A Structural Model of Contingent Bank Capital*

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Abstract

This paper develops a structural credit risk model of a bank that issues short-term deposits, shareholders' equity, and fixed- or floating-coupon contingent capital (CoCos). The model assumes that bank assets follow a jump-diffusion process, interest rates are stochastic, and capital ratios are mean-reverting. Allowing for sudden declines in asset values, as occur during financial crises, has distinctive implications. CoCo credit spreads are higher when: the capital conversion trigger is lower; the conversion write-down is greater; and conversion awards a fixed, rather than variable, number of shares. Dual price trigger CoCos are more similar to nonconvertible subordinated debt. Issuing CoCos can create a "debt overhang" problem and a moral hazard incentive for the bank to raise its asset risk, but these problems are often less than if the bank issued a similar amount of subordinated debt. In general, incentive problems are least when contract terms minimize CoCos' credit risk.

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1 Introduction

The recent financial crisis exposed flaws in the regulation of bank capital. At the start of the crisis, there was consensus among U.S. regulatory officials that banks had strong capital positions.[1] Why did these substantial capital levels prove inadequate, leading the federal government to inject more capital into many banks? One explanation is that the crisis produced sudden, extreme losses in bank asset values that rapidly depleted banks' initially high levels of capital. A compounding factor was that significant amounts of capital took the form of subordinated debt.[2] If a bank fails, subordinated debt protects depositors and the Federal Deposit Insurance Corporation (FDIC) from asset value losses. However, prior to failure subordinated debt adds to leverage and does not reduce financial distress when asset values and shareholders' equity capital decline. Subordinated debt can worsen the moral hazard of excessive risk-taking and the problem of "debt overhang" which is a disincentive for the bank to replenish its common shareholders' equity following a decline (Myers (1977)). Moreover, because the federal government considered some financial institutions to be "too big to fail," it contributed public capital that prevented subordinated debt from absorbing losses.

To avoid future government bailouts, new capital instruments called "contingent capital" or "contingent convertibles" (CoCos) have been proposed with the goal of reducing the likelihood that banks experience financial distress. As first proposed by Flannery (2005), contingent capital takes the form of debt that converts to common shareholders' equity if a bank's original shareholders' equity or capital is depleted. It is a mechanism for automatic capital restructuring that extinguishes debt and replaces it with new common equity. Banks may prefer contingent capital to an equivalent amount of common shareholders' equity because its status as debt provides a corporate tax shield.[3] Many bank regulators have embraced the concept of contingent capi-

[1] For example, in September 5, 2007 testimony to the U.S. House of Representatives Financial Services Committee, Federal Deposit Insurance Corporation Chair Sheila Bair stated "Because insured financial institutions entered this period of uncertainty with strong earnings and capital, they are in a better position both to absorb the current stresses and to provide much needed credit as other sources withdraw....As the current period of financial stress began, both the banking industry and the deposit insurance system were sound." In an October 15, 2007 speech to the Economic Club of New York, Federal Reserve Chairman Ben Bernanke stated "Fortunately, the financial system entered the episode of the past few months with strong capital positions and a robust infrastructure. The banking system is healthy."

[2] For the 20 largest U.S. bank holding companies as of June 2007, subordinated debt equaled 2.2% of total assets and equity capital equaled 8.4 % of total assets. These statistics are book values from Y-9C Reports.

[3] Coupons on contingent capital would be deductible from income prior to the calculation of corporate income taxes whereas shareholder dividends are not. Absent major tax reform that eliminates the disincentive to issue shareholders' equity, contingent capital can both mitigate this tax distortion and improve financial stability. The alternatives of simply requiring more common shareholders' equity capital or taxing bank debt can worsen other problems. For example, Han et al. (2015) show that corporate taxes paid by banks create incentives to excessively securitize loans. Relative to non-financial firms, banks may be especially sensitive to corporate taxes because many of their competitors are tax-exempt, such as special purpose securitization vehicles, mutual funds, small banks organized as S-corporations, and credit unions.

tal, though other policymakers, bankers, credit rating agencies, and investors remain skeptical.[4] Differences in opinion regarding the viability of contingent capital may be due to insufficient understanding of its valuation and risk characteristics.

The goal of this paper is to clarify how contingent capital's contractual terms and the risk of its issuing bank affect its value and, therefore, the yields that contingent capital investors should require. The need to better understand how contingent capital should be valued has been expressed by both investors and credit rating agencies.[5] In addition, the paper explores the risk-taking incentives of banks that issue different forms of contingent capital and compares them to those of banks that issue non-convertible subordinated debt. It also examines the degree to which contingent capital mitigates the problem of debt overhang. Policymakers responsible for determining whether particular contingent capital designs will qualify to meet Basel III capital requirements should be particularly concerned with these incentive issues.[6] More broadly, practitioners, policymakers, and academics often express positive or negative views of contingent capital in general, but contingent capital qualities can be highly sensitive to their contractual terms. Differing views may reflect misunderstandings of the relationship between contingent capital design and performance.

The paper investigates a variety of contingent capital designs, including proposals by Flannery (2005), Flannery (2009b), Sundaresan and Wang (2015), and McDonald (2013). The common feature of these proposals is that conversion of contingent capital into new shareholders' equity is linked, at least partially, to the market value of the issuing bank's original shareholders' equity or capital.[7] Consistent with these proposals, contingent capital takes the form of a bond that pays coupons and has a fixed maturity such that if the market value of capital does not breach a pre-specified threshold, contingent capital would mature and could be rolled over into a new issue of contingent capital.

Contingent capital is analyzed in the context of a structural credit risk model of a individual bank. Importantly, what differentiates the model from many others is that the bank's assets can suffer sudden losses in value as might occur during a financial crisis. Specifically, the returns on the bank's assets are assumed to follow a jump-diffusion process. The bank finances these

[4] At present, the Swiss National Bank has provided the most support for contingent capital, proposing that the two largest Swiss banks (UBS and Credit Suisse) have a 19% capital to risk-weighted assets ratio requirement, of which up to 9% can take the form of contingent capital. The 2010 Dodd-Frank Wall Street Reform and Consumer Protection Act requires that the Financial Stability Oversight Council conduct a study of contingent capital and make recommendations to the Federal Reserve Board, which is given authority to impose a contingent capital requirement on bank holding companies and the non-bank financial institutions that it supervises.

[5] See "Credit Suisse CoCo Investors Uncertain How to Value Notes," *The Financial Times* April 15, 2011. Fitch gave Credit Suisse's contingent capital a BBB rating, but Moody's and Standard & Poor's have yet to rate contingent capital, citing uncertainty regarding potential losses.

[6] Recommendations for Basel III capital requirements applicable to systematically important financial institutions (SIFIs) are due in December 2011.

[7] A proposal by Squam Lake Working Group (2009) is similar but envisions contingent capital conversion based on regulatory discretion.

assets by issuing three types of claims: short-term deposits; common shareholders' equity; and bonds in the form of contingent capital or subordinated debt. The model captures other realistic characteristics of banks, such as their tendency to increase (*decrease*) their deposit borrowing and leverage as their capital rises (*declines*).[8] It also permits the term structure of default-free interest rates to be stochastic and allows coupons paid by contingent capital (prior to possible conversion) to be either fixed rate or floating rate. Different capital thresholds at which contingent capital converts and different amounts of new equity shares received by contingent capital investors are considered.

The model leads to a simple formula for the fair credit spread that the bank pays on its deposits. This is possible because deposits are modeled as having a short (instantaneous) maturity, and therefore depositors can suffer losses only if the bank's assets decline suddenly. The simplifying assumption of short-term deposits is not unrealistic, particularly for large banks that are approaching financial distress. During the recent financial crisis, credit risk fears limited many large banks to wholesale deposit funding having very short (overnight) maturities. Hence, the model's derived deposit credit spread can be realistically interpreted as the bank's spread on overnight LIBOR borrowing. As will be discussed, this modeling of deposits makes it easier to value the bank's other liabilities.

The value of bonds in the form of contingent capital or subordinated debt is calculated using the Monte Carlo simulation approach pioneered by Boyle (1977). Two correlated, risk-neutral stochastic processes are simulated: the jump-diffusion process for the bank's assets and the process for the instantaneous-maturity interest rate that determines the default-free term structure. A bond's value is calculated for a given fixed-coupon rate or floating-coupon spread. By varying this rate or spread, one can determine the fair coupon rate or spread for which the newly-issued bond is valued at par.

The paper's main findings can be summarized as follows. First, permitting the possibility of sudden declines in a bank's asset value (jumps), as might characterize a financial crisis, has a qualitatively distinct impact on contingent capital credit spreads. Indeed, without the possibility of jumps, many of the contingent capital designs that the paper analyzes would be default-free and carry a zero credit spread. When jumps in bank asset values are permitted, credit spreads become positive and differences emerge based on the particular contractual terms of the contingent capital and the issuing bank's risk. Second, contingent capital credit spreads are higher when: the issuing bank's capital is low; conversion is triggered at a low equity capital threshold; conversion is at a fixed, rather than variable, number of shares; and conversion is at a write-down from the bond's par value. Credit spreads on contingent capital whose

[8] The model displays mean-reverting leverage similar to Collin-Dufresne and Goldstein (2001) who argue that it better explains corporate credit spreads. Adrian and Shin (2010) document that large U.S. financial institutions adjust short-term borrowings to target capital, as do Memmel and Raupach (2010) for the case of German banks.

conversion also requires a decline in a financial stock index (the "dual-price trigger" design of McDonald (2013)) are intermediate between those of standard contingent capital and non-convertible subordinated debt.

Third, a bank that issues contingent capital can have a moral hazard incentive to raise the risks of its assets' returns in order to transfer value from contingent capital investors to the original bank shareholders. A bank's risk-shifting incentives increase as its capital declines, but such moral hazard is usually less than if it had issued an equivalent amount of subordinated debt. Fourth, debt overhang, which is the disincentive for a bank to replenish its shareholders' equity following a decline, is often less when a bank issues contingent capital compared to when it issues a comparable amount of subordinated debt. Importantly, both risk-shifting incentives and debt overhang are minimized when a bank issues contingent capital having terms that minimize the bond's default losses. Contingent capital with low credit risk restores incentives for the bank's shareholders similar to those under unlimited liability.

The following is the plan of the paper. Section 2 introduces a structural model of a banking firm that issues short-term deposits, longer-term (possibly convertible) bonds, and shareholders' equity. It discusses how fair credit spreads on deposits can be derived and how fair new-issue coupon rates or spreads (yields-to-maturity) can be computed for contingent capital or subordinated debt. This section also considers how one might specify a contingent capital bond's conversion threshold (trigger) and the conversion sharing rule for allocating total capital between contingent capital investors and the bank's initial shareholders. Section 3 gives the model's results. It presents comparative statics for the fair fixed-coupon yields or floating-coupon credit spreads of contingent capital and subordinated debt under various assumptions regarding a bank's risk and the contractual terms of the bonds. It also examines the risk-taking incentives of a bank's shareholders as well as the debt overhang problem when the bank issues different forms of contingent capital or subordinated debt. Section 4 concludes.

2 A Structural Banking Model

Some recent papers model contingent capital using a structural approach. Raviv (2004) extends Black and Cox (1976) by assuming that contingent capital converts to a fixed proportion of total capital when bank assets hit a lower boundary. Glasserman and Nouri (2012) is similar, but allows conversion to be a gradual, partial process in amounts just sufficient to meet a fixed capital ratio.[9] Albul et al. (2013) and Barucci and Del Viva (2010) extend the model of Leland (1994) to study a financial firm's choice of a senior bond, contingent capital, and shareholders'

[9]Both of these models assume that the bank also issues senior debt having the same finite maturity as the contingent capital bond.

equity in the presence of corporate taxes and direct costs of bankruptcy.[10] They focus on a firm's optimal capital structure decision, and Albul et al. (2013) also investigate incentives for stock price manipulation and risk-shifting.

The model presented in this section differs from these others. Rather than a pure diffusion process, the model assumes that the market value of the bank's assets follows a jump-diffusion process. In addition, the bank's deposits (senior debt) do not have the same maturity as contingent capital, but rather a much shorter (instantaneous) maturity. Moreover, the model permits the bank to gradually adjust the amount of its deposits so as to have a mean-reverting capital (or leverage) ratio. Lastly, the model accounts for the uncertainty in default-free interest rates. The richness of the model can potentially provide a realistic analysis of contingent capital values as well as risk-shifting and debt overhang incentives.

2.1 Assumptions

This section describes the model's basic assumptions, which relate to the bank's assets and the types of securities that are issued to fund them. Let us start by describing the assets' rate of return process and then discuss the bank's various liabilities.

2.1.1 Bank Assets

A bank's assets are invested in a portfolio of loans, securities, and off-balance sheet positions whose rate of return follows a mixed jump-diffusion process. Denote the date t value of this asset portfolio as A_t. The change in the quantity of bank assets equals the assets' return plus changes due to the bank's cash inflows less cash outflows. The sources of inflows and outflows from bank assets will be specified shortly, but for now the superscript $*$ is used to distinguish asset changes solely due to their rate of return, not including net cash flow changes. Under the risk-neutral probability measure, Q, the instantaneous rate of return that the bank earns on its assets is assumed to follow the process:

$$dA_t^*/A_t^* = (r_t - \lambda_t k_t)\, dt + \sigma\, dz + \left(Y_{q_{t^-}} - 1\right)\, dq_t \tag{1}$$

where r_t is the date t default-free, instantaneous-maturity (short-term) interest rate. Note that dz is a standard Brownian motion process under the risk-neutral measure and q_t is a Poisson counting process that increases by 1 whenever a Poisson-distributed jump event occurs. During each time interval, dt, the risk-neutral probability that q_t augments by 1 is $\lambda_t\, dt$, where λ_t is the risk-neutral Poisson intensity. $\{Y_n\}_{n\in\mathbb{N}}$ is a sequence of random variables such when $q_{t^-} = n-1$

[10] Both senior bonds and contingent capital are assumed to be perpetuities. Their model assumptions, which include a pure diffusion process for bank asset returns, imply that contingent capital is default-free.

and $q_t = n$, there is a discontinuous change in the bank's assets at date t equal to

$$A^*_{t+} = Y_{q_{t-}} A^*_{t-} \tag{2}$$

where $Y_{q_{t-}}$ is a random variable realized at date t. Thus, if $Y_{q_{t-}}$ is greater (*less*) than one, there is an upward (*downward*) jump in the value of the bank's assets. $k_t \equiv E^Q_t [Y_{q_{t-}} - 1]$ is the risk-neutral expected proportional jump in the value of the assets given that a Poisson event occurs. It is assumed that the risk-neutral jump probability and jump intensity are independent, so that the risk-neutral expected change in A^* from the jump component $\left(Y_{q_{t-}} - 1\right) dq_t$ over the time interval dt is $\lambda_t k_t \, dt$.

The sample path of A^*_t for a process described by equation (1) will be continuous most of the time, but can have finite jumps of differing signs and amplitudes at discrete points in time, where the timing of the jumps depends on the Poisson random variable q_t and the jump sizes depend on the random variable $Y_{q_{t-}}$. As in Duffie and Lando (2001), these jump events may be interpreted as times when important information affecting the value of the assets is released.

2.1.2 Default-Free Term Structure

The model can accommodate different specifications of the default-free term structure. Allowing stochastic interest rates is important for distinguishing between bonds that pay fixed versus floating coupons. For concreteness, consider the term structure of Cox et al. (1985) where the risk-neutral process followed by r_t is[11]

$$dr_t = \kappa \left(\overline{r} - r_t\right) dt + \sigma_r \sqrt{r_t} d\zeta \tag{3}$$

and where $d\zeta$ is a Brownian motion process such that $d\zeta dz = \rho dt$. This process implies that the date t price of a default-free, zero-coupon bond that pays \$1 in T years is

$$P\left(r_t, T\right) = A\left(T\right) e^{-B(T) r_t} \tag{4}$$

where

$$A\left(T\right) \equiv \left[\frac{2\theta e^{(\theta+\kappa)\frac{T}{2}}}{\left(\theta+\kappa\right)\left(e^{\theta T}-1\right)+2\theta} \right]^{2\kappa\overline{r}/\sigma_r^2}, \tag{5}$$

$$B\left(T\right) \equiv \frac{2\left(e^{\theta T}-1\right)}{\left(\theta+\kappa\right)\left(e^{\theta T}-1\right)+2\theta}, \tag{6}$$

[11] Note that this is not the physical process for the interest rate, $dr_t = \kappa^P \left(\overline{r}^P - r_t\right) dt + \sigma_r \sqrt{r_t} d\zeta^P$ where $\kappa = \kappa^P + \psi$ and $\overline{r} = \overline{r}^P \kappa^P / \kappa$ and ψ is a parameter reflecting the price of interest rate risk. Empirical evidence suggests that ψ is negative, so that $\overline{r} > \overline{r}^P$.

and $\theta \equiv \sqrt{\kappa^2 + 2\sigma_r^2}$. Define c_r as the fixed coupon rate of a default-free bond that pays a continuous coupon of $c_r F dt$, matures in T years, and is issued at a market price equal to its par value, F. Then the fair coupon rate (par yield-to-maturity) for this bond issued at date t equals

$$c_r = \frac{1 - A(T)\, e^{-B(T) r_t}}{\int_0^T A(s)\, e^{-B(s) r_t} ds} \approx \frac{1 - A(T)\, e^{-B(T) r_t}}{\sum_{i=1}^{i=n} A(\Delta t \times i)\, e^{-B(\Delta t \times i) r_t} \Delta t} \tag{7}$$

where $n = T/\Delta t$. This default-free par yield serves as a benchmark for comparing the fixed-coupon par yields of the bank's bonds.

2.1.3 Deposits

In addition to longer-term bonds and shareholders' equity, deposits are one of the bank's three funding sources. The date t quantity of deposits is denoted D_t. Deposits are the most senior claim and have an instantaneous maturity; that is, they are short-term or overnight sources of funding for the bank. Deposits pay a competitive return. Some deposits may be fully insured by a government deposit insurer, such as the FDIC, that assesses an instantaneous insurance premium per dollar of deposit, h_t, that fairly reflects its risk-neutral expected insurance claims. In addition, the bank pays interest to the insured depositors at the competitive, instantaneous-maturity default-free rate, r_t. Other deposits may be uninsured and are paid the competitive, default-free interest rate, r_t, plus the fair credit risk premium, h_t. In either the case of insured or uninsured deposits, the bank is assumed to continuously pay out total interest and deposit premiums of $(r_t + h_t) D_t dt$.

