Contingent Convertibles, Point of non-Viability and Bank Default Risk

April 5, 2024

Abstract

This paper adopts Merton’s structural approach to value contingent convertible bonds (CoCos) with the discretionary trigger that regulators could activate if they consider the bank has reached the point of non-viability (PONV). This regulatory risk could trigger a complete write-down of the value of CoCos and affect their prices and the bank's default probability. Our dynamic model has a fixed default barrier and an additional discretionary trigger at a specific discrete time point. Our numerical results show that a high-risk environment has higher regulation uncertainty premiums than a low-risk environment. The policy implication is that the yield spreads of CoCos with the discretionary trigger are a better measure of bank risk than those of CoCos without discretionary trigger because the price (yield spread) information of CoCos with the discretionary trigger is more sensitive to the issuing bank's risk. Furthermore, the discretionary feature of CoCos raises regulatory risk and, therefore, the issuing bank's default probability, especially in a high-risk economic environment.

Keywords: Contingent convertible; Credit Suisse; Point of non-viability; Discretionary trigger; Regulatory risk premiums; Bank default.

1. Introduction

Contingent convertible bonds (CoCos) are a financial innovation that emerged in response to the 2008 global financial crisis. CoCos are designed to function as both debt and equity to enhance financial stability and protect taxpayers; hence, the issuance of such securities is recommended by French et al. (2010). Some empirical studies provide evidence that CoCos improve financial stability and reduce systemic risk (e.g., Avdjiev et al., 2020; Mendes et al., 2022; Kund and Petras, 2023). Basel III mandates that all non-common equity capital instruments must contain a mandatory write-down or conversion feature if issued by an internationally active bank. Basel III-complying CoCos allow banks to undertake prompt private recapitalization and avoid the need for government intervention and taxpayer bailouts (Flannery, 2014). However, UBS's takeover of Credit Suisse puts Swiss taxpayers at risk. Several interesting research topics arise with the unexpected wipeout of Credit Suisse CoCos due to the discretionary activation by regulators. To the best of our knowledge, the extent to which the discretionary trigger causing regulatory uncertainty influences the price of CoCos and the issuing bank's default probability has not been studied. Therefore, the main objectives of this article are to fill this gap by developing a structural approach and modeling the discretionary event to examine further the impacts of regulatory uncertainty on the price of CoCos and the issuing bank's default probability.

On March 19, 2023, UBS agreed to acquire Credit Suisse in an all-stock deal brokered by the Swiss government. FINMA (the Swiss Financial Market Supervisory Authority) announced that the extraordinary government support of Credit Suisse would trigger a complete write-down of the value of CoCos (the book value totaled approximately \$17.3 billion), but shareholders received approximately \$3.2 billion in value, which appeared to violate the absolute priority between debt and equity. Credit Suisse event is the existence of multiple triggers, a mechanical trigger when a common equity tier 1 (CET1) capital ratio is triggered and a discretionary trigger that the financial regulator could activate if it deemed that the bank had reached the point of non-viability (PONV). The complexity of this contract results in unnecessary and costly uncertainty. It also increases the risk of misrepresentation to investors. One of the challenges with the discretionary trigger is determining what the PONV is precisely. No clear criteria have been defined, giving regulators considerable ex post discretion and causing regulatory uncertainty (Bolton et al., 2023). The Credit Suisse situation, therefore, highlights a fundamental aspect of CoCos-their contractual nature and the regulatory discretion they provide. The extent of regulatory ambiguity embedded in CoCos contributes to pricing challenges and complexity. For investors and issuers, it is necessary to reassess the risks and pricing associated with CoCos with multiple triggers and its role in disciplining bank risk.

