk neutral probabilities, which are larger than real default probabilities as long as there is a positive risk premium. Second, we are interested primarily in the relative magnitudes of the default probabilities which show that the default probability in the case of coco is significantly smaller than in the case of subordinated debt.

4 Incentives to change risk

If contingent capital is introduced, how should it be designed? We now address this question. While in the previous section we assumed that asset risk is exogenous, we now assume that the bank's management can change the level of asset risk and analyze the effect of contingent capital on the motivation to do so. Indeed, the potential for inefficient asset substitution due to conflicts of interest between stockholder and creditors (Jensen and Meckling, 1976; Galai and Masulis, 1976) is particularly high for banks. A bank can choose what type of lending it engages in and may therefore be more able to change its risk profile than, for example, a mature manufacturing firm. The main debtholders are dispersed and insured depositors and so they have little incentive to monitor the bank's activities (John, Mehran, and Qian, 2010). Indeed, regulators and policymakers are trying to understand the relationship between contingent capital, financial stability, and the risk-taking motivation of equity holders in financial institutions (Acharya, Cooley, Richardson, and Walter, 2009).[17]

We consider how introducing contingent capital into a bank's capital structure can affect stockholders' incentives to change risk. We assume that the dominant component of the executive pay package that is sensitive to asset risk is equity-based compensation and that management chooses the level of asset risk that maximizes the value of stock, for example by choosing the riskiness of the bank's lending activities.[18]

We assume that incentives to either increase or decrease risk are inefficient so that the optimal compensation contract is one that avoids rewarding activities that change risk. In doing so we follow the sentiment expressed in Jensen and Smith (1985), who point out that it is inefficient for management to choose negative net present value projects in an effort to change volatility.[19] Our view is motivated by the perspective of a policymaker who is

[17] The Basel committee points out that an analysis of the effect of contingent capital on incentives is desirable. In fact, they do not strongly endorse issuance of contingent capital with a trigger above the point of non-viability because of the uncertainty about the effect of its design on managerial incentives.

[18] We thus analyze the incentives that management has to either increase or decrease risk given the existing contract. In theory it is possible to formulate a pricing model that takes into account that equity holders will maximize equity value by choosing asset volatility. We do not consider such a setup but instead analyze ex-post risk-shifting by management. We note that this approach, which allows for transfers of wealth from debt to equity, is standard in the literature.

[19] Jensen and Smith (1985) note that agency costs may be lowered "by reducing incentives for the

maximizing surplus in the economy. Investments in negative net present value activities for the purposes of risk targeting and inefficient bailouts in times of distress are undesirable. In addition, incentives in either direction may be undesirable – high risk may result in instability (an important reason for the financial crisis), while low risk may result in a credit freeze and a lack of lending by financial institutions.

4.1 General patterns in equity vega

We analyze incentives to change risk for different contingent capital terms. Importantly, we show that it is possible to choose terms that entirely eliminate incentives to change risk. This is in contrast to the other two alternative capital structures – subordinated debt or equity only – which we again use as comparison cases. For both there is always at least some motivation to increase risk.

We first consider common patterns in incentives and then analyze incentives when choosing specific ranges of parameter values. We measure incentives to change risk by calculating the sensitivity of equity value to changes in asset risk, commonly referred to as 'vega.' In order to calculate equity vega for the capital structures discussed in Section 2, the online appendix (Section B) derives the sensitivities to asset risk for the four types of options which are used as building blocks in the valuation of bank equity.[20]

4.1.1 Achieving zero vega through appropriate choice of the conversion ratio

In the case of contingent capital it is always possible to identify a unique level of the conversion ratio α that achieves zero vega. Intuitively, this important role of the conversion ratio in determining stockholders' risk-changing motivation is the result of two opposing effects on incentives. As the level of asset risk increases and the probability of touching the conversion

firm to take highly risky negative net present value projects." They also point out that choosing low-risk projects is not efficient either (which might result from handing control to bondholders) noting that "bondholders would have incentives to [...] choose projects with too little risk."

[20] The vega of the *down-and-out* call option for which the barrier lies below the strike (e.g. the case of a default threshold) was derived by Johnson and Tian (2000). We extend their analysis to derive the case where the barrier lies above the strike (e.g. conversion).

threshold increases:

1. There is a negative effect on equity value, since in case of conversion stockholders lose some of their position to contingent capital holders.

2. There is a positive effect on equity value, since leverage decreases in case of conversion.

For an intermediate values of the conversion ratio these two effects cancel and the motivation to change risk is eliminated.

We briefly sketch the argument for this result. As the conversion ratio decreases, stockholders receive a larger and larger share of the post-conversion institution. Stockholders are motivated to increase risk so that there is a higher chance that conversion will be triggered. In the extreme, if $\alpha = 0$ contingent capital holders receive no stock in the event of conversion – the debt is simply written off. In this case stockholders prefer higher levels of asset risk. In contrast, if $\alpha = 1$ contingent capital holders take over the firm in the event of conversion. Stockholders now try to decrease risk. As the conversion ratio increases from zero to one, equity vega switches sign. Indeed, as the conversion ratio increases, equity vega monotonically decreases. Therefore, for a given set of parameters, there is a unique conversion ratio for which equity vega is zero. We provide a more detailed argument in Section C of the online appendix.

4.1.2 Equity only and subordinated debt

It is instructive to compare the equity vega to a bank that, instead of contingent capital, issues additional equity. If the capital structure does not include coco, incentives to increase risk are almost always present. The reason for this is that a higher level of asset volatility results in a transfer of wealth from depositors to shareholders. Specifically, equity vega of a bank that includes only equity and deposits is positive as long as there is some limit to the ability of the regulator to monitor the bank and seize it exactly at the time at which assets are equal to the face value of deposits (assuming reasonable levels of volatility and leverage).[21]

[21] In such a situation the regulator is able to seize the bank so promptly depositors are paid in full. This in turn eliminates any motivation for stockholder risk-shifting. Of course, as we point out above (Section 2 footnote 12), our assumption of limited seizing policy ($\gamma > 0$) is in line with the depletion of the FDIC's Deposit Insurance Fund (DIF) during the financial crisis.

If subordinated debt is in the capital structure, equity vega is always strictly larger than if only equity and deposits are present. The appendix provides more detailed discussion for both cases.