With interest and insurance premiums paid out continuously, the bank's total quantity of deposits changes due to growth in net new deposits (deposit inflows or outflows), which are not directly related to the accrual of interest and premiums. Because much empirical evidence, including Flannery and Rangan (2008), Adrian and Shin (2010), and Memmel and Raupach (2010), finds that banks have target capital ratios and deposit growth expands (*contracts*) when banks have an excess (*a shortage*) of capital, the model assumes that deposit growth is positively related to the bank's current asset-to-deposit ratio, defined as $x_t \equiv A_t/D_t$. Specifically,

$$dD_t/D_t = g(x_t - \widehat{x})\, dt \tag{8}$$

where g is a positive constant and $\widehat{x} > 1$ is a target asset-to-deposit ratio. When the actual asset-to-deposit ratio exceeds its target, $x_t > \widehat{x}$, the bank issues positive amounts of new deposits. When $x_t < \widehat{x}$, the bank gradually shrinks its balance sheet. Thus, the deposit growth rate per unit time, $g(x_t - \widehat{x})$, creates a mean-reverting tendency for the bank's asset-to-deposit ratio, x_t.

A bank failure, which results from bank regulators taking control of the bank, is assumed to occur whenever the value of the bank's assets falls to or below the value of total deposits.[12] That is, failure is the date t_f at which $A_{t_f} \leq D_{t_f}$ for the first time, equivalent to $x_{t_f} \leq 1$. When failure occurs, the deposit insurer and the uninsured depositors are assumed to proportionally share any loss which totals $D_{t_f} - A_{t_f}$.[13]

The assumptions that deposits have an instantaneous maturity and that a bank is closed whenever the value of assets falls below the promised value of deposits imply that only Poisson jumps can cause bank failure losses to depositors. These assumptions simplify the calculation of the fair credit risk spread on deposits, h_t, and they also simplify the valuation of the bank's other liabilities (shareholders' equity and bonds). Because deposits are fairly compensated for possible losses at each point in time, changes in bank capital or the design of other liabilities do not shift value from or to depositors. This allows us to examine how changes in capital, bond contract terms, and asset risk affect the relative values of the bank's other liabilities without having to consider value transfers to or from deposits. Moreover, these assumptions regarding deposits may not be a gross departure from reality. For many large banks, especially large banks nearing financial distress, wholesale deposits are indeed typically of short maturity, often overnight Eurodollar deposits paying a rate close to overnight LIBOR.

2.1.4 Bonds

The bank issues a bond that is subordinated to deposits and may or may not be convertible to shareholders' equity. Different conversion triggers and equity conversion rules for contingent capital will be discussed shortly, but any bond is assumed to be issued at date 0 and to mature at date $T > 0$. It has a par (principal or face) value of B and continuously pays a coupon of $c_t B dt$ as long as the bond is not converted or the bank has not failed. If the bond is specified to pay a fixed-rate coupon, then $c_t = c$, a constant. If, instead, it has a floating-rate coupon, then $c_t = r_t + s$, where s is a fixed spread over the short-term (instantaneous-maturity) interest rate. The value of c or s is set at the time of issue (date 0) such that the bond's equilibrium market value equals par, B. Hence, defining the date t market value of the bond as V_t, the bond's coupon rate at issue is set such that $V_0 = B$.

Subordinated Debt If a bond is not convertible, so that it takes the form of standard subordinated debt, the bank is closed by regulators if the value of bank assets fall to or below the sum of the par values of deposits and subordinated debt; that is, when $A_t \leq D_t + B$.[14] Then if

[12] As discussed below, an exception to this closure policy is considered if the bank issues subordinated debt rather than contingent capital. In this case, the bank is assumed to be closed whenever that value of bank assets first falls below the sum of the par values of both deposits and subordinated debt.

[13] Resolutions of U.S. bank failures require proportional sharing of losses by uninsured depositors and the FDIC.

[14] One could assume that regulators close the bank only after some portion of the subordinated debt is wiped out. For example, the closure rule might be $A_t \leq \delta B + D_t$, where $0 \leq \delta \leq 1$. This alternative assumption would

t_r is a date of regulatory closure, subordinated debt's value satisfies

$$V_{t_r} = \begin{cases} A_{t_r} - D_{t_r} & \text{if } 0 < A_{t_r} - D_{t_r} \leq B \\ 0 & \text{if } A_{t_r} - D_{t_r} \leq 0 \end{cases} \tag{9}$$

If assets remain above the par values of deposits and subordinated debt, the bank continues to make coupon payments until the bond matures at date T.

Contingent Capital Various contingent capital designs can be specified by the mechanism that triggers conversion and by the conversion rule that describes how bank capital is shared between the bank's initial equityholders and the contingent capital investors who become new equityholders. Let us begin by characterizing a general form of the conversion trigger. This will be followed by descriptions of different conversion sharing rules.

Conversion Trigger For a "single-price trigger" contingent capital bond, conversion occurs when the market value of the bank's capital ratio falls to or below a threshold, where the capital ratio is defined as $(A_t - D_t)/D_t = x_t - 1$.[15] At any date t, this ratio can be measured from the date t market value of the bank's contingent capital bond, V_t, and the date t value of its shareholders' equity, which is denoted E_t. Since $A_t = D_t + V_t + E_t$, then $x_t - 1 = (V_t + E_t)/D_t$ is an observable, operational ratio given market prices for the bank's equity and its contingent capital.[16] The contingent capital bond does not convert (and the bank would not fail) as long as the bank's asset to deposit ratio, x_t, stays above a pre-specified threshold conversion level, $\overline{x}_t > 1$, during the period from 0 to T. Alternatively, the first time x_t takes the value $x_t \leq \overline{x}_t$, the bond converts to common shareholders' equity.[17]

A conversion trigger based on this market value capital ratio has potential advantages. First, it is a natural market value counterpart to the book value regulatory capital conversion triggers found in the first issues of contingent capital.[18] Second, relative to proposals for triggers based

increase the default risk of subordinated debt since losses could occur even without a downward jump in asset value.

[15] A later section discusses assumptions and valuation of the "dual-price trigger" contingent capital design of McDonald (2013).

[16] I thank Stewart Myers for pointing this out.

[17] Some contingent capital proposals allow for only part of the contingent capital to convert when a threshold is breached, and Glasserman and Nouri (2012) model partial conversion when bank assets follow a pure diffusion process. For simplicity, the current paper's model assumes that the entire amount of the bank's contingent capital converts to equity. Partial conversion introduces additional complications because the value of shareholders' equity at conversion will depend on the value of unconverted contingent capital, making it more difficult to specify conversion values. However, the model is consistent with the assumption that the bank could be required to issue new fairly priced contingent capital after the old is converted. This requirement would have no effect on the model's valuation of existing contingent capital.

[18] The conversion of Lloyds Bank's November 2009 issue of contingent capital is specified to occur when its Core Tier 1 capital ratio falls below 5%. Rabobank's May 2010 issue of contingent capital converts when its

solely on the market value of equity (or the equity price) such as Flannery (2009a) and McDonald (2013), a market value of total capital trigger avoids the multiple equilibrium problem pointed out by Sundaresan and Wang (2015). While Sundaresan and Wang (2015) propose a contingent capital design for avoiding multiple equilibria when the trigger is based solely on the bank's equity value, their solution holds when a bank's assets follow a pure diffusion but does not hold when assets are subject to possible jumps.[19] Given an arguably more realistic jump-diffusion environment, basing the conversion trigger on the sum of the market values of equity and contingent capital bonds makes conversion independent of how equity and bonds are individually valued. Third, a conversion trigger based on the market value of total capital may discourage speculative manipulation of the bank's equity price.[20]

Conversion Sharing Rule This section considers different contractual terms for allocating the bank's total capital between the original shareholders and the new shareholders represented by the contingent capital investors. Alternative sharing rules can be categorized by whether the contract gives contingent capital investors a fixed number of shares based on the conversion trigger value of capital versus a variable number of shares based on the actual value of capital or equity following conversion. In addition, sharing rules can be categorized by whether the shares received by contingent capital investors are calibrated to return the bonds' par value versus a writedown from the bonds' par value.

Suppose that date t_c is the first date that $x_t \leq \overline{x}_t$; that is, the date of conversion. Then a general form for the value of contingent capital at the conversion date, V_{t_c}, is

$$V_{t_c} = \begin{cases} pB & \text{if } pB < \alpha_{t_c}\left(A_{t_c} - D_{t_c}\right) \\ \alpha_{t_c}\left(A_{t_c} - D_{t_c}\right) & \text{if } 0 < \alpha_{t_c}\left(A_{t_c} - D_{t_c}\right) \leq pB \\ 0 & \text{if } A_{t_c} - D_{t_c} \leq 0 \end{cases} \tag{10}$$

regulatory capital ratio falls below 7%. Typically, a regulatory capital ratio is stated as capital-to-asset ratio, $\left(A_t - D_t\right)/A_t = 1 - 1/x_t$. Basing conversion on a capital-to-deposit ratio, $x_t - 1$, as assumed in the model, can be made equivalent with a translation of the conversion threshold. Because a bank's regulatory capital tends to lag its market value of capital, contingent capital with a regulatory trigger might be analyzed in the context of the paper's model by translating the regulatory capital trigger into a lower market value trigger.

[19] Sundaresan and Wang (2015) consider contingent capital that pays a floating-rate coupon and converts at par. In a pure diffusion environment, this design ensures that contingent capital always trades at its par value and is default-free. However, when bank assets can potentially suffer large, sudden losses (jumps), it may not be possible to have contingent capital convert at par. Consequently, contingent capital is defalt-risky and there is no design that avoids a potential value transfer between equityholders and contingent capital investors at conversion, which is the root of potential multiple equilibria when conversion depends solely on equity value.

[20] As discussed in Flannery (2009b) and McDonald (2013), with an equity value trigger a speculator that owns contingent capital and short-sells the bank's stock might put downward sales pressure on the value of bank equity that could trigger conversion. After ending the short-selling, the speculator may obtain a capital gain on his converted contingent captial shares. However, if other investors recognize this ploy and bid up the value of contingent capital prior to conversion, it could reduce the likelihood of conversion if the trigger is based on the sum of equity and contingent capital values.

where $0 \leq p \leq 1$ and $0 \leq \alpha_{t_c} \leq 1$ dictate the payoffs to contingent capital investors as a function of the bond's par value, B, and the bank's total capital at conversion, $A_{t_c} - D_{t_c}$. As will be discussed, p represents the maximum proportion of the bond's par value that contingent capital investors could receive in the form of new shares while α_{t_c} is the maximum proportion of all shares that contingent capital investors could receive. This paper's analysis considers the following cases:

i. Variable Shares at Par (VSP): $p = 1$, $\alpha_{t_c} = 1$. As proposed in Flannery (2009b), conversion would be at a variable number of shares such that at the contemporaneous (post-conversion) stock price, contingent capital investors would receive a share value equal to the par value of their bonds, B. Of course, if a sudden decline in the bank's asset value leaves total capital less than par, $(A_{t_c} - D_{t_c}) < B$, then the most contingent capital investors can receive is the bank's remaining capital.

ii. Fixed Shares at Par (FSP): $p = 1$, $\alpha_{t_c} = B / \left[\left(\overline{x}_{t_c} - 1\right) D_{t_c}\right]$. Under this sharing rule, contingent capital investors receive a fixed number of shares such that at the trigger level capital ratio, they would receive the par value of their bonds. Note that $\overline{x}_{t_c} - 1$ denotes the total market value of capital at which conversion would be triggered, so that $\left(\overline{x}_{t_c} - 1\right) D_{t_c}$ is the absolute level of total capital at the conversion threshold. Thus, α_{t_c} denotes the share of total capital at the trigger point that would give contingent capital investors exactly their par value. Equivalently, α_{t_c} is the proportion of total post-conversion stock shares owned by contingent capital investors, and if conversion occurs exactly at the threshold such that $\left(\overline{x}_{t_c} - 1\right) D_{t_c} = (A_{t_c} - D_{t_c})$, then investors receive their par value. However, if conversion is triggered due to a sudden decline in the bank's asset value such that $(A_{t_c} - D_{t_c}) < \left(\overline{x}_{t_c} - 1\right) D_{t_c}$, then this fixed share rule gives contingent capital investors a share value below par. Relative to VSP, McDonald (2013) argues that FSP reduces the profitability of attempted stock price manipulation. Flannery (2010) also argues that FSP, relative to VSP, prevents the type of "death spiral" problem documented in Hillion and Vermaelen (2004). However, as mentioned in Flannery (2009b), FSP exposes contingent capital investors to potentially greater losses.

iii. Variable Shares at Par subject to a Maximum (VSPM): $p = 1$, $B / \left[\left(\overline{x}_{t_c} - 1\right) D_{t_c}\right] \leq \alpha_{t_c} \leq 1$. As a result of α_{t_c} taking a value between the FSP and VSP cases, this case is intermediate in the protection afforded contingent capital investors: VSPM is a middle ground between VSP which pays par whenever feasible and FSP which pays par only when capital is exactly equal to the conversion threshold. Indeed, the VSPM payoff is equivalent to the variable share VSP payoff but with a ceiling (maximum) on the number of new shares that contingent capital investors can receive, so that the proportion of new shares to total shares can never exceed α_{t_c}. VSPM provides greater protection to contingent capital investors relative to FSP but avoids potential "death spirals" by limiting the number of new shares that can be issued.

iv. Variable Shares at Writedown (VSW): $0 \leq p < 1$, $\alpha_{t_c} = 1$. This sharing rule issues a variable number of shares to contingent capital investors such that at the contemporaneous stock price, contingent capital investors would receive a share value equal to a pre-specified writedown from the par value of their bonds. For example, if $p = 0.9$, contingent capital investors can at most receive new shares valued at 90% of their bonds' par values. McDonald (2013) discusses how writedowns can make attempted manipulation of the bank's stock price more difficult. Writedowns have also been advocated by Basel Committee on Banking Supervision (2010) as a way to instill market discipline.

v. Fixed Shares at Writedown (FSW): $0 \leq p < 1$, $\alpha_{t_c} = B/\left[\left(\overline{x}_{t_c} - 1\right) D_{t_c}\right]$. Contingent capital investors receive a fixed number of shares such that, at the trigger level capital ratio, they would obtain the proportion, p, of their bonds' par value.

Contingent Capital with a Dual-Price Trigger The bank's long-term bonds can take a third form. As proposed by McDonald (2013), contingent capital with a dual-price trigger modifies the design of Flannery (2009b) to impose an additional condition for conversion. Not only must the bank's market value of capital fall below a threshold, but an index of financial firms' stocks also must breach a pre-specified threshold. The rationale for including this second condition is to permit conversion, so that a bank remains a going concern, only during a general financial crisis. Instead, if the contingent capital-issuing bank is performing badly while other financial institutions are not, conversion would not occur and the bank could fail. Thus, dual-price trigger contingent capital acts like single-price trigger contingent capital in a crisis but acts like standard subordinated debt in a non-crisis.

Let I_t be the date t value of a financial stock index, and let $\overline{I}_t$ be the pre-specified threshold required for conversion. Thus, only if $I_t \leq \overline{I}_t$ and $x_t \leq \overline{x}_t$ would conversion to shareholders equity occur as in equation (10). If $I_t > \overline{I}_t$ even though $1 + pB/D_t < x_t \leq \overline{x}_t$, there is no conversion and the bond continues to pay coupons. If $x_t \leq 1 + pB/D_t$ then regulators are assumed to close the bank and the bond's liquidation value satisfies equation (9).[21]

The risk-neutral process for the financial stock index is assumed to be

$$dI_t/I_t = r_t dt + \sigma_i dz_i \tag{11}$$

[21] Note that for the case of $p < 1$, so that conversion would occur at a writedown from par, it is assumed that regulators would not close the bank until $A_t \leq pB + D_t$, rather than $A_t \leq B + D_t$. The logic is that when $pB + D_t < A_t \leq B + D_t$, there is still the possibility that full conversion at pB may occur in the future if I_t later falls below $\overline{I}_t$. However, the model assumes that at maturity an unconverted contingent capital bond will lead to a failure whenever $A_t \leq B + D_t$ since there is insufficient asset value to pay the bond's par value of B.

where σ_i is a constant and dz_i is a Brownian motion that is correlated with the individual bank's asset return Brownian motion, dz.[22]

2.1.5 Shareholders' Equity

Along with deposits and bonds, the bank receives funding from its initial shareholders' equity, whose date t value is denoted E_t. If the bank's bonds take the form of contingent capital and the bank's asset-to-deposit ratio never falls below $\overline{x}_t$ during the period from 0 to T, then the contingent capital never converts, the bank does not fail, and the value of original shareholders' equity is worth $E_T = A_T - B - D_T$ when the contingent capital matures at date T.[23] Alternatively, the first date that x_t takes the value $x_t \leq \overline{x}_t$, say t_c, then the value of the original shareholders' equity equals

$$E_{t_c} = \begin{cases} A_{t_c} - D_{t_c} - V_{t_c} & \text{if } D_{t_c} + V_{t_c} < A_{t_c} \\ 0 & \text{if } A_{t_c} \leq D_{t_c} + V_{t_c} \end{cases} \tag{12}$$

Note that if contingent capital converts or matures, the total value of shareholders' equity (including possibly converted contingent capital) equals the bank's net worth or capital, $A_t - D_t$. At any time afterwards, new contingent capital can be issued at its fair value, B, without any immediate change in the value of existing shareholders' equity. Therefore, the model's valuation of existing contingent capital and shareholders' equity is consistent with any fairly-priced new issue of contingent capital that occurs after the existing issue converts or matures. Thus, the model's valuation of contingent capital and shareholders' equity is consistent with a regulatory requirement that new contingent capital must be issued following the current issue's conversion or maturity. Any subsequent "resetting" of the bank's capital structure, as long as any new security issues are fairly priced, would not affect model's valuation of the bank's current liabilities.