Several studies address pricing and risk management of CoCos using various modeling approaches. Wilkens and Bethke (2014) categorized the pricing models for CoCos into three types: structural models, equity derivatives models, and credit derivatives models. The structural model uses the fundamental information of a bank's balance sheet dynamics (e.g., Pennacchi, 2011; Glasserman and Nouri, 2012; Brigo, Carcia, and Pede, 2015; Albul, Jaffee, and Tchistyi, 2015; Yang and Zhao, 2015; Chen et al. 2017; Chang and Yu, 2018). Several studies (e.g., McDonald, 2013; Pennacchi et al., 2014; Albul, Jaffee and Tchistyi, 2015; Chen et al., 2017) recommend various types of CoCos with stock price triggers. Sundaresan and Wang (2015) showed that a stock price trigger leads to the lack of a unique equilibrium in equity and contingent capital prices. But, Pennacchi and Tchistyi (2019a, 2019b) offered a correction to Sundaresan and Wang (2015) model and pointed out that a unique stock price equilibrium exists for certain realistic conditions. Javadi, Li, and Nejadmalayeri (2023) extended Sundaresan and Wang (2015) by incorporating both asset and equity jumps into the conversion ratio. Several studies focus on the capital ratio trigger because all existing CoCos rely mainly on capital ratio triggers based on accounting values. For instance, Von Furstenberg (2011) built a binomial diffusion process for the evolution of a bank's capital ratio. Glasserman and Nouri (2012) derived closed-form expressions for the market value of CoCos with a capital ratio trigger based on accounting values. Conducting an environment of stochastic interest rates and the bank's assets are subject to jump risk, Pennacchi (2011) discussed the moral hazard and debt overhang problems and Chang and Yu (2018) investigated the regulatory closure rules and the bank's default risk.

The other strand of literature on the valuation of CoCos uses the pricing techniques of equity and credit derivatives, as proposed by De Spiegeleer and Schoutens (2012). Cheridito and Xu (2015) applied a reduced-form approach; however, this approach is less intuitive because it ignores the link between the capital ratio and the trigger event (Brigo, Carcia, and Pede, 2015). Corcuera et al. (2014) derived a closed-form formula for coupon-cancellable CoCos, a new type of CoCos where coupons can be canceled during the contract. Leung and Kwok (2015) and Chung and Kwok (2016) first priced CoCos under both mechanical and discretionary trigger mechanisms by using the equity derivatives approach. Leung and Kwok (2015) modeled the discretionary trigger mechanism using the Parisian feature, which resembles the cumulative Parisian feature on the knock-out condition in barrier-style derivatives. Chung and Kwok (2016) integrated both the structural approach of accounting trigger and the reduced-form approach of discretionary trigger of equity conversion. The discretion of the regulator is indicated by the first jump of the Poisson process in the stock price model.

The extant literature on CoCos fails to investigate how the discretionary feature causing regulatory risk affects the valuation of CoCos and the bank's default risk. Under Basel III rules, all regulatory capital CoCos are required to have a discretionary trigger. There have been two cases where the discretionary of CoCos was triggered before the mechanical trigger: Spain's Banco Popular in 2017, declared by the European Central Bank (ECB), and Credit Suisse in 2023, announced by FINMA. At the time, the CET1 capital level of Banco Popular and Credit Suisse was still much higher than the trigger for its outstanding CoCos. The discretionary trigger rule, therefore, affects the triggering probability of CoCos and its value.

Our work incorporates the discretionary trigger rule into a multi-period structural model for CoCos, allowing us to investigate how various factors, such as asset diffusion risk, crisis frequency, and the intensity of discretionary triggers, affect the values of CoCos and the original shareholders' equity. We further investigate how the discretionary trigger influences the price of CoCos and the bank's default probability. Our model framework follows Pennacchi (2011) and Chang and Yu (2018) to consider stochastic interest rates and the jump risk of the bank's assets, except that our model involves the discretionary event and allows a fixed default barrier and an additional discretionary trigger at specific discrete time points. The random time of discretionary events is modeled by the first jump of the Poisson process, where the intensity of discretionary triggers is dependent on the capital ratio and leverage ratio.

The regulatory uncertainty premiums are calculated by the values of CoCos without discretionary triggers minus the values of CoCos with discretionary triggers. Our simulation findings indicate that the regulatory uncertainty premium is positive, implying that the discretionary feature of CoCos increases banks' cost of capital because investors demand additional risk premiums. As expected, the regulatory uncertainty premium increases with the intensity of the discretionary trigger. Furthermore, a high-risk environment has higher regulation uncertainty premiums than a low-risk environment. Therefore, our model provides an interesting policy implication that the yield spreads of CoCos with discretionary features are a better measure of bank's risk than those of CoCos without discretionary features, because the price (yield spread) information of CoCos with discretionary features is more sensitive to the issuing bank's risk. The size of CoCos increases the price of CoCos, but decreases the original shareholders' equity. The relationship between CoCos price, original shareholders' equity, the size of CoCos, and capital ratio trigger are consistent with Pennacchi (2011) and Chang and Yu (2018). Furthermore, when the bank issues CoCos with discretionary trigger rather than CoCos without discretionary trigger, the issuing bank may increase the default probability in a high-risk environment. This provides the information that although raising new capital by issuing CoCos can help to reduce the issuing bank's default risk, the discretionary feature of CoCos creates regulatory uncertainty and increases the bank's insolvency risk, especially in a high-risk environment.