4.2 Contingent capital design

We next show that including what we will refer to as 'well-designed' contingent capital results in a robustly low level of incentives. That is, incentives to change risk are not only eliminated for a given set of fundamentals. Incentives remain low when the risk profile of the bank changes (volatility or leverage change). Our analysis focuses on our base case parameter values from Section 3 and demonstrates the effect of contingent capital terms (conversion ratio and threshold) on incentives.

We assume that asset volatility lies in a range around 5%. When considering management's incentives to increase or decrease asset volatility we assume that banks' asset volatilities lie within about two standard deviations of the mean level, or between 1% and 9%. We might view levels of volatility outside of this range as being difficult to achieve due to the availability of a limited set of lending opportunities and projects (John, Saunders, and Senbet, 2000). In addition, levels of asset volatility that lie substantially above the normal range may draw additional attention from the regulator who will try to restrict such levels of risk-taking.

We first consider the conversion ratio. Figure 2 presents the effect of the conversion ratio (α) on the risk-taking motivation of the stockholder. All else equal, the value of the stock decreases as the conversion ratio increases. In addition, the stockholder's choice of asset risk strongly depends on the conversion ratio. For a relatively low conversion ratio ($\alpha = 0$ or 0.25, "stock-friendly") the value of the stock increases with asset risk. Intuitively, an increase in asset risk results in a larger increase in equity value due to the potential decrease in leverage at conversion than the loss of equity value due to stock dilution at conversion. The reverse relationship is present for a relatively high conversion ratio ($\alpha = 0.75$ or 1, "coco-friendly"). Importantly, the value of the stock is almost insensitive to asset risk for intermediate levels of the conversion ratio. For example, the value of the stock is close to constant with respect to asset risk when the conversion ratio is equal to 50%.[22]

Figure 3 shows the effect on incentives of changing the conversion threshold, the level of asset value at which conversion takes place. We find that the conversion threshold has little impact on the relationship between incentives and the conversion ratio, which is the dominant factor affecting risk taking motivation. Figure 3 shows the sensitivity of the stock price for three levels of β $(0\%, 1\%, 2\%)$, the percentage difference between asset value and the conversion threshold. We report equity value as a function of asset risk for three levels of the conversion ratio ($\alpha = 0.1, 0.5, 0.9$), each time considering the effect of varying the conversion threshold. Figure 3.A shows that when the conversion ratio is relatively low (equal to 0.1, "stock friendly") stockholders will try to choose the maximum level of asset risk for any level of the conversion threshold. Figure 3.C considers a conversion ratio that is relatively high (equal to 0.9, "coco-friendly"). In this case the relationship between the stock value and asset risk is downward sloping for all three conversion thresholds; thus stockholders prefer the minimum level of asset risk. For intermediate levels of the conversion ratio, risk-taking incentives remain small for the different conversion ratios. Figure 3.B presents the sensitivity of the stock price to asset risk for a conversion ratio of 0.5, for which the effect of asset risk on equity value is small for all three levels of the conversion threshold.

Since there are likely costs associated with a change in the composition of a bank's loan portfolio, we assume that stockholders need reasonably large incentives to induce them to actively engage in changing the financial institution's risk profile. We measure incentives by finding the maximum absolute value of vega, calculated across asset volatility levels from 1% to 9%.[23] If the absolute value of maximum vega does not exceed 0.1% of asset value, costs associated with risk-shifting are unlikely to outweigh the benefits and therefore will most likely make changes in asset risk not worthwhile. We classify such incentives as weak, or 'indifferent.'

[22] Consistent with our findings, Sundaresan and Wang (2011), Pennacchi (2010), and Albul et al. (2010) also suggest that a particular choice of conversion ratio may have implications for risk-shifting. However, these studies do not analyze optimal contingent capital design or compare incentives to financial institutions with alternative capital structures.

[23] We note that it may be desirable for incentives to not change dramatically for different levels of asset volatility. This analysis is thus more general than the result that it is always possible to find a level of the conversion ratio for which vega is equal to zero.

To get a better sense of the economic magnitude of a maximum vega of 0.1% of asset value, we calculate maximum vega for the three capital structures. For the base case parameters (and assuming leverage varying from 0.91 to 0.95 and asset volatility varying from 1% to 9%) maximum absolute vega is equal to 0.03% (coco), 0.21% (subordinated debt), and 0.10% (equity only).

Table 2 summarizes the incentives to change risk for different contingent capital terms. If for some values of asset volatility stockholders have strong incentives to increase or decrease risk we report 'Increase' or 'Decrease'; if incentives are weak (the maximum absolute value of vega is less than 0.1% of asset value) the table reports 'Indifferent.' The results in the table emphasize the importance of contingent capital design. The stockholders are indifferent with respect to the level of asset risk when the conversion ratio is equal to 50% and the conversion threshold lies between 0% and 2%. For high levels of the threshold ($\beta = 2\%$) the conversion ratio for which stockholders are indifferent is equal to 40% and 50%, while for low levels of the conversion threshold ($\beta = 0\%$) incentives are low for levels of the conversion ratio between 50% and 90%. Thus, for all conversion thresholds, levels of indifference exist for an intermediate level of the conversion ratio, though the range of conversion ratios for which incentives are small depends on the conversion threshold.

4.2.1 Leverage

It is important to examine whether or not the effect of contingent capital on incentives changes across different environments (e.g. good times: low leverage ratio, and bad times: high leverage ratio). We find that the effect of issuing contingent capital on risk-taking is very stable across different levels of leverage.

In Figure 4 we consider three levels of leverage ($LR = 91\%, 93\%, 95\%$) and find that the dominant factor that determines incentives is the conversion ratio, similar to the effect on risk-taking motivation of varying the conversion threshold. Figures 4.A and 4.C show that for all levels of leverage, conversion ratios that are low ($\alpha = 0.1$) or high ($\alpha = 0.9$) result in relationships between asset risk and stock value that are upward and downward sloping respectively. As leverage increases the value of the stock becomes more sensitive to asset risk but the direction of the incentives remains the same. In Figure 4.B the conversion ratio is set equal to 0.5. For this conversion ratio the sensitivity of equity value to asset risk is small for all three levels of leverage (specifically, maximum vega is equal to 0.03% in all three cases). Thus for an intermediate level of the conversion ratio the value of the stock has a low sensitivity to asset risk for different levels of leverage.

To summarize, across both different conversion thresholds and leverage ratios, the primary determinant of incentives is the conversion ratio. The intuition is that only the conversion ratio affects the distribution of value in the event of conversion. Therefore, while the conversion threshold and leverage affect the overall likelihood of conversion taking place, they do not affect whether or not making conversion more likely is beneficial for stockholders.