Conversion Trigger in Terms of Post-Conversion Equity The model can accommodate different specifications of a conversion threshold, $\overline{x}_t$. The threshold can be stated in terms of a total capital to deposit ratio, $\overline{x}_t - 1$, or total capital to asset ratio, $1 - 1/\overline{x}_t$. Another way of stating this threshold can be in terms of the post-conversion ratio of original shareholders equity to deposits. Specifically, suppose that a conversion occurs at date t_h that is exactly at

[22] At the expense of additional parameters, the index return process (11) could be generalized to include a Poisson jump component correlated with the individual bank's Poisson jump process. The quantitative effect may be to make conversion more likely, but qualitatively the results will be similar.

[23] The model assumes that no dividends are paid to shareholders, but it is straightforward to allow payment of a continuous dividend out of the bank's assets, similar to the way coupons on bonds and interest on deposits are paid. For example, dividends might be a function of the bank's asset-to-deposit ratio, x_t. The model's qualitative results regarding the pricing of contingent capital and risk-taking incentives would be little changed. Dividend payments would increase the rate at which the bank's assets (and capital) are depleted, thereby leading to somewhat higher coupon rates (yields) required by bond investors.

the threshold, so that $x_{t_h} = \overline{x}_{t_h}$. Such a conversion would follow a Brownian motion decline in asset value rather than a Poisson jump that takes x_t strictly below $\overline{x}_t$. If the threshold were expressed in terms of a fixed ratio of the post-conversion market value of original shareholders' equity to deposits, say $\overline{e}$, it would be

$$\overline{e} = \frac{E_{t_h}}{D_{t_h}} = \frac{A_{t_h} - D_{t_h} - pB}{D_{t_h}} = \overline{x}_{t_h} - 1 - pb_{t_h} \tag{13}$$

where $b_t \equiv B/D_t$ is defined as the ratio of the contingent capital's par value to the date t value of deposits. This equity threshold (13) is equivalent to the asset-to-deposit threshold of $\overline{x}_{t_h} = 1 + \overline{e} + pb_{t_h}$. For example, if $p = 1$, $b_{t_h} = 4\%$, $\overline{e} = 2\%$, the conversion threshold would be when the original shareholders' equity following conversion equaled 2% of deposits, at which time contingent capital would convert to new equity worth 4% of deposits, so that total capital would be worth 6% of deposits, or assets worth 106% of deposits. If $\overline{e} = 2\%$, $b_{t_h} = 4\%$, but $p = 0.9$, so that contingent capital converts at a writedown from par value, equal to new equity worth 3.6% of deposits, then total capital would be worth 5.6%, or total assets would be worth 105.6% of deposits.

All else equal, if a threshold is stated in terms of the post-conversion value of original shareholders' equity and contingent capital converts at a writedown from par value, the threshold total capital will be less than if conversion was at par value. To adjust for writedowns, it may make sense to raise $\overline{e}$ to be higher compared to a case of par conversion. Hence, in the above example if $\overline{e}_{p=1} = 2\%$, then $\overline{e}_{p=0.9} = 2.4\%$. With this adjustment, the conversion threshold is always at the point where total capital (*total assets*) is 6% (*106%*) of deposits.

The next section's comparative analysis implements this adjustment to keep the total capital to deposit threshold approximately the same for contingent capital with and without a write down. Thus, the chosen post-conversion equity to deposit threshold that is set when the contingent capital is issued equals

$$\overline{e}_p = \overline{e}_{p=1} + (1-p)\,\frac{B}{D_0} = \overline{e}_{p=1} + (1-p)\,b_0 \tag{14}$$

which is equivalent to the asset to deposit threshold of[24]

$$\overline{x}_{t_h} = 1 + \overline{e}_{p=1} + b_0 + p\,(b_{t_h} - b_0) \tag{15}$$

[24] If as in (14) the post conversion original equity-to-deposit threshold, $\overline{e}_p$, is constant, then (15) shows that $\overline{x}_{t_h}$ is time varying. It would be a constant, equal to $1 + \overline{e}_{p=1} + b_0$ if bank deposits did not vary over time; that is $b_{t_h} = B/D_{t_h} = b_0 = B/D_0$. Since it realistic to permit mean-reversion in capital ratios by allowing deposit issuance to vary, allowing for a time-varying asset-to-deposit ratio conversion threshold would appear to be important given that issuance of new contingent capital (which would change B) would not occur as frequently as new issuance of deposits.

Another rationale for this adjustment is that when contingent capital converts at a write-down, conversion should occur at a level of total capital exceeding the full par value of contingent capital: $A_{t_h} - D_{t_h} > B$, or $\overline{x}_{t_h} > 1 + b_{t_h}$. Doing so avoids situations where contingent capital has not converted but there is insufficient total capital to pay its par value of B at maturity.[25]

Suppose that due to a downward diffusion movement in asset value that conversion does occur exactly at the threshold value of original shareholders equity equal to $E_{t_h} = \overline{e}D_{t_h}$. Then given N original shares of stock so that $\overline{e}D_{t_h}/N$ is the post-conversion price per share, contingent capital worth pB would convert to $pB/\left(\overline{e}D_{t_h}/N\right) = pBN/\left(\overline{e}D_{t_h}\right)$ new shares under each of the five conversion sharing rules.

If, instead, there is a downward jump in asset and equity values such that $x_t < \overline{x}_t$ and $E_t < \overline{e}D_t$, then under the fixed share FSP and FSW rules the number of shares issued to contingent capital investors continues to be $pBN/\left(\overline{e}D_{t_h}\right)$ even though they are valued less than pB. Under the variable share VSP, VSPM, or VSW rules it may or may not be possible to issue sufficient new shares to make the market value of contingent capital equal pB. For VSPM, new shares cannot exceed $\alpha_{t_c}N$, so if $B/E_t > \alpha_{t_c}$, contingent capital investors would receive new shares worth less than their bond's par value. For the case of VSP or VSW, if upon issuance of shares equal to pBN/E_t, the value of contingent capital equals its full conversion value of pB, then the original shareholders would retain a positive stake in the bank. However, if upon issuance of pBN/E_t shares, the price per share falls to nearly zero, it might be described as a "death spiral" but the implication is that contingent capital cannot be converted in full and the original shareholders' stake must be wiped out.[26] If, after giving the previous contingent capital holders complete ownership of the bank, the new market value of total equity is very small, this should signal to regulators that there may have been a large enough loss in asset value that capital may even be negative. Such an event should trigger an examination of the bank to determine whether it should be closed.[27]

[25] Based on (15), such situations do not occur if $\overline{e}_{p=1} > (b_t - b_0)(1-p)$. Because b_t is random, these situations cannot be completely ruled out when $p < 1$. The situation arises if deposits decline so drastically that the ratio of equity to deposits remains above the threshold but the bank's total capital shrinks below B. For example, if $\overline{e}_{p=1} = 2\%$, $b_0 = 4\%$, and $p = 0.9$, then the value of b_t for which this inequality fails would be $b_t = 24\%$, representing an 83% decline in deposits, which is probably outside the realm of possibility for a bank that has yet to fail.

[26] Under the variable share VSP or VSW rules, extinguishing the claims of the original shareholders likely requires regulatory intervention since the equilibrium price of original shares would be nearly zero. The VSPM design avoids a "death spiral" and regulatory intervention because it limits the number of shares that can be issued to contingent capital investors, thereby allowing the original shareholders to retain a positive stake in the bank as long as total capital is positive.

[27] Another indication of whether the bank is still viable would be if it can now issue new contingent capital, which is possible only if current equity capital is non-negative. Hence, a regulatory minimum contingent capital requirement may have merit.

2.2 Credit Spreads on Deposits

Given the risk-neutral distribution of asset returns, the fair deposit insurance premium or deposit credit risk premium, h_t, can be solved as a function of the current asset to deposit ratio, x_t. Since the bank is closed by regulators whenever $x_t \leq 1$, if x_t reaches 1 following a continuous movement in the bank assets, the bank is closed with $A_t = D_t$ and depositors suffer no loss. Therefore, depositors experience losses only following a downward jump in asset value that strictly exceeds the bank's total capital, $A_t - D_t$.[28] If such a jump does occur at date $\widehat{t}$, the instantaneous proportional loss to deposits is $\left(D_t - Y_{q_{\widehat{t}-}} A_{\widehat{t}-}\right)/D_t$. At any point in time, the credit risk premium on the instantaneous-maturity deposits, h_t, must reflect the risk-neutral expectation of such a loss. Thus, the risk-neutral rate of return process for deposits equals

$$dD^*/D^* = (r_t + h_t)\,dt - \max\left(\frac{D_t - Y_{q_{t-}} A_{t-}}{D_t}, 0\right) dq_t \tag{16}$$

For the risk-neutral instantaneous expected return on deposits to equal the risk-free rate, it must be that

$$h_t = \lambda_t E_t^Q\left[\max\left(\frac{D_t - Y_{q_{t-}} A_{t-}}{D_t}, 0\right)\right] \tag{17}$$

To calculate h_t, additional assumptions regarding the risk-neutral frequency of jumps and the distribution of jumps sizes are required. Specifically, let us assume that $\lambda_t = \lambda$, a constant, and that risk-neutral jump sizes are independent and identically distributed draws from the lognormal distribution:[29]

$$\ln\left(Y_{q_{t-}}\right) \sim N\left(\mu_y, \sigma_y^2\right) \tag{18}$$

and therefore $k_t \equiv E_t^Q[Y_{q_{t-}} - 1] = e^{\mu_y + \frac{1}{2}\sigma_y^2} - 1$ also is a constant. With these assumptions, the Appendix shows that

$$h_t = \lambda\left[N(-d_1) - x_{t^-}\exp\left(\mu_y + \frac{1}{2}\sigma_y^2\right) N(-d_2)\right] \tag{19}$$

where $d_1 = \left[\ln(x_{t^-}) + \mu_y\right]/\sigma_y$ and $d_2 = d_1 + \sigma_y$. Since h_t changes continuously with the asset-to-deposit ratio, x_t, while the bank is a going concern, depositors always receive fair compensation for their risk of loss and the value of deposits always equals their par value of D_t.

[28] The formula for h_t as a function of x_t is unchanged if, for the case of subordinated debt, the regulatory closure threshold is $A_t \leq D_t + B$, rather than $A_t \leq D_t$. In either case, for any bank currently in operation, a downward jump in asset value is necessary for depositors to suffer a loss.

[29] Modeling time-variation in λ_t could be accomplished by having it satisfy a Hawkes process. Alternatively, it could be made a function of an aggregate uncertainty state variable, such as the S&P 500 volatility index, VIX.

2.3 Valuing Contingent Capital

Consider a bank that issues bonds in the form of contingent capital. Because deposit credit spreads adjust continuously to fairly compensate depositors for potential losses, the date t sum of contingent capital and original shareholders' equity always equals total capital, $A_t - D_t$, as long as capital is non-negative. As a result, once the value of contingent capital is derived, the value of original shareholders' equity equals the residual capital. Moreover, any changes in the model's state variables (x_t and r_t) transfers value only between contingent capital investors and shareholders, not depositors.

Recall that the model assumes that contingent capital is issued at date 0 having a value, V_0, equal to its par value, B. Thus, at the time of issue, the contingent capital's fixed-coupon rate, c, or its floating-coupon spread, s, is set such that $V_0 = B$. The equilibrium coupon rate or spread is found by valuing contingent capital for a given coupon rate or spread and then iterating over c or s until one finds the value c^* or s^* such that $V_0 = B$. c^* or s^* is then be the fair coupon rate or spread at the contingent capital's issue date. Accordingly, the date 0 value of original shareholders' equity is simply $E_0 = A_0 - B - D_0$.

Valuing contingent capital for a given coupon rate or spread is calculated using the risk-neutral valuation (martingale pricing) method:

$$V_0 = E_0^Q \left[\int_0^T e^{-\int_0^t r_s ds} v(t)\, dt \right] \tag{20}$$

where $v(t)$ is the contingent capital bond's cashflow per unit time paid at date t. The cashflow equals $c_t B$ as long as the bond is not converted or the bank does not fail, where $c_t = c$ for a fixed-coupon bond and $c_t = r_t + s$ for a floating coupon bond. If at date T the bond has not been converted and the bank has not failed, there is a final cashflow of B. If the bond is converted, say at date t_c, there is the one-time cashflow given by equation (10). Thereafter, $v(t) = 0$ for all $t > t_c$.

Given the bank's initial asset and deposit values, A_0 and D_0, respectively, as well as the initial default-free interest rate, r_0, equation (20) can be computed using the Monte Carlo simulation technique of Boyle (1977). The Appendix provides details of this simulation which is based on a jump-diffusion discretization method similar to Zhou (2001).

2.4 Valuing Subordinated Debt

If a bank issues subordinated debt rather than contingent capital, the valuation process is similar. Subordinated debt is paid a continuous coupon $c_t B dt$ while the bank is a going concern, with closure occurring whenever $x_t \leq 1 + b_t$, where $b_t = B/D_t$ is now the ratio of the subordinated debt's par value to the par value of deposits. As with contingent capital, by varying the fixed coupon rate, c, or the floating coupon spread, s, the initial value of subordinated debt is changed until one finds the coupon rate or spread such that its initial value equals par, B.

2.5 Valuing Contingent Capital with a Dual Price Trigger

Valuing contingent capital with a dual-price trigger requires the additional state variable, I_t, equal to the index of financial stock prices. Dual-price trigger contingent capital is paid a coupon $c_t B dt$ until either conversion occurs or the bank is closed. Assuming $\overline{I}_t = \delta I_0$, where $\delta < 1$, conversion occurs at the first instance when both $I_t \leq \delta I_0$ and $x_t \leq \overline{x}_t$, and its conversion value equals equation (10). If $I_t > \overline{I}_t$, the bank remains in operation until $x_t \leq 1 + pb_t$, at which time it is closed and the terminal value of contingent capital equals equation (9). If maturity occurs before closure or conversion, the contingent capital bond's terminal value equals $\min [B, A_T - D_T]$. The Appendix provides details of the the Monte Carlo simulation for valuing dual-price trigger contingent capital.

3 Results

To examine how contract terms affect valuation and the bank's risk-taking incentives, this section computes model values for a given set of benchmark parameters. The parameters of the default-free term structure are similar to those estimated by Duan and Simonato (1999) and equal $\kappa = 0.114$, $\sigma_r = 0.07$, and $\overline{r} = 0.069$. The initial (date 0) instantaneous-maturity interest rate is assumed to be $r_0 = 3.5\%$.These assumptions produce an upward sloping term structure such that the fair default-free coupon (par) rate for a five-year maturity coupon bond given by c_r in equation (7) equals 4.23%.

Ideally, parameters of the bank's asset return jump-diffusion process might be estimated from information on a bank's stock returns, debt prices, and/or credit default swap spreads. Unfortunately, there appears to be no prior research carrying out such an estimation, and performing this exercise is left to future research. The current paper simply assumes plausible benchmark parameters: $\sigma = 0.02$, $\rho = -0.2$, $\lambda = 1$, $\mu_y = -0.01$, and $\sigma_y = 0.02$. In words, the bank's asset returns have an annual standard deviation deriving from Brownian motion uncertainty of $\sigma = 2\%$. These Brownian motion returns are negatively correlated changes in short-term interest rates with correlation coefficient $\rho = -0.2$.[30] The risk-neutral frequency of jumps, λ, is once per year and the risk-neutral mean jump size is μ_y = -1% with a standard deviation of $\sigma_y = 2\%$. For a bank with an equity-to-asset ratio of 10%, these jump-diffusion

[30] This is approximately the long-run daily correlation between changes in Treasury bill yields and the return on the S&P 500 stock index.

assumptions produce a standard deviation of bank stock returns of approximately 35%.

3.1 Deposit Credit Spreads

Given the jump process parameters of $\lambda = 1$, $\mu_y = -0.01$, and $\sigma_y = 0.02$ along with a given ratio of assets to deposits, x_t, the fair credit spread h_t can be computed from equation (19). Figure 1 plots the fair credit spread, in basis points, for various capital-to-deposit ratios, $x_t - 1$, ranging from 0.5% to 10%. Schedule A is the credit spread for this benchmark parameter case. As expected, the credit spread is inversely related to the capital-to-deposit ratio because lower capital makes it more likely that a downward jump in asset value will wipe out the remaining capital and cause a loss to depositors. Schedule B is the same as Schedule A except that the volatility of jumps, σ_y, is increased from 2% to 3%. It can be seen that more volatile jumps raise credit spreads at each level of capital. Schedule C deviates from the benchmark case by changing the mean jump size, μ_y, from -1% to -2%, and this also leads to higher credit spreads, particularly for low levels of capital. Finally, Schedule D raises the risk-neutral frequency of jumps, λ, from once per year to twice per year, which from equation (19) simply doubles the benchmark case credit spread for each level of capital.

3.2 Yields on Contingent Capital

This section presents fair, new issue yields for fixed-coupon contingent capital as well as fair new issue spreads for floating-rate contingent capital. In addition to the benchmark parameters described earlier, it is assumed that the bank has a target capital to deposit ratio of 10%; that is, $\widehat{x} = 1.10$. Moreover, the mean-reversion parameter for bank deposit growth is $g = 0.5$, implying that when the bank's capital ratio deviates from target, the expected reduction in the deviation over the next year is approximately one half.

The benchmark contingent capital bond is assumed to have a five-year maturity ($T = 5$) and a new issue amount (par value) equal to 4% of deposits ($b_0 = 0.04$). Thus, if the bank is initially at its 10% target capital ratio, 4% is contingent capital and 6% is original shareholders' equity. The conversion sharing rule for this benchmark bond is assumed to be variable shares at par (VSP); that is, conversion would be at a variable number of shares such that at the contemporaneous stock price, contingent capital investors would receive a share value equal to the par value of their bonds whenever feasible ($p = 1$). The conversion threshold is assumed to be when the post-conversion market value of original shareholders' equity equals 2% of deposits; that is, $\overline{e} = 2\%$. Hence, using the conversion threshold rule discussed earlier of $\overline{x}_{t_h} = 1 + \overline{e} + pb_{t_h}$, conversion of this benchmark bond will tend to occur when total capital is approximately 6% or less of deposits.

3.2.1 Jumps and Mean-Reversion of Capital Ratios

Figure 2 shows the new issue yields for fixed-coupon contingent capital, c, when the bank's initial total capital ranges from 6.5% to 15%. Recall that the default-free term structure is assumed to have an initial instantaneous maturity interest rate of r_0 equal to 3.5% and the par yield on a five-year Treasury coupon bond is 4.23%. This 4.23% default-free, five-year par yield is given by the dashed line denoted Schedule A in the figure. In comparison, Schedule B of Figure 2 shows that the benchmark VSP contingent capital bond's new issue yield is 5.41%, 4.56%, and 4.39% when initial capital is 6.5%, 10%, and 15%, respectively.