The rest of the paper is organized as follows. The following section presents the multiperiod structural model. Section 3 states the payoffs of two types of CoCos and SD under various scenarios. Section 4 provides numerical results and discussions. Section 5 gives our conclusion.

2. Pricing Model

Several interesting research topics arise with the unexpected wipeout of Credit Suisse CoCos triggered by the regulator's discretionary assessment. First, how do the discretionary trigger and capital ratio trigger influence the price of CoCos and the bank's default probability? Second, how do their results differ from models that do not have a discretionary trigger? In order to investigate these interesting questions, we set up a structural banking model of Merton (1974), Duan and Yu (1994, 2005), Pennacchi (2011), and Chang and Yu (2018) for the valuation of CoCos.

We consider a bank that finances its assets by issuing deposits, a mixture of bonds in the form of CoCos and subordinated debt (SD), and common shareholders' equity. To discuss the effect of discretionary trigger on the price of CoCos and the bank's default probability, we consider two types of CoCos. The first is the CoCos with both triggers: mechanical trigger and discretionary trigger. The second is the CoCos, which only has a mechanical trigger. We assume that deposits are fully insured by the government and CoCos take a lower priority than SD in repayment. In order to value CoCos and SD, we first specify the interest rate, asset, and deposit dynamics and then display their corresponding payoffs under different scenarios.

2.1 The Interest Rate Dynamics

The instantaneous interest rate is assumed to follow the square-root process of Cox et al.

(1985), which avoids the negative interest rate that might appear in Vasicek's model (1977). Hence, the interest rate process under the risk-neutralized pricing measure Q are:

$$dr(t) = \eta(\gamma - r(t))dt + \sigma_v\sqrt{r(t)}dW_{r,t}^Q \tag{1}$$

2.2 The Asset Dynamics

Merton (1974) models asset dynamics by a lognormal diffusion process. However, Merton's model fails to consider the impact of stochastic interest rates on the asset value and the likelihood of a discontinuous decline in the value of bank assets. Pennacchi (2011) and Duan and Yu (2005) fill these two disadvantages by adopting the jump-diffusion model and considering the correlation between the interest rate and the diffusion process of a bank's asset value. In this study, we follow Merton (1976), Pennacchi (2011) and Duan and Yu (2005) to adopt the jump-diffusion model and consider the correlation between the interest rate and the diffusion process of bank asset value. The asset value is assumed to drop suddenly due to the random arrival of negative jumps that occurred during a financial crash. This jump can cause a rapid decline in asset value, leading to CoCos being triggered or even defaulting. Hence, under the risk-neutralized measure Q, the value of a bank's assets can be written as:

$$\frac{dA(t)}{A(t)} = (r(t) - \lambda_A\kappa)dt + \varphi_A\sigma_v\sqrt{r(t)}dW_{r,t}^Q + \sigma_A dW_{A,t}^Q + d\sum_{n=0}^{N_t} Y_n, \tag{2}$$

where $A(t)$ is the value of the bank's total assets at time t; $r(t)$ is the instantaneous interest rate at time t; φ_A measures the interest rate elasticity of assets; σ_A is the volatility of the bank's total assets; $W_{A,t}^Q$ is a Wiener process for the risk-neutral probability measure Q.$\{Y_n: n = 1,2,\ldots\}$ is the n^{th} jump magnitude and a sequence of independent identically distributed nonnegative random variables such that the jump magnitude is assumed to follow lognormally distributed with a negative mean μ_y and variance δ_y^2. The term, $\lambda_A\kappa dt$, compensates for the jump process, where $\kappa = E(Y - 1) = exp(\mu_y + \frac{1}{2}\delta_y^2)$, i.e., the expected percentage changes in the assets' value if the financial crisis event occurs. $\{N_A(t): t > 0\}$ is the total number of jumps in the assets' value observed up to time t and is an independent

Poisson process with an intensity parameter λ_A. We assume that all four sources of randomness: standard Wiener processes ($W_{r,t}^{Q}$, $W_{A,t}^{Q}$), Poisson process $N_A(t)$, and jump size Y_n are independent.