4.2.2 Regulatory seizing policies

We also consider differences in regulatory seizing policies and monitoring abilities. Our setup allows us to compare incentives for different levels of asset value at which the regulator seizes the bank. In our model the level at which the bank is seized is measured by the percentage difference between the par value of the deposits and the value of the bank's assets at which seizing occurs (the parameter γ). We consider the value of stock versus asset risk for different regulatory seizing policies ($\gamma = 2\%, 3\%, 4\%$). For all three levels the stock value is stable across different levels of asset risk; maximum vega is equal to $(0.03\%, 0.03\%, 0.05\%)$. Regulators can be differentiated according to their ability and willingness to seize a bank in financial distress. Our results show that the terms of the coco, which lead to stable incentives that minimize stockholder risk-shifting motivation, do not need to be adjusted to different seizing policies.

4.2.3 Comparing to alternative capital structures

We next consider the motivation to change risk for our comparison capital structures. Figure 5 graphs equity value against asset risk for banks that are identical to our previous analysis (same base case parameter values), expect that they have capital structures that instead of contingent capital include subordinated debt (Figure 5.A) or additional equity (Figure 5.B). As before, we consider different levels of leverage ($LR = 91\%, 93\%, 95\%$). For the case of additional equity we replace subordinated debt with additional equity, resulting in leverage ratios of 88%, 90%, and 92%.

Stockholders in a bank with subordinated debt are motivated to increase asset risk and this motivation is stronger for higher levels of leverage. Risk-shifting incentives are present for all three leverage ratios and the sensitivity of the stock price to asset risk increases with leverage (Figure 5.A). In the three cases maximum vega is equal to 0.18, 0.21, and 0.21. When subordinated debt is included in the capital structure, the risk of losses that wipe out equity is borne by subordinated debt investors and thus is not internalized by stockholders. In contrast, if a reduction in equity value results in stockholder dilution (when contingent capital is present), stockholders are directly affected by large losses.[24] Of course, these patterns are consistent with the classic risk-shifting intuition associated with high levels of debt (Jensen and Meckling, 1976; Galai and Masulis, 1976). Importantly, the higher risk-shifting incentives associated with higher leverage are in contrast to the case of well-designed contingent capital, where financial distress does not lead to a large increases in risk-taking motivation.

While the typical capital structure of large financial institutions is composed of deposits, stocks and subordinated debt, one criticism raised against contingent capital is the claim that a capital structure which includes only deposits and stock has the same probability of default as a structure which includes coco, and that there is thus no advantage of introducing coco into a bank's capital structure (Admati et al., 2010). In both cases default occurs only if the bank is seized before maturity or if at maturity asset value lies below the face value of deposits so that the default probability is the same, assuming the same level of risk.

However, volatility (and default probability) may be higher for the equity only case since incentives to increase risk may be present. Figure 5.B shows the risk-taking motivation for the equity only case. The value of the stock increases with asset risk for any level of leverage and thus the stockholders are motivated to increase asset risk to the highest possible level. As in the case of subordinated debt, risk-shifting incentives are higher for higher levels of leverage. If changes in volatility are possible, the default probability of the bank with equity and deposits will therefore be higher compared to a bank with a well-designed coco that has

[24] We would like to thank an anonymous referee for pointing out this intuition.

no strong incentives for risk-shifting. Nevertheless, it is useful to recall that motivation to increase risk for the equity only bank are always smaller than for the subordinated debt case. In addition, for very low levels of leverage (0.88 and 0.90), incentives to increase risk are small; maximum vega in these cases lies slightly below 0.1% of asset value. However, this level is reached if leverage is equal to 0.92. For the three levels of leverage, maximum vega is equal to $(0.07\%, 0.08\%, 0.1\%)$.[25]

To summarize, potentially inefficient risk-shifting incentives are present both if the bank's capital structure (in addition to deposits) includes either only equity or both equity and subordinated debt. From the perspective of a policymaker interested in eliminating or minimizing incentives to change risk, both cases may be inferior to a capital structure that includes well-designed contingent capital. However, equity holders may prefer a high sensitivity of equity value to risk since it could allow them to transfer wealth from depositors (or the government). Well-designed contingent capital thus will most likely not be issued endogenously; rather, issuance may have to be mandated.

4.2.4 Minimizing incentives to change risk

Varying contingent capital terms means varying the conversion ratio (α) and the conversion threshold (β). In theory both parameters can be chosen so as to find the combination that minimizes the incentive to change the bank's risk. An important parameter that forms part of the environment and that may affect the choice of contingent capital design is the regulatory seizing policy. A high monitoring capability (low gamma) may result in lower incentives to increase risk as compared to a lower level of monitoring ability (high gamma).

Table 3 reports equity vega for different seizing policies and leverage ratios. As before, we find the maximum absolute value of vega across levels of volatility ranging from 1% to 9%. Since the low sensitivity of risk-taking incentives to changes in leverage (Figure 5) is an

[25] As discussed above, incentives in the stock only case depend on the regulatory seizing ability. If this ability is slightly lower ($\gamma = 4\%$) then the stock only maximum vega increases to $(0.09\%, 0.12\%, 0.14\%)$, while the coco maximum vega numbers change only slightly to $(0.04\%, 0.04\%, 0.05\%)$. Changing the coco terms (conversion ratio and threshold) can reduce maximum vega further. For $\alpha = 0.67$ and $\beta = 0$, maximum vega for $\gamma = 4\%$ and the different leverage ratios are equal to $(0.02, 0.02, -0.03)$. Also see Section 4.2.4.

important and desirable feature, we assume that contingent capital terms are fixed for different levels of leverage (the rows in the table). Panel A reports vega for the base case parameters. Consistent with the results discussed above, risk-taking incentives are small throughout – maximum vega is everywhere smaller or equal to 0.03%, where percentages are relative to asset value. Using our earlier criterion for classifying risk-taking, stockholders are in all cases indifferent to changes in volatility and thus have virtually no incentive to change the bank's risk.[26]

In Panel B we search for the combination of conversion ratio and threshold that result in the lowest incentives to change risk. For each level of the seizing ability of the regulator we find the parameter combination that minimizes the sum of squared vegas across different levels of leverage. We find that incentives are very similar to the base case values. The optimal conversion ratio is close to 0.6 and the optimal conversion threshold is close to zero.