This contingent capital bond's yield spread above the five-year Treasury is due to the possibility that it could convert at less than par following a downward jump in the bank's asset (and equity) value. If all of the benchmark parameters are maintained except one assumes there is no possibility of jumps ($\lambda = 0$), then the contingent capital bond's spreads over the five-year Treasury yield would not be positive. Indeed, given the assumption of an upward-sloping term structure, Schedule C of Figure 2 shows that spreads would be slightly negative. Since conversion lowers the effective maturity of contingent capital and, without jumps, it always converts at par, it is effectively a default-free bond with a maturity of less than five years. Hence, its yield is more like a that of a shorter-term default-free bond, which is below the five-year default-free yield. Indeed, when there are no jumps so that conversion always occurs at the threshold, Schedule C would also be the new issue yields for contingent capital under the Fixed Shares at Par (FSP) or Variable Shares at Par subject to a Maximum (VSPM) conversion sharing rules. Thus, one sees that the possibility of jumps in the bank's asset value, as might occur during a financial crisis, has a qualitatively important impact on the pricing of contingent capital.

Schedule D of Figure 2 maintains the benchmark bond's contractual terms except that the mean-reversion parameter for bank deposit growth is lowered from $g = 0.5$ to $g = 0.25$. Such a bank is slower to adjust deposits in order to move toward its target capital to deposit ratio of 10%. The effect is to raise new issue yields when the bank has low capital but lower them when the bank has high capital. The intuition is that if the bank starts out undercapitalized, slower capital ratio reversion tends to keep it undercapitalized for a longer time, thereby increasing opportunities where a downward jump in asset value could require conversion at less than par. In contrast, if the bank starts out overcapitalized, slower capital ratio reversion tends to keep it overcapitalized for a longer time, reducing the likelihood that a downward jump in asset value could require conversion at less than par.

3.2.2 Maturity

Figure 3 examines how new issue yields for fixed-coupon contingent capital vary by maturity. The dashed-line Schedules A, B, and C give the default-free par coupon rates for 3-, 5-, and

10-year Treasury bonds, which are 3.99%, 4.23%, and 4.64%, respectively. Schedules D, E, and F then show the new issue yields for VSP contingent capital having the benchmark parameters except that their times until maturity are 3 years, 5 years, and 10 years, respectively.[31] When the bank has high capital, the yields on contingent capital bonds approach the default-free yields for their respective maturities. However, when capital is 7.5% of deposits or less, their yields converge in the 5% to 5.6% range reflecting similar high probabilities of experiencing a downward jump in asset value that could require conversion at less than par. Note that when capital is low and the likelihood of conversion losses are high, the contingent capital bonds' spreads over their respective default-free Treasury yields are a decreasing function of maturity, a result consistent with other structural models, such as Merton (1974).[32]

3.2.3 Conversion Threshold

Figure 4 considers how the threshold level for conversion, $\bar{e}$, affects new issue yields. Schedules A and B are repeated from Figure 2 and are the five-year default-free par yield and the par yield on the benchmark VSP contingent capital bond with $p = 1$ and $\bar{e} = 2\%$. Figure 4 Schedule C shows new-issue yields for a five-year VSP contingent capital bond that converts at par ($p = 1$) but at a smaller equity threshold of $\bar{e} = 1\%$. In this case, conversion occurs at or below a total capital ratio threshold of 5%, so new issue yields are graphed over the capital to deposit ratios from 5.5% to 15%. Importantly, this contingent capital bond's yields are higher than the benchmark $p = 1$, $\bar{e} = 2\%$ VSP case because the smaller 1% equity cushion makes it more likely that a downward jump in asset value would prevent conversion at par. In other words, at capital ratios just above their thresholds, there needs to be a sudden asset value loss exceeding 2% to prevent conversion at par for the bond with $\bar{e} = 2\%$ while the loss need only be slightly more than 1% for the bond with $\bar{e} = 1\%$ to sustain a conversion loss. This finding has implications for recent Basel III recommendations that would have contingent capital convert when a bank was at the "point of non-viability" and near seizure by regulators.[33] Delaying conversion to a point when the value of original shareholders' equity is low raises contingent capital's likelihood of default losses and the new issue yields required by investors.

The final Schedule D in Figure 4 gives the new issue yields on fixed-coupon, five-year subordinated debt having a par value equal to 4% of deposits. Recall that regulators are assumed to

[31] Schedules B and E for the benchmark five-year maturity are the same as those in Figure 2.

[32] For example, at 6.5% capital, the contingent capital bond spreads over equivalent maturity default-free yields are 162, 117, and 80 basis points for maturities of 3, 5, and 10 years. The inverse spread maturity relationship holds for bonds with relatively high default risk. In contrast, Merton (1974) finds a hump-shaped yield-maturity relationship for bonds with relatively low default risk. This is also true in our model's example, since at 15% capital, the contingent capital bonds' spreads over equivalent maturity default-free yields are 15, 16, and 9 basis points for maturities of 3, 5, and 10 years, respectively.

[33] See Basel Committee on Banking Supervision (2010) where regulatory discretion determines conversion of contingent capital at the point that a public sector bailout of the bank becomes imminent.

close the bank when assets fall to, or below, the sum of the par values of deposits and subordinated debt. Thus, subordinated debt can be viewed as similar to VSP contingent capital with $p = 1$ but $\bar{e} = 0$; that is, it has no equity conversion buffer and failure triggers its conversion (to cash in a liquidation or equity shares in a restructured bank). This makes it more likely that a downward jump in asset value would impose losses and explains why subordinated debt's yields are higher than VSP contingent capital having a positive equity conversion threshold ($\bar{e} > 0$).

3.2.4 Conversion Allocation Rule

Figure 5 compares new issue yields on contingent capital for different conversion sharing rules, namely, variable versus fixed share issuance and conversion at par versus a writedown. Schedules A and B are repeated from previous figures and are the five-year default-free par yield and the par yield on the benchmark VSP contingent capital bond with $p = 1$ and $\bar{e} = 2\%$. Schedule C illustrates new issue yields on FSP contingent capital; that is, where contingent capital investors receive a fixed number of shares such that at the trigger level capital ratio, they would receive the par value of their bonds. Notably, yields are much higher compared to those under the VSP conversion rule. As mentioned earlier, investors in FSP contingent capital are relatively more likely to suffer losses when a sudden decline in bank capital triggers a conversion that leaves original equity (and the stock price) below the trigger level. Given that bank assets are subject to downward jumps in value, investors in FSP contingent capital demand higher new issue yields to compensate for these potential losses.

The new issue yields in Schedule D of Figure 5 maintain the same assumptions as those of Schedules B and C except that the sharing rule is VSPM. VSPM yields are intermediate between those of the VSP and FSP cases, as would be expected from the intermediate protection VSPM provides bond investors: a variable number of shares are issued to VSPM bondholders that will convert at par as long as the proportion of new shares to total shares is below the maximum of α_{t_c}. Thus, investors should receive their par value at conversion except if a substantial loss in capital makes the maximum number of shares worth less than par.

Schedule E gives new issue yields for five-year VSW contingent capital which specifies variable share issuance but at a forced writedown where investors receive 90% of par value; that is $p = 0.9$ and $\bar{e} = 2.4\%$.[34] Notably, yields under a writedown provision are significantly higher than the benchmark VSP case, particularly for bonds issued when bank capital is low. These higher yields due to a writedown are not dependent on asset value jumps, since bondholders experience losses even at conversion that occurs exactly at the threshold level of capital. Finally, Schedule F shows

[34] Recall that if contingent capital converts at a writedown from par value, the resulting total capital is less than if the conversion was at par. To correct for this, equation (14) raises $\bar{e}$ relative to the par conversion case; that is, if $\bar{e}_{p=1} = 2\%$, then $\bar{e}_{p=0.9} = 2.4\%$. Making this adjustment, the conversion threshold stays at the point where the market value of capital is 6% of deposits.

new issue yields for comparable FSW fixed-share at writedown contingent capital ($p = 0.9$ and $\bar{e} = 2.4\%$). Here one sees that specifying a fixed number of shares that at best give contingent capital investors 90% of par only when conversion occurs exactly at the conversion threshold makes new issue yields highest of all. Contingent capital investors are guaranteed a loss of at least 10% at conversion, and any conversion due to a downward jump that leaves total capital below the threshold imposes further losses.

Figure 6 performs a similar analysis to that of Figures 3, 4, and 5 but for floating-coupon contingent capital.[35] It graphs s, the new issue credit spread (over the instantaneous maturity default-free interest rate) for contingent capital bonds with different conversion terms. Note that a zero credit spread represents no default risk, and this is the equilibrium credit spread for all types of contingent capital that convert at par ($p = 1$) if there were no possibility of jumps in asset returns. Hence, as with the case of fixed-coupon contingent capital, positive spreads on floating-rate, par conversion, contingent capital occur due to the possibility of sudden asset value losses that would prevent par conversion . For example, for the benchmark VSP contingent capital bond of $p = 1$ and $\bar{e} = 2\%$ given in Schedule A, the new issue floating rate spreads are 141, 45, and 23 basis points for initial bank capital of 6.5%, 10%, and 15%, respectively.

Figure 6 compares new issue spreads for floating-coupon contingent capital having different conversion features, and its results are nearly identical to those for fixed-coupon yields analyzed in previous figures. One sees that decreasing the size of the equity conversion threshold, $\bar{e}$, from 2% to 1% to 0% of deposits in Schedules A, B, and C (subordinated debt), respectively, raises credit spreads. Fixed-share issuance (FSP in Schedule D) and requiring a writedown (VSW in Schedule F) also are features that lead to a large increase in credit spreads.

3.2.5 After-Issue Values of Contingent Capital and Shareholders' Equity

Thus far, the results have compared how differences in contract terms affect new issue yields and spreads. Let us now consider the valuation of floating-coupon contingent capital and shareholders' equity after the bonds are issued, so that spreads are fixed prior to examining subsequent changes in capital.[36] Figure 7 considers the prices of contingent capital bonds that were issued at fair spreads when the bank's capital to deposit ratio equaled 10%, and then examines how prices change as the capital ratio declines. The different contingent capital bonds are the same ones considered earlier: Bond A has VSP conversion when equity is 2% of deposits ($p = 1$, $\bar{e} = 2\%$); Bond B has VSP conversion when equity is 1% of deposits ($p = 1$, $\bar{e} = 1\%$); Bond

[35] Figure 6 excludes contingent capital specifying a fixed number of shares at a write down (FSW) whose new-issue credit spreads are 162, 327, 543, and 1,208 basis points at initial capital ratios of 15%, 10%, 8%, and 6.5%, respectively. Since high default risk would likely make FSW contingent capital unattractive to investors, our remaining analysis excludes this contract design.

[36] These valuations are done for floating-coupon contingent capital, but the results for fixed-coupon contingent capital are nearly identical.

C has FSP conversion when equity is 2% of deposits ($p = 1$, $\overline{e} = 2\%$); Bond D has VSPM conversion triggered when equity is 2% of deposits ($p = 1$, $\overline{e} = 2\%$); and Bond E has VSW conversion at a 10% writedown from par when equity is 2.4% of deposits ($p = 0.9$ and $\overline{e} = 2.4\%$). As can be seen from the figure, all five of the bonds equal their par value of 4% of deposits when total capital equals 10% of deposits. As the capital ratio declines, the values of the five bonds tend to fall. However, at a capital ratio of 6.75%, Bonds A, C, and D (VSP, FSP, and VSPM) reach their minimum values of 3.94%, 3.81%, and 3.90%, respectively. At a capital ratio of 5.75%, VSP Bond B ($\overline{e} = 1\%$) researches its minimum value of 3.85%. The values of these bonds then turn upward as each comes close to its conversion threshold, which is 6.00% capital for Bonds A, C, and D and 5.00% capital for Bond B. The intuition for this upturn in price is that it becomes relatively more likely that the bonds will convert at par compared to below par. While the risk of a downward jump in asset value that would prevent par conversion increases as capital declines, as capital approaches the threshold, the likelihood of hitting the threshold via a continuous Brownian motion movement increases even more quickly. If the threshold is hit in such a continuous manner, then these bonds all convert at their par value of 4%, so that their prices rises toward that level. Bond B, which converts when equity is only 1% at the threshold, never rises as high as its VSP equivalent Bond A which converts when equity equals 2% at the threshold. This is because Bond B is exposed to a greater likelihood that a sudden decline in asset value would prevent conversion at par.

Price dynamics are qualitatively different for Figure 7's VSW Bond E which converts at a 10% writedown from par value. This bond's value declines at an increasing rate as the 6.00% capital ratio threshold is approached. Conversion at the threshold for this bond would be at $0.90 \times 0.04\% = 3.6\%$ of deposits, so that even a continuous decline in asset value would impose losses on the bondholders.

Recall that since credit spreads on deposits adjust instantaneously to the current level of capital, deposits are always priced at par as long as capital is non-negative. Consequently, the sum of the values of contingent capital and original shareholders' equity must equal total capital, $A_t - D_t$. Therefore, subtracting the values of contingent capital bonds in Figure 6 from total capital gives the corresponding equilibrium values of shareholders' equity. These shareholders' equity values are graphed in Figure 8. Consistent with par conversion Bonds A, B, C, and D having slight upward rises in value as total capital declines to their respective 6% and 5% capital ratio thresholds, the corresponding market values of equity in Schedules A, B, C, and D decline at slightly greater than one-for-one as capital approaches these thresholds. In contrast, because contingent capital Bond E converts at a writedown from par, making its value decline as capital approaches its 6.00% conversion threshold, the corresponding value of shareholders' equity declines at a somewhat less than one-for-one rate as the conversion threshold is met. However, for all bonds the equilibrium value of shareholders' equity declines monotonically with a fall in total capital and, from equation (12), equity's value approaches its full conversion value of $E_{t_c} = A_{t_c} - D_{t_c} - pB$, equal to 2% of deposits for Bonds A, C, and D, 1% of deposits for Bond B, and 2.4% of deposits for Bond E.

3.2.6 Dual-Price Conversion Trigger

This section considers the effects of an additional conversion feature, namely, the dual-price conversion trigger proposed by McDonald (2013). It is assumed that the financial stock index, I_t, must fall at least 10% from its level at the time that contingent capital is issued; that is, $\overline{I}_t = \delta I_0 = 0.9 I_0$. Similar to McDonald (2013), the volatility of the index's return is assumed to be $\sigma_i = 20\%$, and the index return's correlations with interest rate changes and the bank's asset return are $dz_i d\zeta = -0.2dt$ and $dz_i dz = 0.85dt$. Figure 9 compares new issue yields on fixed-coupon VSP and VSW contingent capital with, and without, the financial index trigger. As before, Schedule A's dashed line gives the par yield on a five-year Treasury bond while Schedule B repeats the fixed-coupon yields for the benchmark five-year, single-price trigger contingent capital bond with VSP conversion ($p = 1$, $\overline{e} = 2\%$). Schedule C is then the equivalent par-conversion VSP contingent capital bond ($p = 1$, $\overline{e} = 2\%$) except that it has the dual-price trigger. As can be seen, its new issue yields are above those of the standard single-price trigger contingent capital. However, they are below the new issue yields of subordinated debt graphed in Schedule D.

The logic behind this ordering of yields relates to the previously discussed benefit of an equity cushion. Yields on standard single-price trigger contingent capital (Schedule B) are lowest because it is converted at par without loss to its holders when equity hits the 2% threshold. The yields on subordinated debt (Schedule D) are higher because it completely lacks this equity conversion cushion. Dual-price trigger, par-conversion, contingent capital (Schedule C) is an intermediate case because sometimes the equity cushion is effective in providing the protection resulting from par conversion (when $I_t \leq \overline{I}_t$), but other times it is not (when $I_t > \overline{I}_t$). Thus, in some states of the world, dual-price trigger contingent capital acts like its single-price trigger counterpart, but in other states it acts like non-convertible subordinated debt. Hence, its initial pricing reflects a mix of both convertible and non-convertible debt.

Schedule E of Figure 9 repeats Figure 5's new issue yields of single-price trigger, fixed-coupon VSW contingent capital that converts at a 10% writedown ($p = 0.9$, $\overline{e} = 2.4\%$). Schedule F of Figure 9 then gives the equivalent VSW contingent capital but with a dual-price trigger. Interestingly, for contingent capital that converts at a writedown, the impact of the dual-price trigger is to lower, rather than raise, yields. However, this should be expected since a writedown from par now makes conversion a costly feature for contingent capital investors. As in the par conversion case, when conversion is at a writedown the yields on contingent capital with a dual-price trigger fall between those of single-price trigger contingent capital (Schedule E) and non-convertible subordinated debt (Schedule D). In summary, one can understand the characteristics of dual-price trigger contingent capital by viewing it as a blend of standard, single-price trigger contingent capital and non-convertible subordinated debt.

3.3 Incentives for Risk-Taking

This section considers the risk-taking incentives of a bank that issues contingent capital by investigating how changes in asset risk and capital ratios affect the relative values of contingent capital and shareholders' equity. Since credit spreads on short-maturity deposits adjust instantly, changes in the bank's risk do not affect deposits' value. Hence, in the model if a bank issues only deposits and shareholders' equity, it would have no incentive or ability to transfer value from depositors to shareholders by increasing risk. Shareholders' equity would always equal the bank's total capital as long as capital is non-negative. While this model implication is stark, it helps to isolate the incentives of bank shareholders to increase risk for the purpose of exploiting the bank's longer-term bond investors.

Unlike structural credit risk models such as Merton (1974), Black and Cox (1976), or Leland (1994) where assets follow a pure diffusion process and asset risk can be summarized by a single parameter, σ, the current paper's model has several additional risk parameters that need to be considered: the risk-neutral probability of jumps (λ); the jump size volatility (σ_y); and the mean jump size (μ_y). As will be seen, these parameters of the risk-neutral distribution of asset returns can have disparate effects on risk-taking incentives.