2.3 The Deposit Dynamics

To be consistent with the empirical evidence (e.g., Flannery and Rangan, 2008; Memmel and Raupach, 2010; and Adrian and Shin, 2010), we assume that the dynamics of deposits have a mean-reverting tendency toward the target capital ratio. Hence, the deposit dynamics are described as:

$$\frac{dD(t)}{D(t)} = g(z(t) - \bar{z})dt, \tag{3}$$

where $D(t)$ denotes the value of total bank deposits at time t, $z(t) = \frac{A(t)}{D(t)}$ is the bank's current asset-to-deposit ratio, g is a positive constant value, and $\bar{z}$ is the target asset-to-deposit ratio.

3. Valuation of Contingent Convertible Bonds and Subordinated Debt

Once the risk-neutralized processes of the interest rate, asset, and deposit dynamics are displayed, one can price two types of CoCos and SD by discounting the expected payoffs in the risk-neutral world based on the multi-period framework.

We assume a six-month interval based on regular examinations of capital adequacy by regulators. CoCos and SD can be triggered at any half-year point before expiration.[1] Consider a multi-period setting where bank audits occur periodically at times t_i, $i = 1,2,\ldots,h$, $t_i \in [0,T]$, which is an increasing sequence of integer time points and $t_0 = 0$. The T-year CoCos (or SD) are issued at par value CCD (SD) and pay a coupon rate c semiannually.[2] The value

[1] The time interval can be a day, a month, a quarter, or a year, depending on how often regulators update their information of a bank's capital ratio.

[2] Some studies (e.g., Albul, Jaffee and Tchistyi, 2010 and Chen et al., 2017) consider the case that banks use a rolling debt-structure, i.e., old debt is retired and new debt is issued. However, for simplicity we follow most studies (e.g. Pennacchi, 2011, Sundaresan and Wang, 2015, and Chang and Yu, 2018) to consider only a fixed finite maturity bond and banks not issuing new debt.

of c is set at the issuing date such that its market value equals its par value. The bank non-deposit bond mix between CoCos and SD is defined as $Mix = w_1 \times CCD + (1 - w_1) \times SD$, and w_1 is the ratio of CoCos out of CoCos and SD. The following sections specify the payoffs of the multi-period CoCos and SD, respectively.

3.1 Multi-period Contingent Convertible Bonds

3.1.1 The setup of mechanical and discretionary triggers

CoCos have two main contract features: the loss absorption mechanism and a trigger that activates that mechanism. CoCos can absorb losses either by converting into common equity or through a principal write-down (partial or full). The trigger can be either mechanical, defined in terms of a capital ratio, or discretionary, subject to regulator's judgment (such as PONV). The mechanical trigger of existing CoCos is linked to the Tier-1 ratio or the equity capital ratio. We treat both ratios the same and use the term capital ratio as the mechanical trigger in our analytical model. The discretionary, or PONV, trigger is activated based on the regulator's assessment of the bank's possible insolvency. We define that if the capital position of a bank ranges between the capital ratio trigger and the discretionary threshold, regulators may assess the bank's possible insolvency to determine whether to activate the PONV trigger. Hence, the discretionary trigger is a random event, and the random time of the discretionary event, τ_R, is modeled by the first jump of the Poisson process $N_D(t_i)$ with the state-dependent intensity $\lambda_D(t_i)$, where $\tau_R = inf\{t_i \in [0,T]: kA(t_i) < A(t_i) - D(t_i) - Mix < dA(t_i) \; and \; N_D(t_i) = 1\}$.