We note that the optimal conversion ratio increases with gamma. As the regulatory ability to seize banks early decreases, there is stronger motivation to increase risk. The higher conversion ratio (more 'coco-friendly') offsets this motivation and makes stockholders close to indifferent to changes in asset risk.

4.3 Contingent capital components: incentives and default probability

The introduction of contingent capital has two important stabilizing effects: A reduction of default probability and the possibility of choosing terms that result in low levels of risk-taking incentives. Both objectives are desirable, but it may be possible to increase our understanding of their respective sources.

One approach is to think of contingent capital as a combination of two instruments that are bundled together. First, a debt instrument that is written off at conversion, second, an instrument that represents the right to receive stock upon conversion (financial distress), an

[26] Also, consistent with our discussion of equity vega for different capital structures, the absolute value of equity vega is always higher for the cases of subordinated debt or additional equity.

event that dilutes original stockholders. In the context of our model it is possible to analyze the effect of issuing only the latter – which we refer to as a "reverse warrant" – on both risk-taking motivation and default probability.

We analyze the effect on incentives of a reverse warrant. It pays off a fraction α of equity in the case that equity value falls below a threshold. The security has no face value and so $F^C = 0$. In Panel C of Table 2 we choose the conversion ratio and threshold so as to minimize risk-taking incentives.

Issuing a reverse warrant can result in low incentives to change risk. For levels of leverage ranging from 0.91 to 0.95 and for different seizing policies, incentives are smaller or equal to 0.05% in absolute value. We note that, as the regulator becomes less able to seize the bank early, current shareholders must receive a smaller share of the post-conversion equity (α increases with γ) in order to ensure weak incentives. The later seizing policy is thus counteracted by a larger dilution in the case of conversion. However, issuance of the reverse warrant does not alter the default probability (assuming the same level of asset volatility). The face value of contingent capital in this case is equal to zero and there is no longer a buffer or automatic bail-in during times of financial distress.

We conclude that it is possible to disentangle the two effects of contingent capital: the reduction in default probability is related to the contingent capital face value, while the resulting incentives are related to the contingent capital conversion terms. As long as both aspects are desirable, issuing 'well-designed' contingent capital with a positive face value can achieve both objectives.

4.4 The effect on incentives of relaxing assumptions about asset value

In our analysis we assume that (a) assets are continuously traded and (b) claimholders accurately observe asset value. However, some of the liabilities of a financial institution include untraded assets, the value of which cannot easily be measured accurately, and capital ratios are at least partly based on accounting data, proxies for which will be available only at lower than continuous frequencies. We next show that our main results are robust to relaxing these assumptions.

4.4.1 Discrete audit frequency

We assume that monitoring of asset value and the conversion threshold occurs only at discrete intervals. We use a straightforward approximation from Broadie, Glasserman and Kou (1997) to price the relevant barrier options discussed in Section 2. Figure 6.A presents the value of the stock for both continuous and monthly monitoring frequencies. As before, we set the distance between the conversion threshold and the total face value of debt as $\beta = 1\%$. In the case of continuous monitoring, the stockholder is not motivated to change risk (maximum vega is 0.03%). However, we find that audit frequency affects incentives: In the case of monthly monitoring, the stockholder has a slight incentive to increase risk, though it still remains low. In this case maximum vega is equal to 0.11% of asset value, only slightly above incentives that we classify as 'indifferent' in Table 2.

Figure 6.B shows that risk-shifting incentives can be reduced to below 0.1% by choosing a higher conversion ratio. At a level of $\alpha = 75\%$ the motivation for risk-shifting when monitoring is done monthly is very low. Maximum vega is equal to 0.05%. What this means is that, in the case where only discrete audit is possible, the terms of the contract can be adjusted in order to virtually eliminate risk-taking motivation resulting from equity-based compensation.

4.4.2 Asset value is observed with noise

We consider the effect of observing asset value with noise. Specifically, we assume that market participants observe a process that is correlated with asset value, but which may, at times, differ from it. Following Glasserman and Nouri (2012a) we base conversion on this correlated process, assume that the true asset value is known at the beginning and end of the contract, and if default occurs. That is, we assume that both processes agree on whether or not default has occurred, implying that default is based on the true process. We assume both the 'true' and the 'observed' processes follow Geometric Brownian Motions, that they have the same drift, and that the volatility of shocks to the returns are the same, while the correlation of the shocks is imperfect. Based on these assumptions, we can numerically calculate the stock value.[27]

We analyze the effect of this setting on incentives to change risk. We consider maximum vega for different levels of imperfect correlation between the true and the observed processes. We consider maximum vega for a capital structure containing contingent capital designed according to our base case parameters ($\alpha = 50\%$, $\beta = 1\%$, $F^C = 3\%$). In order to benchmark the results, we compare these to levels of maximum vega for the continuous case (reported in Table 3 Panel A), for which maximum vega is equal to 0.03% if leverage is 0.93. For the case of perfect correlation between the two processes, maximum vega is 0.06%, with the difference resulting from the daily sampling frequency. Maximum vega declines as the correlation decreases and becomes negative. For a correlation of 90% it is equal to 0.03%, and for a correlation of 80% it is equal to $-0,02\%$. Thus, for the case of less than perfect correlation incentives continue to be small. This remains true if we vary leverage from 0.91 to 0.95. For the two imperfect correlations, maximum vega never exceeds 0.03% of asset value – incentives that we classify as 'indifferent.'[28]

5 Conclusion

In this paper we analyze the effect of including contingent capital in the capital structure of financial institutions. We provide closed-form solutions for the prices of contingent capital and other bank liabilities by replicating payoffs using sets of barrier options.

We demonstrate that there are two channels through with contingent capital may be effective in stabilizing the banking sector. First, banks that issue contingent capital instead

[27] There is no closed form solution for this case. Instead, we use Monte Carlo simulations to calculate the stock price. For implementation purposes we assume that asset value is sampled on a daily basis.

[28] We note that, as correlation declines, there is a lower motivation to increase risk. This is due to a change in the trade-offs shareholders face. If correlation is imperfect, shareholders are worried about conversion occurring that should not have occurred (conversion in 'good times'). This situation has the potential to result in a very large loss to current shareholders. The opposite case, no conversion if conversion should have occurred (no conversion in 'bad times') is beneficial, but less than the loss in upside, since at maturity actual asset value is observed. Thus, as correlation decreases, shareholders are less interested in increasing risk since that also increases the probability of conversion.

of subordinated debt are significantly less likely to default. Second, it is possible to design contingent capital so that equity-based compensation is not sensitive to changes in risk.