The analysis of risk-taking incentives considers different forms of contingent capital and subordinated bonds, but where each five-year maturity bond was issued at its fair credit spread when the bond had a par value of 4% of deposits and total bank capital was 10% of deposits.[37] It is assumed that the newly-issued bonds' credit spreads reflect the benchmark asset risk parameter values ($\lambda = 1$, $\sigma_y = 0.02$, $\mu_y = -0.01$, and $\sigma = 0.02$). Then, for a given capital ratio, the market value of original shareholders' equity is computed for a 25% change in the value of one of the asset risk parameters ($\lambda = 1.25$ or $\sigma_y = 0.025$ or $\mu_y = -0.0125$ or $\sigma = 0.025$).[38][39] The changes in the market value of shareholders' equity due to these 25% parameter changes are graphed

[37] Contingent capital and subordinated debt are assumed to pay floating coupons. The results for fixed-coupon bonds are extremely similar.

[38] Admittedly, this parameter change is an out-of-equilibrium event in that it was not foreseen by bondholders when initial credit spreads were set. However, it would be straightforward to model parameter change dynamics in a rational framework. For example, risk parameters might be specified as a function of the bank's asset-to-deposit ratio, x_t, and initial fair credit spreads could be computed via a similar Monte Carlo valuation but where risk parameters vary with the state variable, x_t. Most likely initial credit spreads would rise to reflect this moral hazard but the qualitative results regarding banks' incentives to shift risk would be similar to the current analysis.

[39] A change in the asset risk parameters does not affect the risk-neutral expected rate of return on the bank's assets, which continues to equal the instantaneous-maturity interest rate, r_t.

in Figures 10 to 13. Note that since the values of original shareholders' equity plus contingent capital or subordinated bonds always sum to total capital, the change in the value of the bond exactly equals minus the change in shareholders' equity value.

3.3.1 Jump Risk

Figure 10 graphs the increase in shareholders' equity when there is a 25% increase in the probability of jumps, λ. While in all cases the increase in equity (*bond value*) is positive (*negative*), the increase is smallest for the benchmark VSP Bond A which converts at par with a 2% equity threshold ($p = 1$, $\bar{e} = 2\%$) and that was shown to have the lowest default risk. As the equity conversion threshold declines to $\bar{e} = 1\%$ for VSP Bond B and to $\bar{e} = 0\%$ for subordinated Bond C, higher jump risk raises equity value more, indicating greater moral hazard incentives. Intuitively, a rise in the probability of a jump has a greater likelihood of imposing losses on bondholders as the equity conversion cushion declines. Therefore, shareholders have more to gain by raising jump frequencies when bondholders are less protected. Similarly, risk-shifting incentives rise when contingent capital investors receive a fixed number of shares at conversion (FSP Bond D), since higher jump frequency increases the likelihood of conversion strictly below where these investors always bear losses. As expected, risk-shifting incentives under the VSPM Bond E is lower than FSP but higher than VSP. For moderate and high levels of capital, a rise in the frequency of jumps has a significantly adverse effect on FSW Bond F that converts at a writedown ($p = 0.9$, $\bar{e} = 2.4\%$). Intuitively, when capital is high, a greater probability of jumps has a larger marginal effect on reducing the value of contingent capital that would always suffer a loss at conversion.

Figure 11 presents analysis of a 25% increase in the volatility of jumps, σ_y. It is similar to the results in Figure 10 in that risk shifting incentives tend to be greatest when the bank issues subordinated Bond C and FSP Bond D. The next highest risk shifting incentives come with VSP Bond B which converts at a 5% capital threshold ($p = 1$, $\bar{e} = 1\%$), followed by VSPM Bond E, VSW Bond F ($p = 0.9$, $\bar{e} = 2.4\%$), and VSP Bond A ($p = 1$, $\bar{e} = 2\%$) which all convert at a 6% capital ratio. This ordering confirms the importance of the conversion threshold in protecting bondholders. A larger capital buffer between the conversion threshold and the bond's par value (0% for subordinated Bond C, 1% for Bond B, and 2% for Bonds A, E, and F) protects bondholders because a sudden loss in asset value that moves capital into this buffer would not harm bondholders. The exception is FSP Bond C since any jump in equity (capital) value through the conversion threshold imposes losses on bondholders. One interesting aspect of the results is that for all six bonds, the incentive for risk taking peaks at capital levels from around 1.5% to 2% above the bond's respective conversion thresholds. A likely explanation is that the calculations measure the marginal effect of an increase in jump volatility on the values of shareholders' equity and bonds. Since an increase in σ_y fattens the tails of the asset return distribution, the marginal effect of a greater tail probability in exposing bondholders to partial conversion losses may be greatest at a point significantly above the capital conversion threshold.

The results in Figure 12 for a 25% change in the mean jump size, μ_y, from -1% to -1.25% are qualitatively similar to those in Figures 10 and 11. As with the other jump risk parameters, a bank's incentive to risk-shift is greatest with subordinated Bond C and FSP Bond D, followed by the VSP Bond B that converts at the 5% capital threshold and the VSPM Bond E. Risk-shifting incentives are lowest for VSP Bond A ($p = 1$, $\bar{e} = 2\%$), except very near the capital conversion threshold where the marginal effect for VSW Bond F ($p = 0.9$, $\bar{e} = 2.4\%$) becomes least. Again, these results highlight how a capital conversion buffer protects bondholders from jump risk, except when the conversion sharing rule is based on a fixed number of shares.

3.3.2 Diffusion Risk

Figure 13 calculates the change in the value of shareholders' equity from a 25% increase in the bank asset diffusion volatility, σ. In some ways, the results are qualitatively different from those relating to the jump risk parameters. Except for a bank that issues VSW Bond F which converts at a writedown ($p = 0.9$, $\bar{e} = 2.4\%$), shareholders have a disincentive to increase diffusion volatility when capital falls near a bond's conversion threshold. The explanation is that a larger impact of Brownian motion uncertainty makes it more likely that a bond's capital conversion threshold will be reached via a continuous decline in the bank's asset value, rather than a downward jump that could breach the threshold. With a greater likelihood of par conversion occurring at the threshold, there is a smaller possibility of bondholders suffering a loss.[40] Hence, shareholders cannot gain when the bank increases such "small scale" diffusion risk. Contingent capital Bond F is a notable exception because its conversion writedown implies that bondholders suffer a loss even when conversion occurs exactly at the threshold.

3.4 Debt Overhang

A final analysis of the incentive effects of contingent capital examines the debt overhang problem discussed in Myers (1977). Following a sudden large loss in asset value, as might occur during a financial crisis, a bank's original shareholders may be reluctant to raise new equity because doing so transfers value from themselves to the bank's bondholders. An increase in new equity that reduces the bonds' default risk and raises their value must come at the expense of a decline in the value of the bank's original equity.

The magnitude of this debt overhang problem is investigated when a bank issues different

[40] This reasoning holds even for subordinated debt investors due to the assumption that the bank is closed when total capital falls to equal the par value of subordinated debt.

types of contingent capital or subordinated bonds. Similar to the previous section, it assumes that the bank issued a floating-coupon, five-year maturity bond at its fair credit spread when the bond had a par value of 4% of deposits and total bank capital was 10% of deposits. Then, for a new current capital ratio, the change in the value of original shareholders' equity is computed for an increase in new shareholders' equity equal to 0.25% of deposits. In other words, the calculation analyzes the incentive (in terms of a change in the value of original shareholders' equity) to undertake a new issue of stock (equity capital) that would raise the existing capital-to-deposit ratio by $\frac{1}{4}$%.

Figure 14 reports these calculations when a bank issues different types of bonds. The debt overhang problem shows up as a loss (negative change) in the value of existing shareholders' equity when new equity is issued. In general, Figure 14 indicates that this loss in equity value occurs at most capital levels except for the lowest ones near a bond's conversion threshold. The magnitude of the debt overhang problem is clearly linked to the bonds' default risks. Debt overhang tends to be least for VSP Bond A and VSPM Bond E. It becomes greater for VSP Bond B having a delayed conversion ($\overline{e} = 1\%$), for FSP fixed-share Bond D, and for subordinated Bond C. However, for all of these aforementioned bonds, debt overhang is reduced at capital ratios close to the bond's conversion thresholds (or in the case of subordinated debt, the bank closure threshold). The intuition is similar to the discussion of Figures 7, 11, and 13. Conversion due to Brownian motion asset value declines, that would impose no loss on bondholders, become relatively more likely. However, VSW Bond F is, again, the exception since its writedown feature imposes losses even when conversion is exactly at the threshold capital ratio.

In summary, the problem of debt overhang tends to be inversely related to how well a contingent capital bond's contractual terms protect its owners. By reducing contingent capital investors' exposure to default risk, the risk of the original shareholders' equity becomes similar to that when equity has unlimited liability (which would make bonds default-free). It is well known that when shareholders have unlimited liability, problems of moral hazard and debt overhang are mitigated.

4 Conclusion

This paper's structural credit risk model provides a framework for valuing contingent bank capital and bank shareholders' equity. The model incorporates a realistic feature of bank asset returns, namely, that they sometimes experience sudden, discrete declines, often during a financial crisis. Since a primary motivation for contingent capital is to alleviate financial distress and avoid taxpayer bailouts during a crisis, understanding the role of jump risk is critical. Indeed, the possibility of sudden large losses in a bank's asset value has a qualitatively distinct impact on contingent capital credit spreads. Without asset jump risk, standard contingent capital that converts at par would be default-free and require a zero credit spread. With asset jump risk, conversion at below par value becomes possible, thereby requiring strictly positive credit spreads.

Credit spreads for both fixed- and floating-coupon contingent capital will be higher when they are issued at low levels of bank capital and when conversion is triggered at a low level of original shareholders' equity. New issue spreads also depend on the conversion sharing rule, with spreads being the least when a variable number of shares are permitted to ensure that bondholders receive their par values. Contingent capital investors will require higher new-issue credit spreads, even in the absence of jump risk, if the conversion terms mandate a writedown from par value. The effect of a dual-price trigger for conversion is to make contingent capital a blend of non-convertible subordinated debt and single-price trigger contingent capital. Therefore, yields on dual-price trigger contingent capital fall between those of comparable single-price trigger contingent capital and subordinated debt.

A bank that issues contingent capital faces a moral hazard incentive to increase its assets' jump risks. However, this incentive to transfer value from contingent capital investors to the bank's shareholders is often smaller than that if the bank had, instead, issued comparable subordinated debt. Thus, relative to the status quo, there can be a decline in moral hazard if appropriately designed contingent capital replaces subordinated debt. The results show that excessive risk-taking incentives also decline as contingent capital's equity conversion threshold rises. With a bigger "equity cushion" at the conversion threshold, there is a smaller likelihood that a sudden loss in bank asset value would prevent full conversion, thereby better protecting contingent capital investors from losses.

Contingent capital is also a promising way to reduce debt overhang, which creates a disincentive for banks to raise new equity capital during a crisis. Debt overhang is minimized when contingent capital's contractual terms best protect their investors from default losses. Making contingent capital as close to default-free as possible instills incentives in bank equityholders similar to those which would occur under unlimited liability, thereby reducing moral hazard and debt overhang.

In conclusion, this paper's structural analysis suggests that contingent capital can be a feasible, low-cost method of mitigating financial distress when it is designed to convert at early stages of distress and when it contains provisions that minimize its default risk. Because it reduces effective leverage and the pressure for government bailouts, contingent capital deserves serious consideration as part of a package of reforms that stabilize the financial system and eliminate "too big to fail."

Appendix

Derivation of the Deposit Credit Spread

The following derives the formula for h_t in equation (19).

Define

$$
\begin{aligned}
H &\equiv E_t^Q\left[\max\left(\frac{D_t - Y_{q_{t-}}A_{t-}}{D_t}, 0\right)\right] \\
&= E_t^Q\left[\max\left(1 - Y_{t-}x_{t-}, 0\right)\right] \\
&= \int_0^{1/x} (1 - Yx)\exp\left[-\frac{\left(\ln Y - \mu_y\right)^2}{2\sigma_y^2}\right]\frac{1}{Y\sigma_y\sqrt{2\pi}}dY. \qquad \text{(A.1)}
\end{aligned}
$$

Make the change of variable $y = \left(\ln Y - \mu_y\right)/\sigma_y$, then $y|_{Y=0} = -\infty$, $y|_{Y=1/x} = \left[\ln(1/x) - \mu_y\right]/\sigma_y = -\left[\ln x + \mu_y\right]/\sigma_y$, $Y = \exp\left[\mu_y + y\sigma_y\right]$, and $dy = dY/\left(Y\sigma_y\right)$.

Defining $d_1 \equiv \left[\ln x + \mu_y\right]/\sigma_y$, then

$$
H = \int_{-\infty}^{-d_1}\left(1 - \exp\left[\mu_y + y\sigma_y\right]x\right)\frac{e^{-y^2/2}}{\sqrt{2\pi}}dy = N(-d_1) - xe^{\mu_y}\int_{-\infty}^{-d_1}\exp\left[y\sigma_y - \frac{y^2}{2}\right]\frac{1}{\sqrt{2\pi}}dy. \qquad \text{(A.2)}
$$

Completing the square in the exponent, one obtains

$$
\int_{-\infty}^{-d_1}\exp\left[y\sigma_y - \frac{y^2}{2}\right]\frac{1}{\sqrt{2\pi}}dy = e^{\sigma_y^2/2}\int_{-\infty}^{-d_1}\frac{\exp\left[-\frac{1}{2}(y-\sigma_y)^2\right]}{\sqrt{2\pi}}dy = e^{\sigma_y^2/2}\int_{-\infty}^{-d_2}\frac{\exp\left[-\frac{y^2}{2}\right]}{\sqrt{2\pi}}dy. \qquad \text{(A.3)}
$$

where $d_2 = d_1 + \sigma_y = \left[\ln x + \mu_y\right]/\sigma_y + \sigma_y$. Collecting things together, one finds

$$
H = N(-d_1) - x\exp\left[\mu_y + \frac{\sigma_y^2}{2}\right]N(-d_2) = N(-d_1) - \exp\left[\ln x + \mu_y + \frac{\sigma_y^2}{2}\right]N(-d_2). \qquad \text{(A.4)}
$$

Monte Carlo Simulation Method

The following describes how the risk-neutral valuation formula for contingent capital in (20) is computed. The risk-neutral process followed by the bank's assets equals the assets' risk-neutral rate of return plus deposit growth less the payout of interest and premiums to depositors and, as long as contingent capital is unconverted, coupons to contingent capital investors:

$$
\begin{aligned}
dA_t &= \left(dA_t^*/A_t^*\right)A_t + dD_t - (r_t + h_t)D_t dt - c_t B dt \qquad \text{(A.5)} \\
&= \left[(r_t - \lambda k)A_t + \left(g\left(x_t - \widehat{x}\right) - r_t - h_t\right)D_t - c_t B\right]dt + \sigma A_t\,dz + \left(Y_{q_{t-}} - 1\right)A_t\,dq
\end{aligned}
$$

where we have substituted in equations (1) and (8). Equation (A.5) can be rewritten as

$$
\begin{aligned}
dA_t/A_t &= \left[r_t - \lambda k + \left(g\left(x_t - \widehat{x}\right) - r_t - h_t \right) \frac{D_t}{A_t} - c_t b_t \frac{D_t}{A_t} \right] dt + \sigma\, dz + \left(Y_{q_{t-}} - 1 \right) dq_t \\
&= \left[r_t - \lambda k + \frac{g\left(x_t - \widehat{x}\right) - r_t - h_t - c_t b_t}{x_t} \right] dt + \sigma\, dz + \left(Y_{q_{t-}} - 1 \right) dq_t \qquad \text{(A.6)}
\end{aligned}
$$

where recall that $b_t \equiv B/D_t$. Thus, the risk-neutral process for the asset-to-deposit ratio is

$$
\begin{aligned}
dx_t/x_t &= dA_t/A_t - dD_t/D_t \qquad \text{(A.7)} \\
&= \left[r_t - \lambda k + \frac{g\left(x_t - \widehat{x}\right) - r_t - h_t - c_t b_t}{x_t} - g\left(x_t - \widehat{x}\right) \right] dt + \sigma\, dz + \left(Y_{q_{t-}} - 1 \right) dq_t
\end{aligned}
$$

A simple application of Itô's lemma for jump-diffusion processes implies

$$
d \ln\left(x_t\right) = \left[r_t - \lambda k + \frac{g\left(x_t - \widehat{x}\right) - r_t - h_t - c_t b_t}{x_t} - g\left(x_t - \widehat{x}\right) - \frac{1}{2}\sigma^2 \right] dt + \sigma\, dz + \ln Y_{q_{t-}}\, dq_t \qquad \text{(A.8)}
$$

For a given coupon structure, c_t, the risk-neutral processes for the default-free interest rate r_t in equation (3) and the log asset to deposit ratio in equation (A.8) are simulated where h_t at each point in time satisfies (19) and b_t evolves as

$$
db_t/b_t = g\left(\widehat{x} - x_t\right) dt. \qquad \text{(A.9)}
$$

By computing the term in brackets in (20) for each simulation and then averaging over a large number of simulations, the contingent capital's initial value, V_0, is determined. The equilibrium coupon rate, c, or coupon spread, s, is found by iterating until $V_0 = B$.

Solutions for the valuation equation (20) are calculated using a technique similar to Zhou (2001) who provides a discretization method for carrying out a Monte Carlo simulation of a mixed jump-diffusion process. His method is generalized to also consider the stochastic term structure of default-free yields. The time interval $[0, T]$ is divided into n equal sub-periods where $\Delta t \equiv T/n$ is the length of each subperiod. n is chosen to be relatively large, making the length of each subperiod, Δt, sufficiently small so that it is a good approximation to assume there can be at most one jump during each subperiod. With time measured in years, $\Delta t = \frac{1}{250}$ = one trading day is the time interval used in the paper's analysis.

Let t denote the end of trading day $t - \Delta t$ and the beginning of trading day t. Then based on equation (3), the change in the default-free interest rate from day t to day $t + \Delta t$ is approximated as

$$
\begin{aligned}
r_{t+\Delta t} &= r_t + \kappa\left(\overline{r} - r_t\right)\Delta t + \sigma_r \sqrt{r_t}\sqrt{\Delta t}\eta_{t+\Delta t} \\
&= \Delta t \kappa \overline{r} + \left(1 - \Delta t \kappa\right) r_t + \sigma_r \sqrt{r_t \Delta t}\eta_{t+\Delta t}
\end{aligned}
\tag{A.10}
$$

where $\eta_{t+\Delta t} \sim N(0,1)$ are serially independent shocks representing Brownian motion uncertainty. Similarly, the daily risk-neutral process for the log of the bank's asset to deposit ratio, equation (A.8) is approximated as

$$
\begin{aligned}
\ln x_{t+\Delta t} &= \ln x_t + \left[r_t - \lambda_t k_t + \frac{g\left(x_t - \widehat{x}\right) - r_t - h_t - c b_t}{x_t} - g\left(x_t - \widehat{x}\right) - \frac{1}{2}\sigma^2\right]\Delta t \\
&\quad + \sigma\sqrt{\Delta t}\varepsilon_{t+\Delta t} + \ln Y_{t+\Delta t}\varphi_{t+\Delta t}
\end{aligned}
\tag{A.11}
$$

where $\varepsilon_{t+\Delta t} \sim N(0,1)$ are serially independent shocks, $E_t^Q\left[\varepsilon_{t+\Delta t}\eta_{t+\Delta t}\right] = \rho$, $\ln\left(Y_{t+\Delta t}\right) \sim N\left(\mu_y, \sigma_y^2\right)$,

$$
\varphi_{t+\Delta t} = \begin{cases} 1 & \text{with probability } \Delta t \lambda_t \\ 0 & \text{with probability } 1 - \Delta t \lambda_t \end{cases}, \tag{A.12}
$$

h_t is given by (19), and

$$
b_{t+\Delta t} = b_t \exp\left[-g\left(x_t - \widehat{x}\right)\Delta t\right]. \tag{A.13}
$$

For the case of dual price trigger contingent capital, a third state variable is used in the Monte Carlo simulation, $\ln I_t$. Its discretized process is

$$
\ln I_{t+\Delta t} = \ln I_t + \left(r_t - \frac{1}{2}\sigma_i^2\right)\Delta t + \sigma_i\sqrt{\Delta t}\nu_{t+\Delta t} \tag{A.14}
$$

where $\nu_{t+\Delta t} \sim N(0,1)$ are serially independent shocks that are cross-sectionally correlated with the $\varepsilon_{t+\Delta t}$ and $\eta_{t+\Delta t}$ shocks driving the individual bank's asset returns and the default-free term structure.

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Figure 1

Deposit Credit Spreads (h_t)
(in Basis Points)

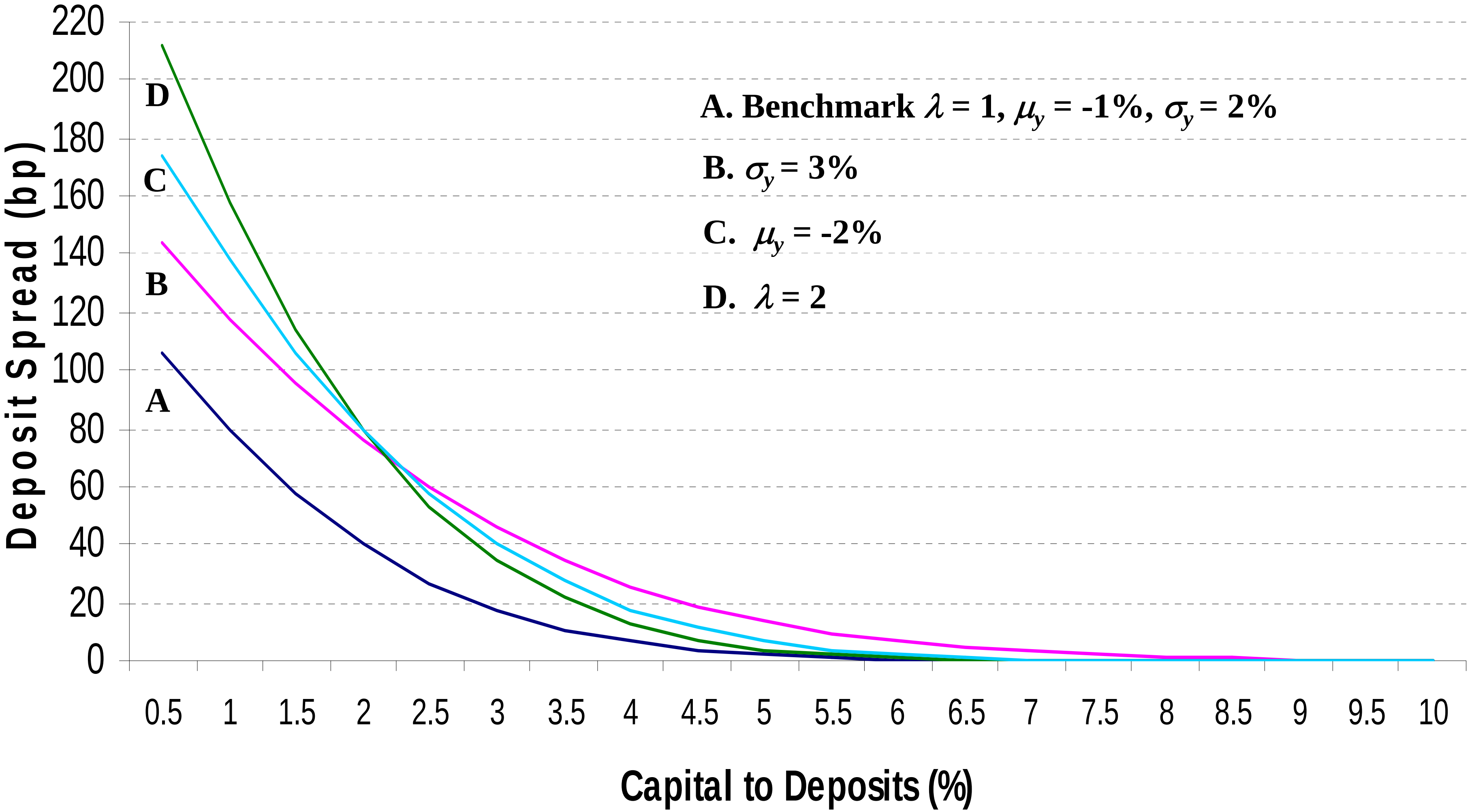

Figure 2

New Issue Par Yields (c) on Fixed-Coupon Contingent Capital Effects of Jumps in Asset Values and Mean-Reverting Capital

(Five-Year Maturity, Initial Value = 4% of Deposits)

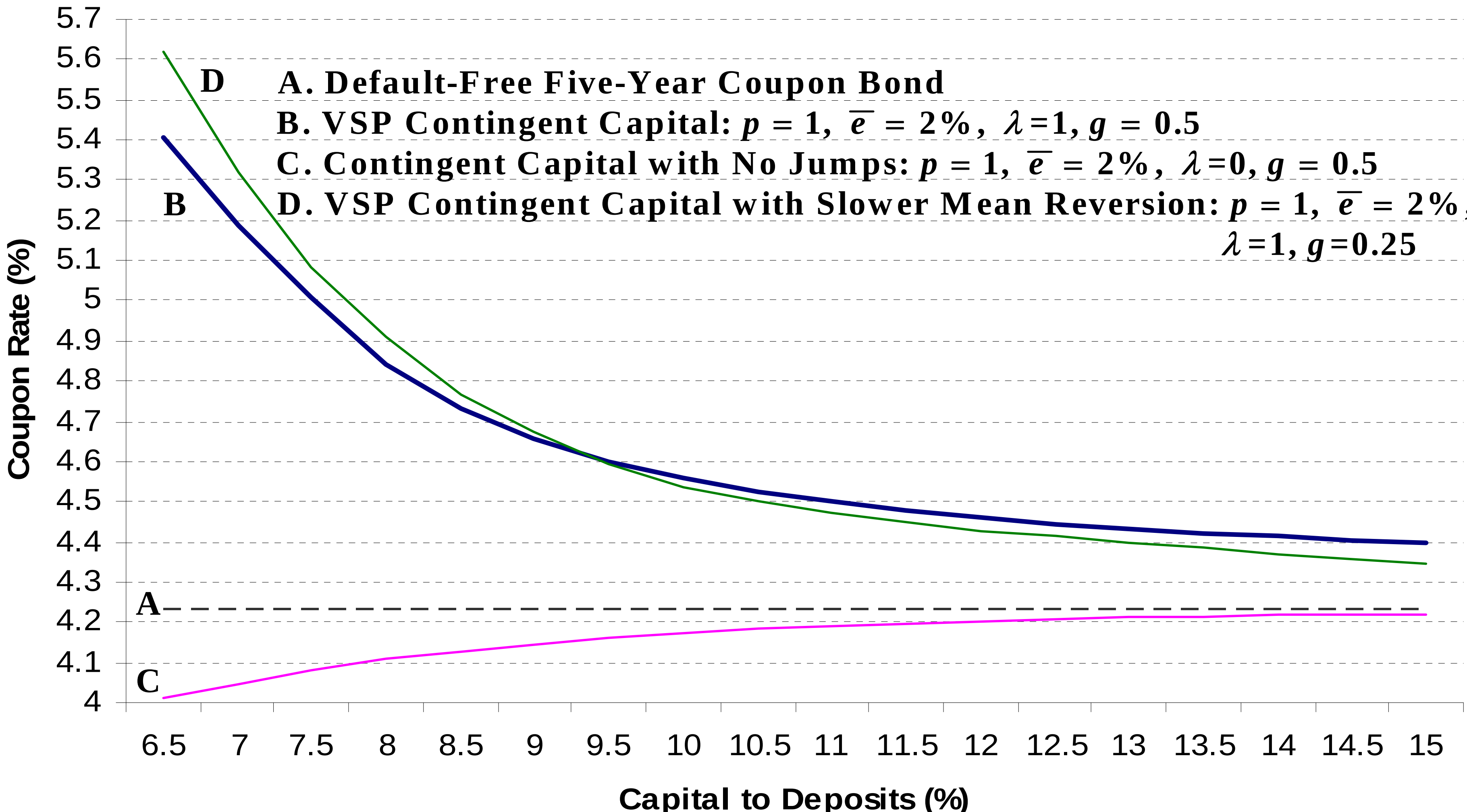

Figure 3

New Issue Par Yields (c) on Fixed-Coupon Contingent Capital
Effects of Maturity
(Initial Value = 4% of Deposits)

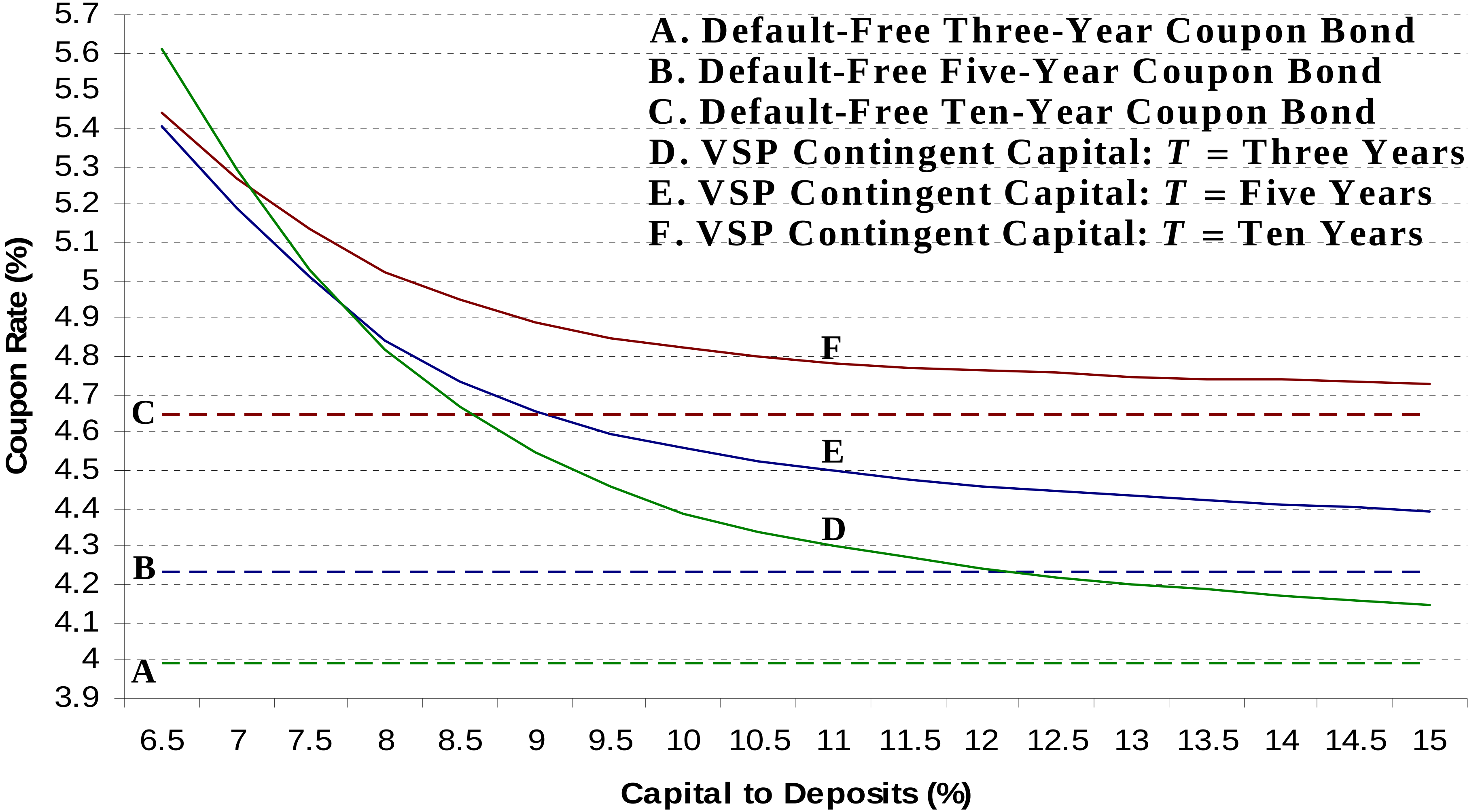

Figure 4

New Issue Par Yields (c) on Fixed-Coupon Contingent Capital Effects of Conversion Threshold

(Five-Year Maturity, Initial Value = 4% of Deposits)

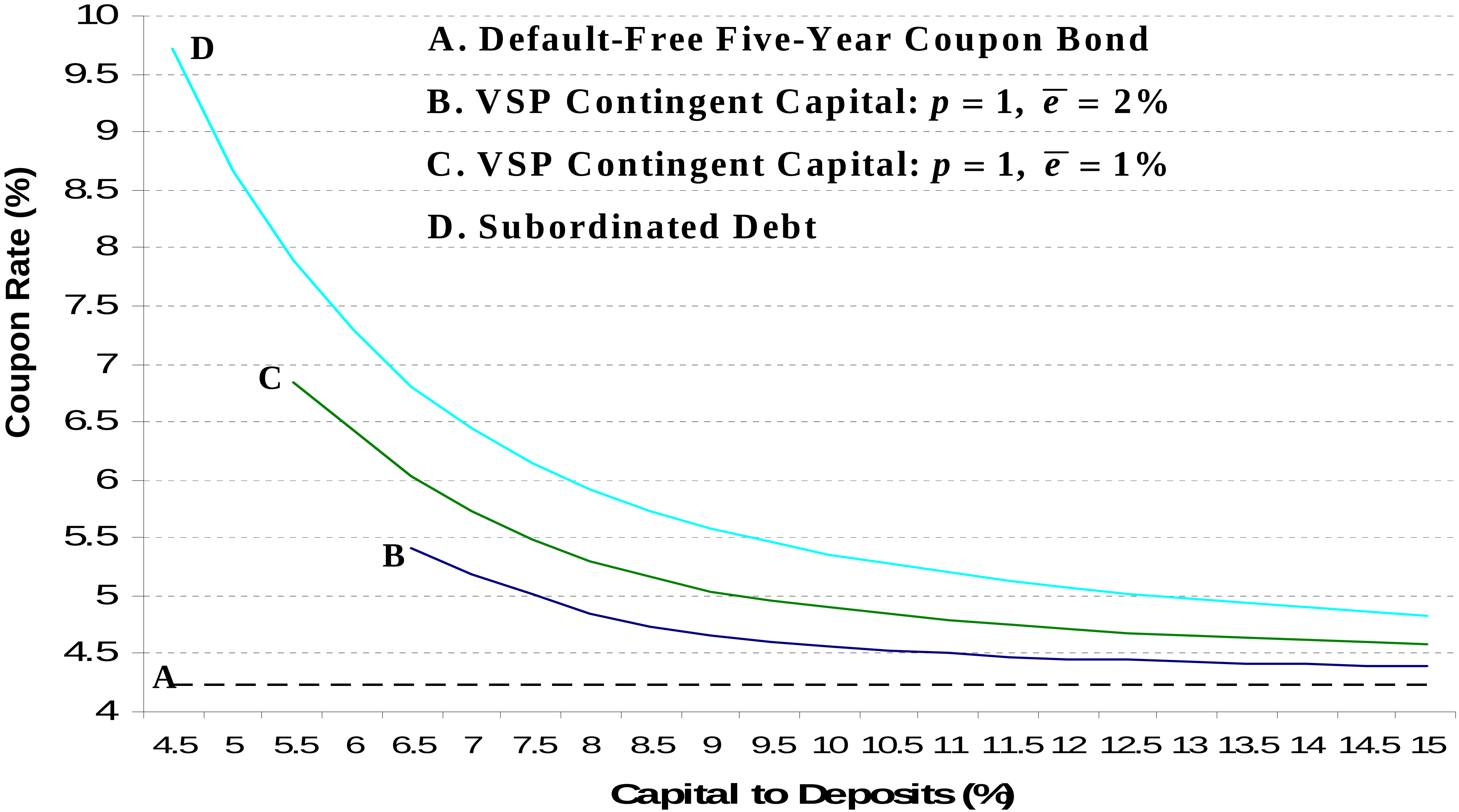

Figure 5

New Issue Par Yields (c) on Fixed-Coupon Contingent Capital
Effects of Conversion Sharing Rule
(Five-Year Maturity, Initial Value = 4% of Deposits)