We show that contingent capital design (in particular the conversion ratio, the fraction of post-conversion common equity that contingent capital holders receive) has an important impact on risk-taking motivation. For relatively low ("stock-friendly") conversion ratios stockholders have an incentive to increase asset risk, while a high ("coco-friendly") conversion ratio leads to a desire to reduce risk. Importantly, for intermediate levels of the conversion ratio, incentives to change risk can virtually be eliminated. It is therefore possible to create contingent capital contract terms that may be able to cancel out the adverse effects of equity-based compensation.

The presence of contingent capital can reduce risk-taking incentives relative to two important benchmarks: replacing contingent capital with subordinated debt or with additional equity. We show that risk-taking incentives for a bank with well-designed contingent capital are smaller than both of these. The higher incentives to increase risk for the equity only bank imply that its default probability will also tend to be higher than if coco was in the capital structure.

Incentives in the presence of well-designed contingent capital remain low even when a bank enters financial distress, while incentives to risk-shift increase with leverage for banks with subordinated debt or additional equity financing. Incentives also remain close to unaffected by different regulatory seizing policies (the level of bank losses at which the regulator takes over the institution).

During the recent financial crisis banks were severely undercapitalized and had to be bailed out. We show that introducing well-designed contingent capital into banks' capital structures represents a possibility to substantially reduce incentives to increase bank risk, decrease the bank failure rate, and reduce the need for costly provision of capital.

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Table 1: Payoffs to claimholders for capital structures with contingent capital or subordinated debt

Panel A: Capital structure with contingent capital

Liability Type	**Scenario**			
	$\tau_C > T$	$\tau_D \geq T \geq \tau_C$ (2) Early conversion		$T > \tau_D$
	(1) No early conversion	$V_T \geq F^D$ (2.A) No default	$V_T < F^D$ (2.B) Default	(3) Early default
Secured debt	F^D	F^D	V_T	$F^D(1-\gamma)$
Coco	F^C	$\alpha(V_T - F^D)$	0	0
Equity	$V_T - (F^C + F^D)$	$(1-\alpha)(V_T - F^D)$	0	0

Panel B: Capital structure with subordinated debt

Liability type	**Scenario**			
	$T > \tau_D$ (1) No early default			$T \geq \tau_D$
	$V_T \geq (F^D + F^B)$ (1.A) No default	$(F^D + F^B) > V_T \geq F^D$ (1.B) Default only on subordinated debt	$F^D > V_T$ (1.C) Default	(2) Early default
Secured debt	F^D	F^D	V_T	$F^D(1-\gamma)$
Subordinated debt	F^B	$V_T - F^D$	0	0
Equity	$V_T - (F^D + F^B)$	0	0	0

Table 2: Optimal level of asset risk for different contingent capital terms (α,β)

The table shows the level of asset risk that a stockholder trying to maximize wealth would choose for different levels of the conversion ratio (α) and distance between the total debt face value and the conversion threshold (β). We assume that stockholders can choose asset risk in a range from 1% to 9%. For each combination of α and β, we report (1) 'Increase' – there are levels of volatility associated with incentives to increase asset risk, (2) 'Decrease' – there are levels of volatility associated with incentives to decrease asset risk, or (3) 'Indifferent' – there are no levels of asset volatility with strong incentives to change risk. In all cases, classification of incentives is based on the maximum absolute value of vega for levels of asset volatility ranging from 1% to 9%. If the absolute value of maximum vega exceeds 0.1% of asset value, incentives are classified as Increase or Decrease, otherwise incentives are classified as Indifferent. All other parameters are identical to the base case parameters.

Conversion Ratio (α)	**distance between the conversion threshold and the total debt face value (β)**				
	0.0%	**0.50%**	**1.00%**	**1.50%**	**2.00%**
0%	Increase	Increase	Increase	Increase	Increase
10%	Increase	Increase	Increase	Increase	Increase
20%	Increase	Increase	Increase	Increase	Increase
30%	Increase	Increase	Increase	Increase	Increase
40%	Increase	Increase	Increase	**Indifferent**	**Indifferent**
50%	**Indifferent**	**Indifferent**	**Indifferent**	**Indifferent**	**Indifferent**
60%	**Indifferent**	**Indifferent**	**Indifferent**	**Indifferent**	Decrease
70%	**Indifferent**	**Indifferent**	Decrease	Decrease	Decrease
80%	**Indifferent**	Decrease	Decrease	Decrease	Decrease
90%	**Indifferent**	Decrease	Decrease	Decrease	Decrease
100%	Decrease	Decrease	Decrease	Decrease	Decrease

Table 3: Contingent capital terms and motivation to change risk

For each combination of input parameters, the table reports equity vega (in percentage of assets value), when the capital structure includes contingent capital. We report the vega that has the highest absolute value for levels of asset volatility ranging from 1% to 9% for leverage levels of 91% to 95%. Panel A uses the base case contingent capital terms. Panel B reports levels of the conversion ratio and threshold (α,β) that minimize vega (for each level of gamma). Panel C reports results when the face value of contingent capital is set equal to zero ('reverse warrant') and conversion terms are chosen freely.

Seizing policy	**Coco terms**			**Leverage ratio**				
γ	**α**	**β**	**F^C**	**91%**	**92%**	**93%**	**94%**	**95%**
Panel A: Vega for base case contingent capital terms								
2%	50%	1%	3%	0.03	0.03	0.03	0.03	0.03
3%	50%	1%	3%	0.03	0.03	0.03	0.03	0.03
4%	50%	1%	3%	0.04	0.04	0.04	0.04	0.05
Panel B: Conversion ratios and thresholds that minimize vega								
2%	59.9%	0.4%	3%	0.02	0.02	0.02	0.02	-0.03
3%	66.4%	0.0%	3%	0.02	0.02	0.02	0.02	-0.03
4%	66.6%	0.0%	3%	0.02	0.02	0.02	0.02	-0.03
Panel C: Optimal terms for a 'reverse warrant' (F^C=0)								
2%	13.6%	0.7%	0	0.02	0.02	0.01	-0.02	-0.03
3%	36.0%	0.0%	0	0.02	0.02	0.01	-0.01	-0.04
4%	42.6%	0.0%	0	0.03	0.03	0.02	0.02	-0.05