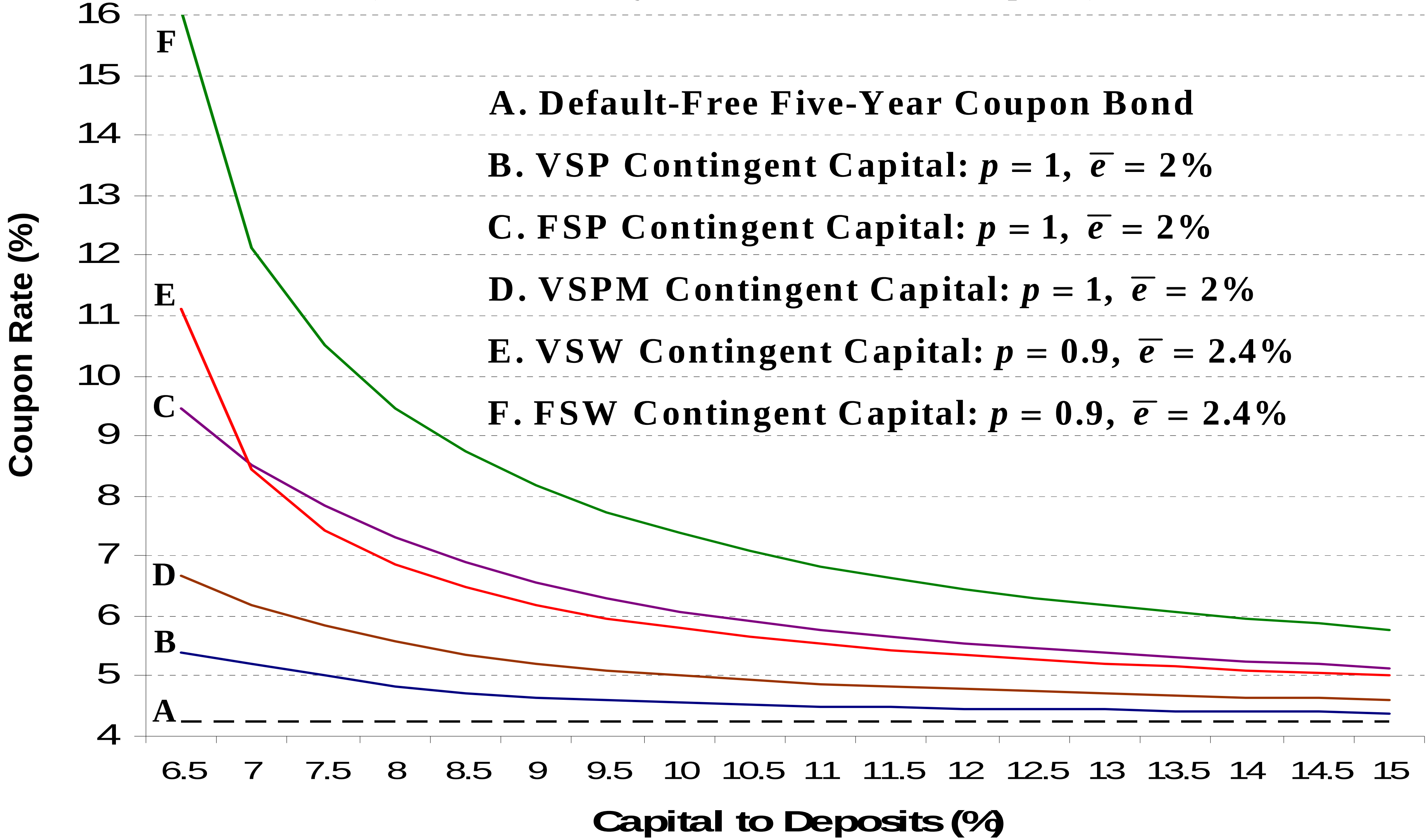

Figure 6

New Issue Credit Spreads (*s*) on Floating-Coupon Contingent Capital Effects of Conversion Terms

(Five-Year Maturity, Initial Value = 4% of Deposits)

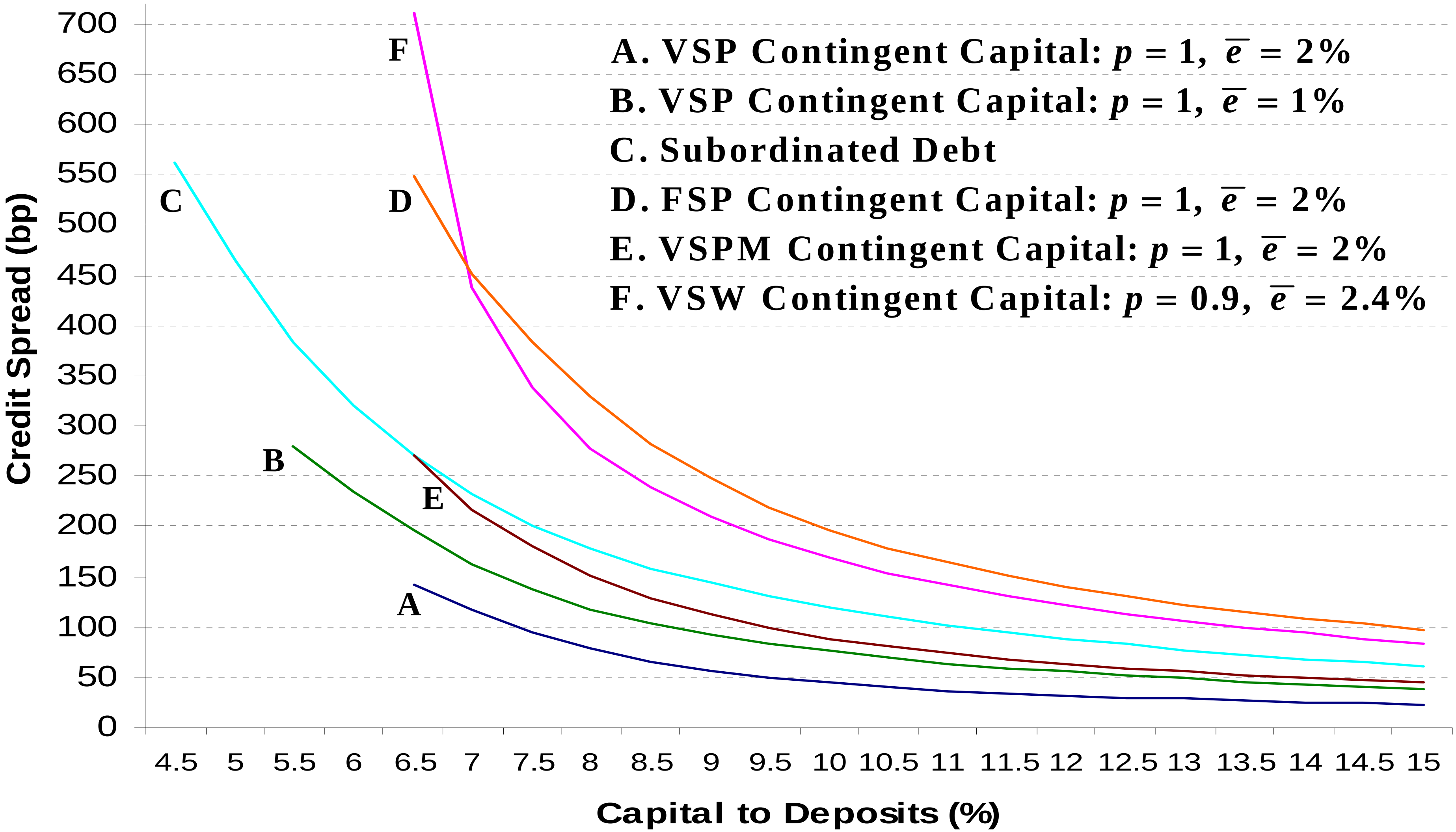

Figure 7

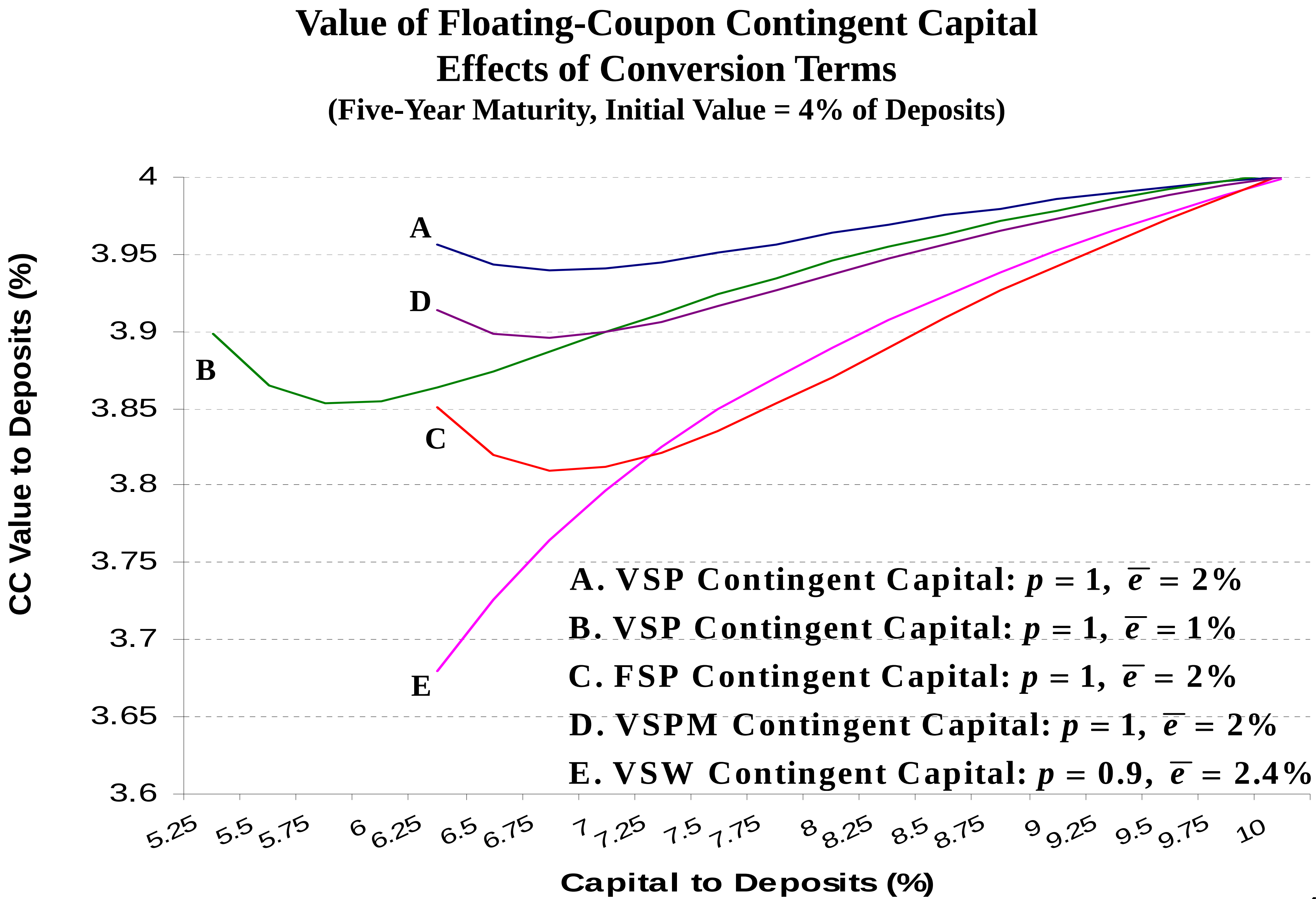
Value of Floating-Coupon Contingent Capital
Effects of Conversion Terms
(Five-Year Maturity, Initial Value = 4% of Deposits)
CC Value to Deposits (%)
Capital to Deposits (%)
4
3.95
3.9
3.85
3.8
3.75
3.7
3.65
3.6
5.25
5.5
5.75
6
6.25
6.5
6.75
7
7.25
7.5
7.75
8
8.25
8.5
8.75
9
9.25
9.5
9.75
10
A
B
C
D
E
A. VSP Contingent Capital: p = 1, ē = 2%
B. VSP Contingent Capital: p = 1, ē = 1%
C. FSP Contingent Capital: p = 1, ē = 2%
D. VSPM Contingent Capital: p = 1, ē = 2%
E. VSW Contingent Capital: p = 0.9, ē = 2.4%

Figure 8

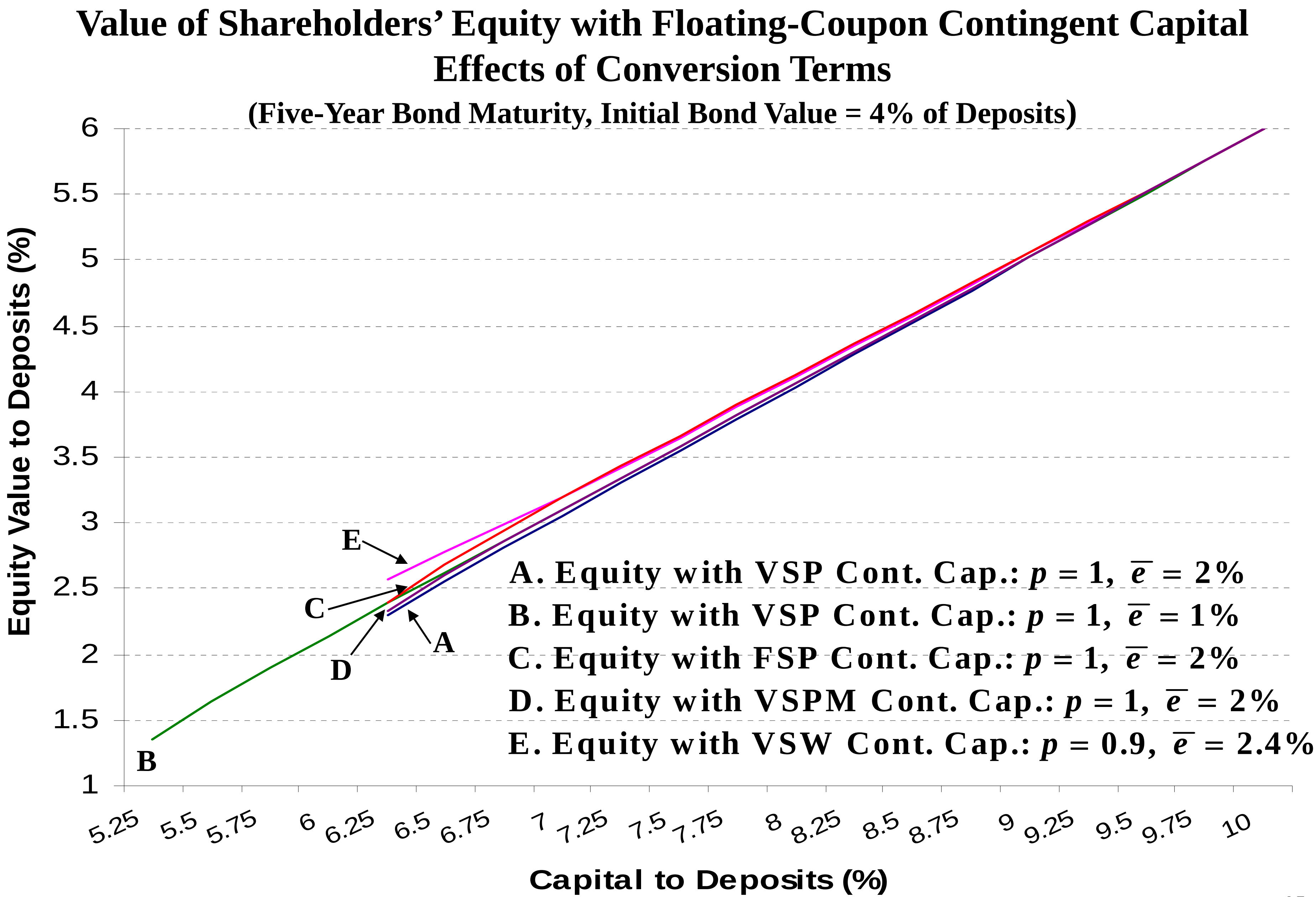
Value of Shareholders' Equity with Floating-Coupon Contingent Capital
Effects of Conversion Terms
(Five-Year Bond Maturity, Initial Bond Value = 4% of Deposits)
Equity Value to Deposits (%)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
5.25
5.5
5.75
6
6.25
6.5
6.75
7
7.25
7.5
7.75
8
8.25
8.5
8.75
9
9.25
9.5
9.75
10
Capital to Deposits (%)
E
C
D
A
B
A. Equity with VSP Cont. Cap.: $p = 1$, $\overline{e} = 2\%$
B. Equity with VSP Cont. Cap.: $p = 1$, $\overline{e} = 1\%$
C. Equity with FSP Cont. Cap.: $p = 1$, $\overline{e} = 2\%$
D. Equity with VSPM Cont. Cap.: $p = 1$, $\overline{e} = 2\%$
E. Equity with VSW Cont. Cap.: $p = 0.9$, $\overline{e} = 2.4\%$

Figure 9

New Issue Par Yields (c) on Fixed-Coupon Contingent Capital
Effect of a Dual-Price Trigger
(Five-Year Maturity, Initial Value = 4% of Deposits)