Figure 1: Time line of the model for contingent capital

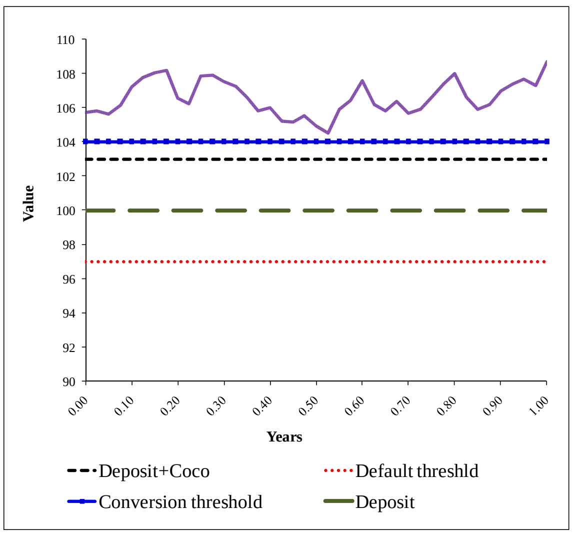
There are three possible states in the model:

(1.A) <u>No conversion event</u>: The value of the bank's assets does not touch the conversion threshold until debt maturity $(\tau_c > T)$ and the coco holder is fully paid, while the stockholder receives the residual assets.

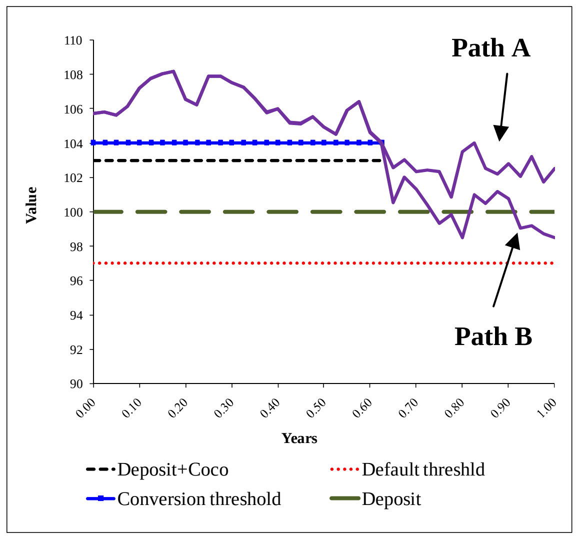
(1.B) <u>Conversion event with no default</u>: The value of the bank's assets has reached the lower conversion threshold and as a result the coco holder receives a predetermined ratio of the bank's stocks in exchange for unwinding its debt obligation $(\tau_d > T \geq \tau_c)$. At maturity, if the value of the bank's assets is above the face value of debt the Coco holders and the original shareholders share the residual assets after payments are made to the secure debt holders (Path A). Otherwise, default occurs and the coco holder and the original stockholder receive nothing (Path B).

(1.C) <u>Early default</u>: The value of the bank's assets has touched the default threshold before maturity. $(\tau_d \leq T)$. The coco holder and the initial stockholders receive nothing.

(1.A) No conversion



(1.B) Early conversion, no early default



(1.C) Early default

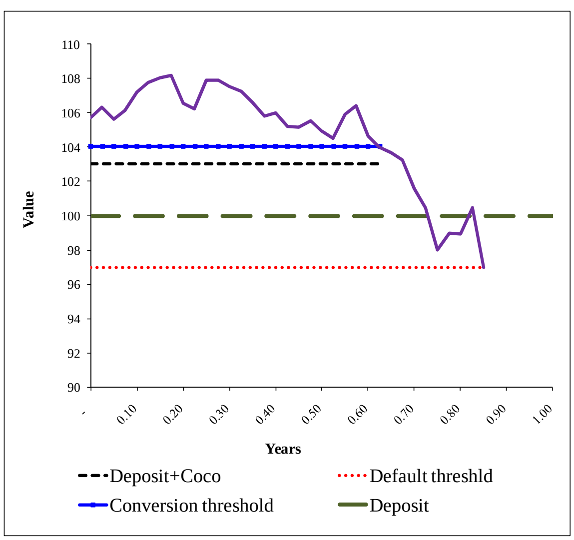


Figure 2: Stock value versus asset risk for different conversion ratios

The figure presents the value of stock versus asset risk for different conversion ratios (α) where the bank capital structure is composed of coco, deposits and stocks. All other parameters are identical to the base case parameters.

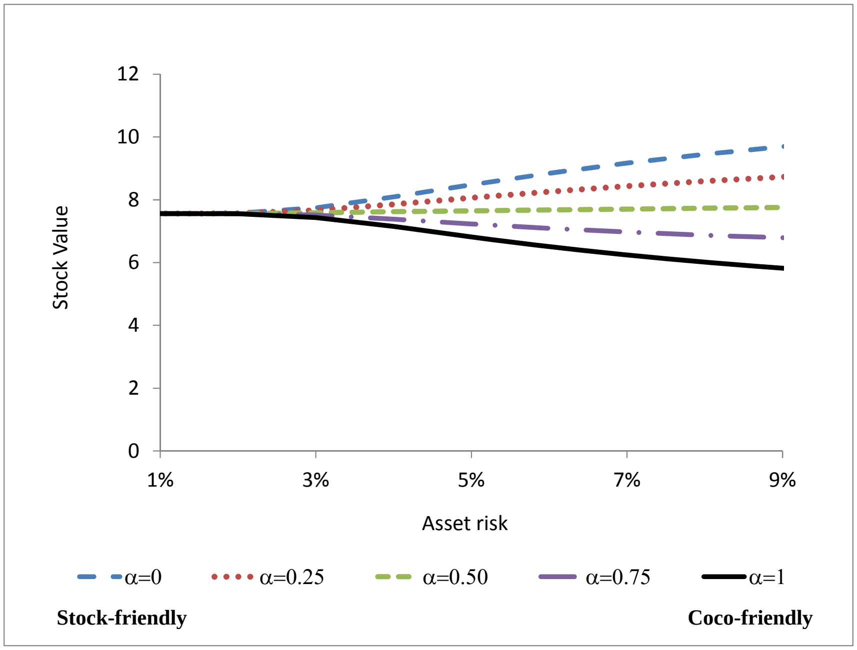
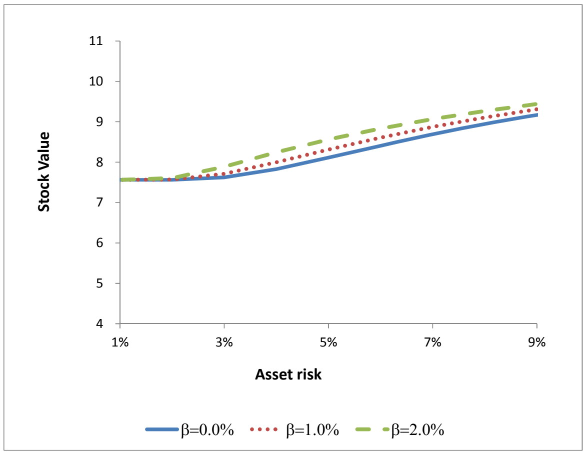


Figure 3: Stock value versus asset risk for different conversion thresholds

The figure presents the value of a stock of a financial institution with Coco as part of its capital structure versus assets risk for different distance between the conversion threshold and the firm's book value of debt (β).The conversion ratio (α) is equal at panel (3.A) to 0.9, and to 0.5 and 0.1 at panels (3.B) and (3.C) respectively. All other parameters are identical to the base case parameters.

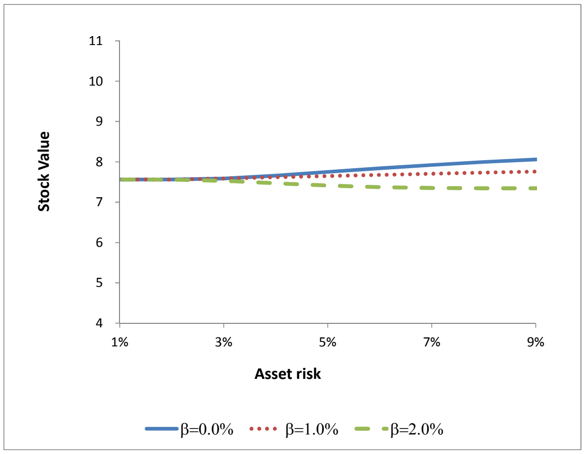
(3.A) "Stock friendly"

Low conversion ratio (α=0.1)



(3.B) Moderate conversion ratio

The conversion ratio (α) is equal to 0.5



(3.C) "Coco friendly"

High conversion ratio (α=0.9)

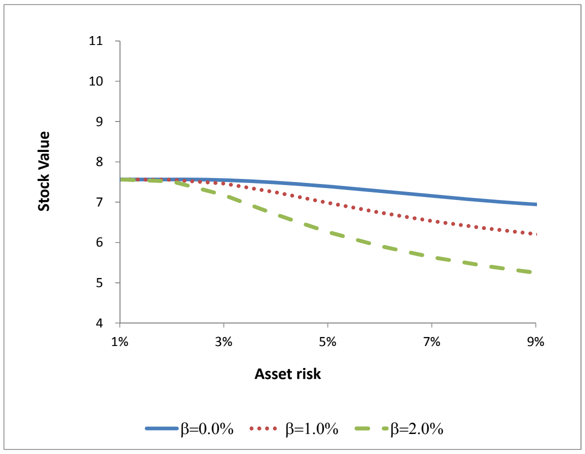
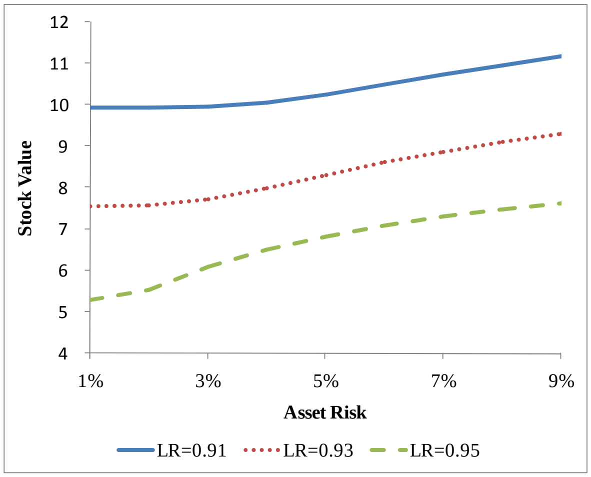


Figure 4: Stock value versus asset risk for different leverage ratios

The figure presents the value of a stock versus asset risk in a bank with a capital structure which includes coco, deposits and stocks. The conversion ratio (α) is equal in panel (4.A) to 10% ("Stock Friendly") and to 90% ("Coco friendly") in panel (4.B). In each case the leverage ratio receives values of 0.91, 0.93 and 0.95. All other parameters are identical to the base case parameters.

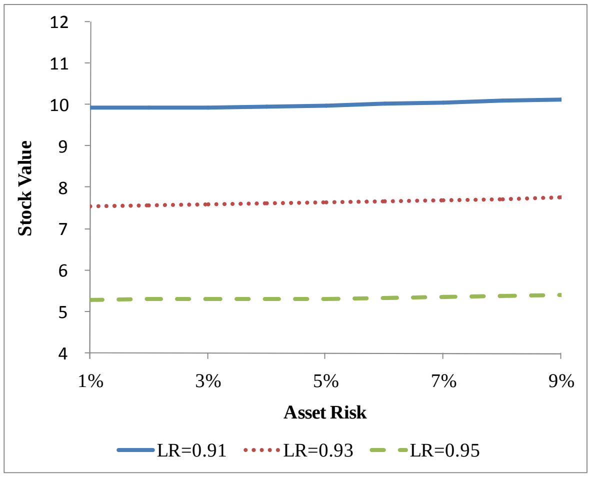
(4.A) "Stock friendly"

Low conversion ratio (α=0.1)



(4.B) "Moderate conversion ratio"

Conversion ratio is equal α= 0.5



(4.C) "Coco friendly"

High conversion ratio (α= 0.9)