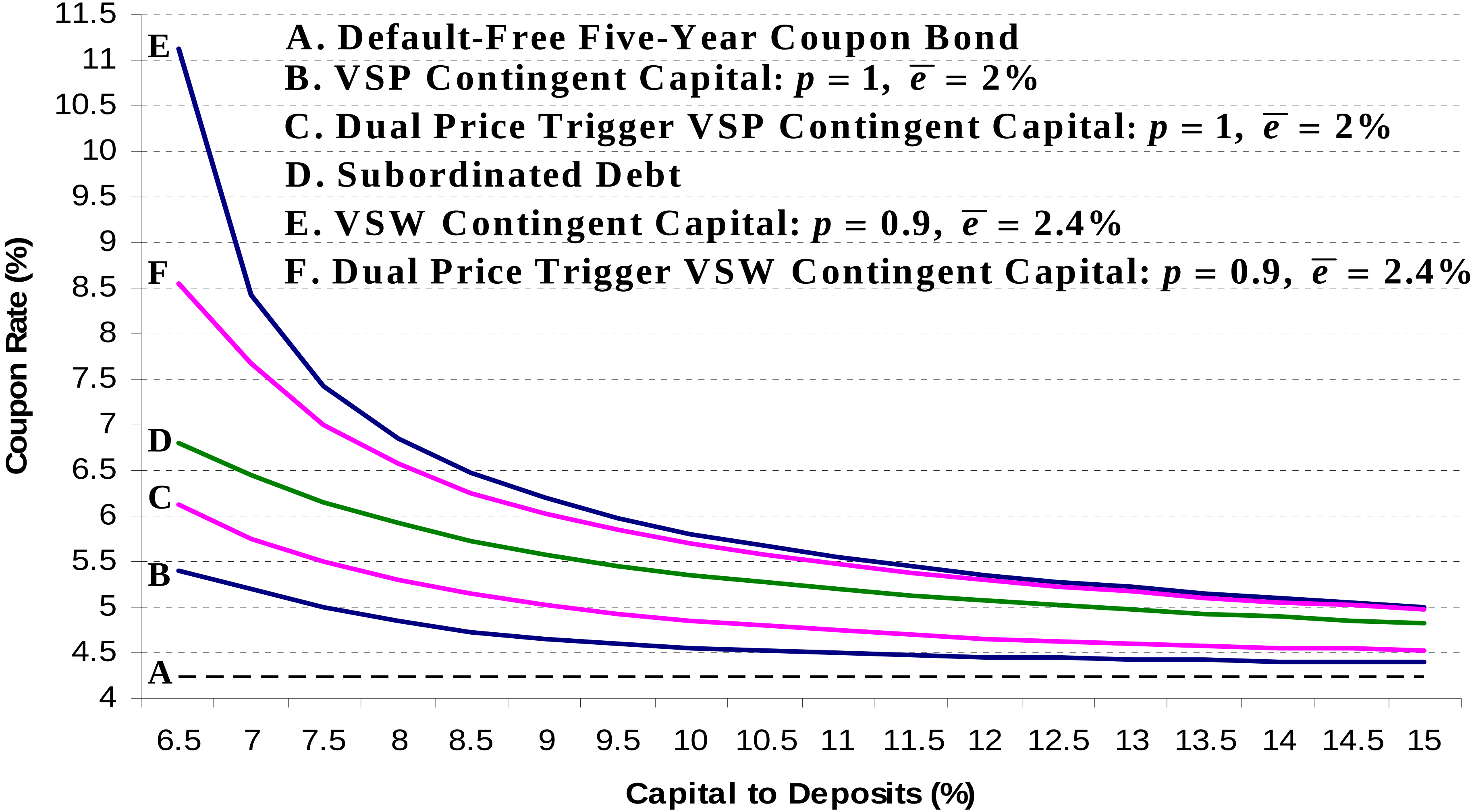

Figure 10

Change in the Value of Shareholders' Equity For a 25% Increase in Frequency of Jumps (λ)

(Five-Year Bond Maturity, Initial Bond Value = 4% of Deposits)

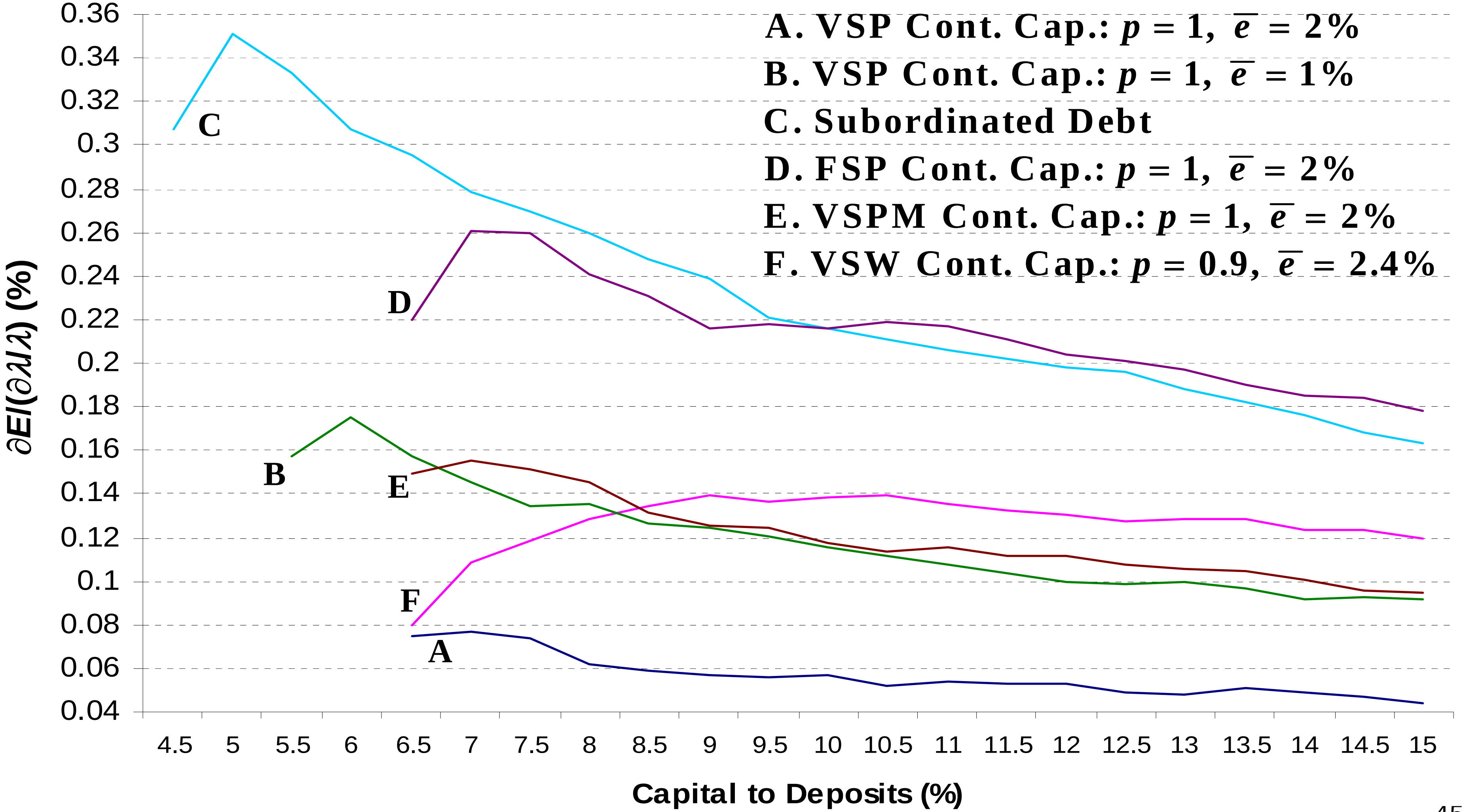

Figure 11

Change in the Value of Shareholders' Equity For a 25% Increase in the Volatility of Jumps (σ_y)

(Five-Year Bond Maturity, Initial Bond Value = 4% of Deposits)

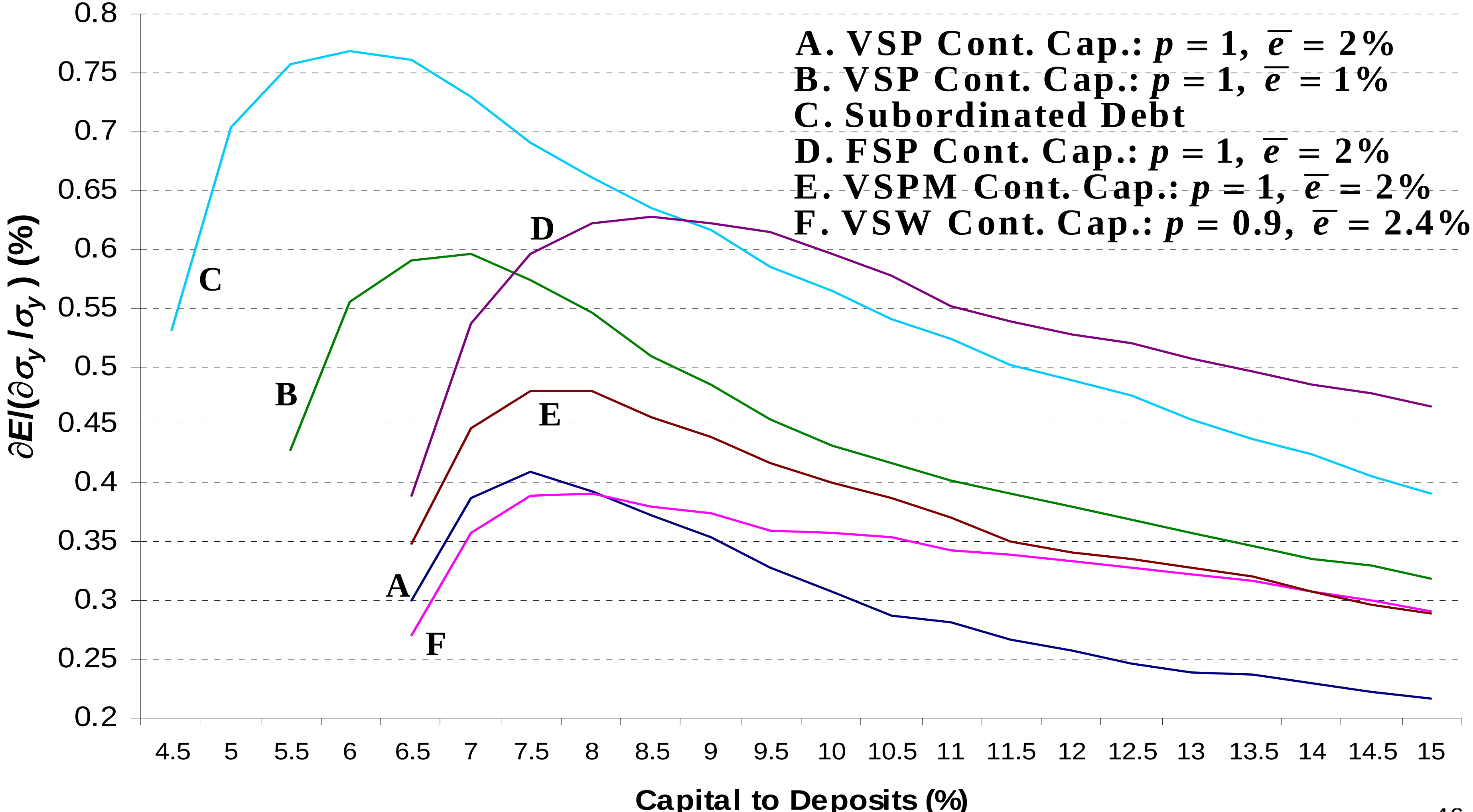

Figure 12

Change in the Value of Shareholders' Equity For a 25% Decline in the Mean Jump Size (μ_y)

(Five-Year Bond Maturity, Initial Bond Value = 4% of Deposits)

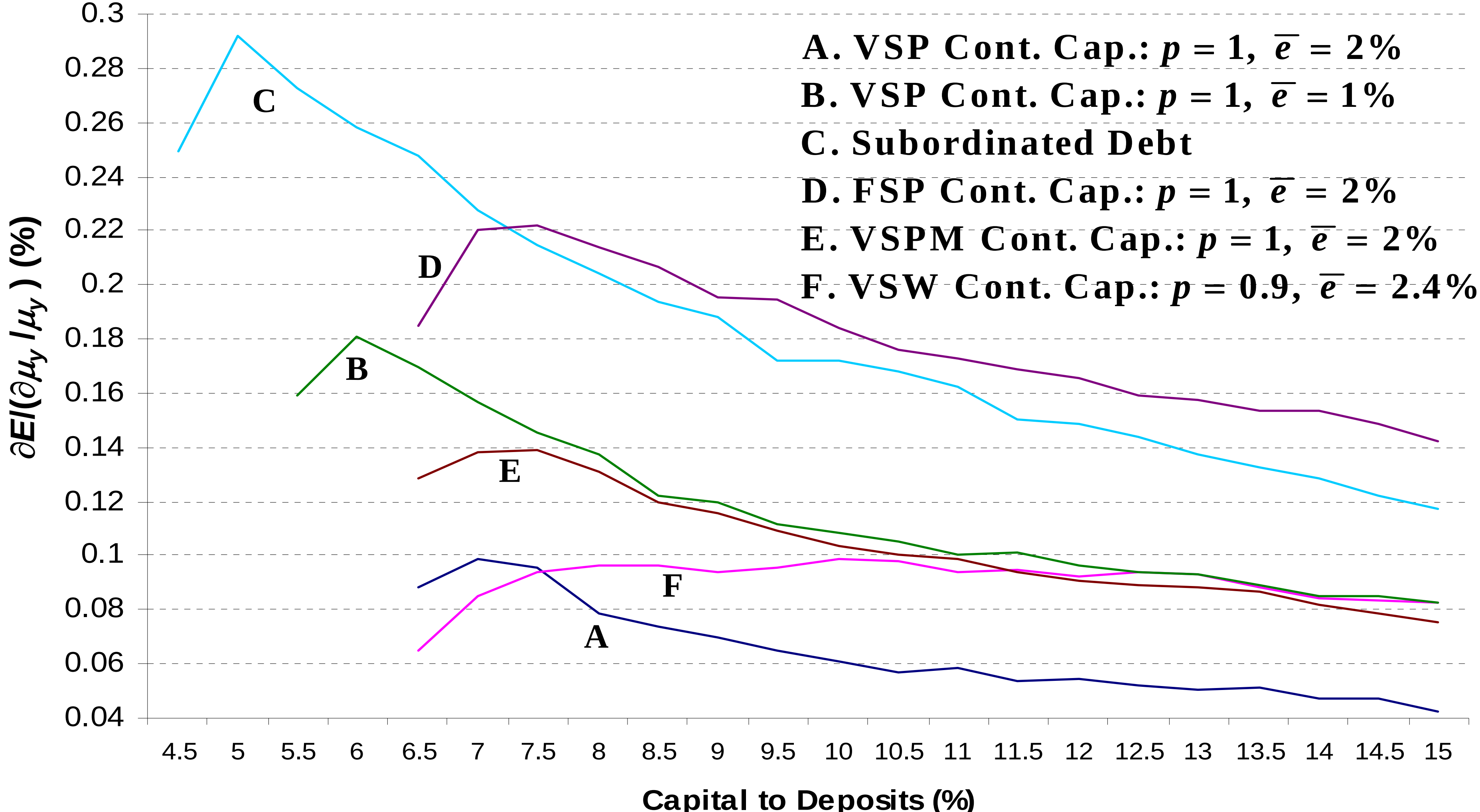

Figure 13

Change in the Value of Shareholders' Equity For a 25% Increase in Diffusion Volatility (σ)

(Five-Year Bond Maturity, Initial Bond Value = 4% of Deposits)

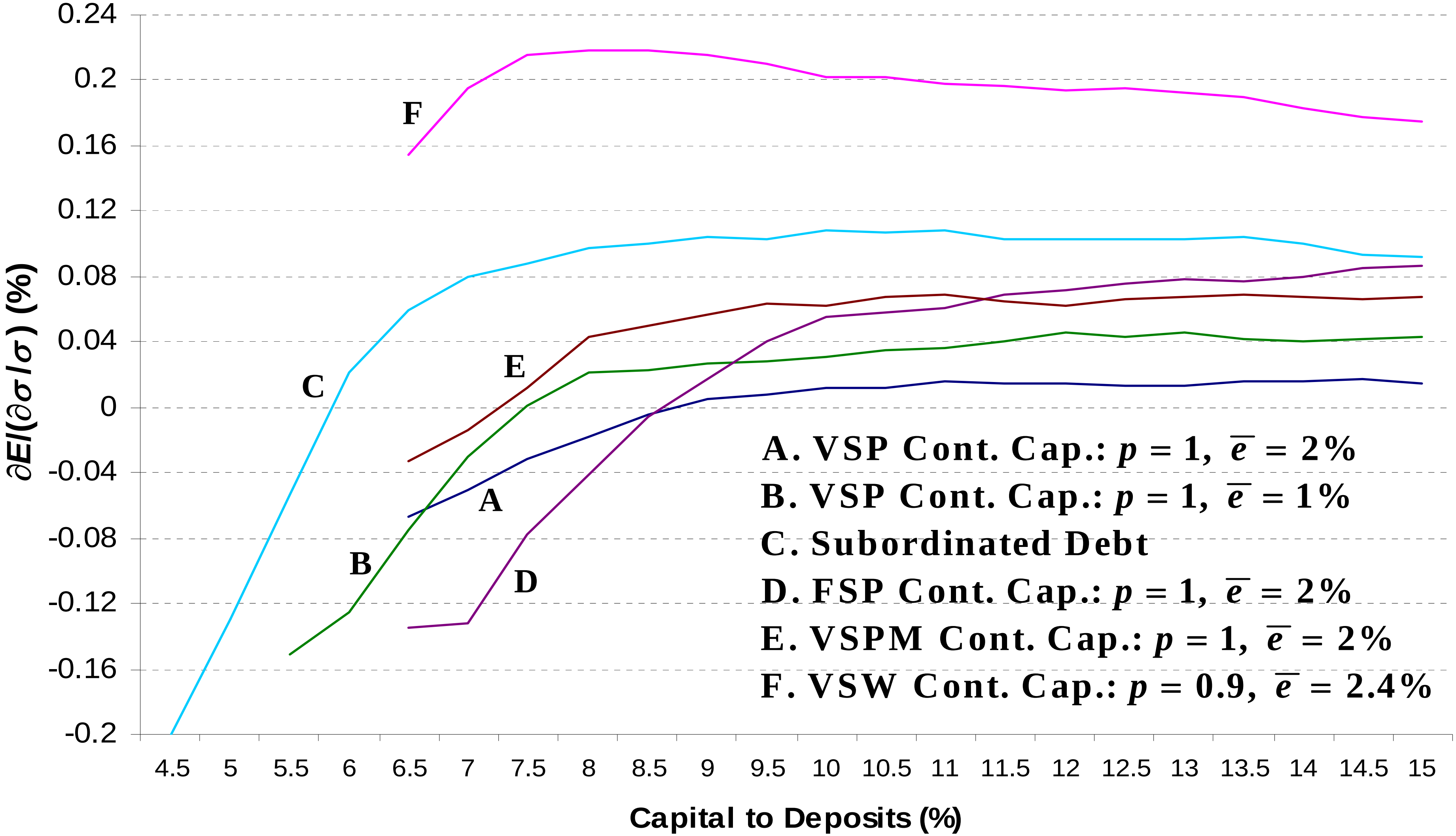

Figure 14

Change in the Value of Existing Shareholders' Equity Following an Increase in New Equity of 25% of Deposits

(Five-Year Bond Maturity, Initial Bond Value = 4% of Deposits)