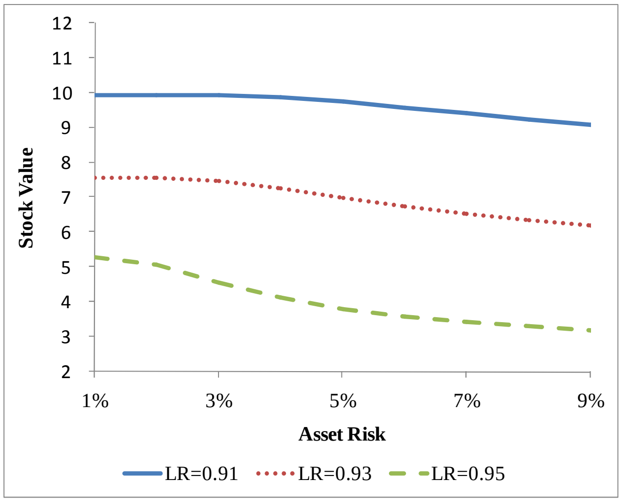
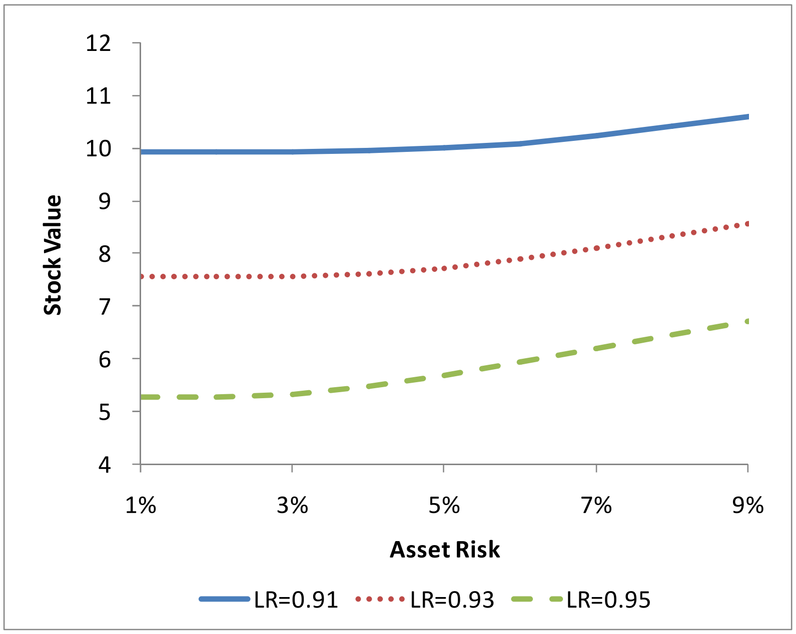


Figure 5: Stock value versus asset risk for different capital structures

Figure (5.A) presents the value of stock versus asset risk for a bank with a capital structure that includes subordinated debt, deposits, and stock. Asset value varies so that leverage is equal to 0.91, 0.93, and 0.95. Figure (5.B) presents the value of stock versus asset risk for a bank where we replace subordinated debt with additional equity, but hold asset value fixed relative to the three cases reported in Figure 5.A. The resulting leverage ratios are 0.88, 0.90, and 0.92. All other parameters are identical to the base case parameters.

(5.A) Capital structure with subordinated debt



(5.B) Capital structure with stock and deposits ('equity only')

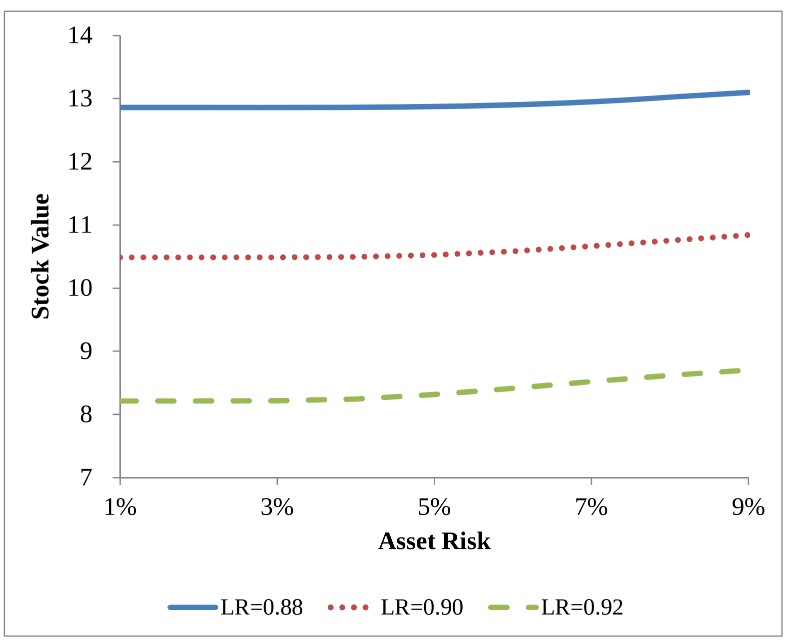
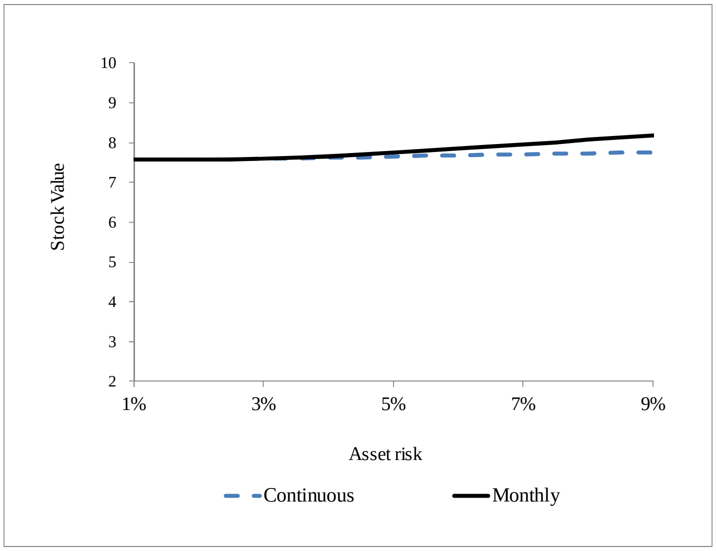


Figure 6: Stock value versus asset risk for different monitoring frequency

Figure (6.A) presents the value of a stock versus asset risk for different monitoring frequency in which information is received about the value of the firm assets and the conversion covenant may be executed. In panel (6.A), as in the base case, conversion ratio is equal to 50%, while in panel (6.B) the ratio conversion ratio is increased to 75% (the parameter α). All other parameters are identical to the base case parameters.

(6.A) Conversion ratio of 50% (α=50%)



(6.B) Conversion ratio is equal to 75% (α=75%)