We further model the intensity of discretionary triggers to be dependent on the state variables that are linked to the financial health of the bank through an appropriate choice of intensity function. Extending Chung and Kwok (2016), we model that the intensity of discretionary triggers, $\lambda_D(t_i)$, to be dependent on the capital ratio $((A(t_i) - D(t_i) - Mix)/A(t_i))$ and leverage ratio $((A(t_i) - D(t_i) - (1 - w_1^{CCD}) \times SD)/A(t_i))$, as follows:

$$\lambda_D(t_i) = a_0 + a_1 1_{\{(A(t_i)-D(t_i)-Mix)/A(t_i)<R\}} + a_2 1_{\{(A(t_i)-D(t_i)-(1-w_1^{CCD})\times SD)/A(t_i)<LR\}},$$

$$a_0 > 0, a_1 > 0, a_2 > 0.$$

where $Mix = w_1^{CCD} \times CCD + (1 - w_1^{CCD}) \times SD$, where w_1^{CCD} is the ratio of CoCos of non-deposit debt. R (LR) respectively is a predetermined capital ratio (leverage ratio) that denotes the warning region in which is close to the minimum regulatory threshold such that regulators initiate the monitoring procedures for potential activation of the discretionary trigger. a_0 is a constant value for the intensity of discretionary trigger, a_1 is the sensitivity to the intensity of discretionary trigger when the capital ratio is lower than R; a_2 is the sensitivity to the intensity of discretionary trigger when the leverage ratio is lower than LR.

3.1.2 Payoffs of CoCos with discretionary trigger (PONV trigger)

The payoffs of the CoCos become more complicated when we consider that the bank may default in between the auditing times. We assume that the bank defaults when its equity value becomes negative at any point in time. Thus, the default time of the bank τ_D is the first moment in the interval $[0, T]$ when the bank's equity is negative - that is, $\tau_D = inf\{t_i \in [0, T]: A(t_i) - D(t_i) - Mix < 0\}$. We specify the payoffs of CoCos with the discretionary trigger, $PO_{CCD}(t_i)$, at time t_i as follows:

$$PO_{CCD}(t_i) = \begin{cases} c \times CCD, & if\ C^*(t_i) > kA(t_i)\ and\ C^*(t_i) \geq dA(t_i)\ and\ \tau_D > t_i \\ CCD, & \begin{cases} if\ C^*(T) > kA(T)\ and\ \tau_D > T \\ if\ kA(t_i) < C^*(t_i) < dA(t_i)\ and\ N_D(t_i) = 0\ and\ \tau_D > t_i \end{cases} \\ \alpha \times CCD, & if\ kA(t_i) < C^*(t_i) < dA(t_i)\ and\ N_D(t_i) = 1\ and\ \tau_D > t_i \\ max[0, A(\tau_D) - D(\tau_D) - (1 - w_1^{CCD}) \times SD], & \begin{cases} if\ C^*(T) > kA(T)\ and\ \tau_D \leq T \\ if\ kA(t_i) < C^*(t_i) < dA(t_i)\ and\ \tau_D \leq t_i \end{cases} \\ CCD - (R - k)A(t_i), & if\ 0 < C^*(t_i) \leq kA(t_i)\ and\ CCD > (R - k)A(t_i)\ and\ \tau_D > t_i \\ 0, & otherwise \end{cases} \quad (1)$$

where CCD is the face amount of the contingent convertible bond, $C^*(t_i) = A(t_i) - D(t_i) - Mix$ is the bank's capital position at the auditing time t_i, and $Mix = w_1^{CCD} \times CCD + (1 - w_1^{CCD}) \times SD$ is the bank's non-deposit debt and w_1^{CCD} is the ratio of CoCos. The term k is the capital ratio trigger specified in CoCos, and d is the discretionary threshold based on the regulator's judgment, which is higher than the term the capital ratio trigger k specified in CoCos. R is the minimum capital requirement set by regulators. The payoffs of CoCos with the discretionary trigger under different scenarios depend on whether or not: (1) the capital ratio is triggered, (2) the discretionary trigger is activated, and (3) the bank defaults. If the bank does not default, i.e., $\tau_D > t_i$, and its capital position is above the capital ratio trigger and discretionary threshold at auditing time t_i (i.e., $C^*(t_i) > kA(t_i)$ and $C^*(t_i) \geq dA(t_i)$), then the trigger will not be pulled, and the bank continues to make coupon payments $cCCD$ until the CoCos matures at date T, and the bank pays the par value of CCD at maturity.

If its capital position is above the capital ratio trigger but lower than the discretionary threshold at auditing time t_i $(kA(t_i) < C^*(t_i) < dA(t_i))$, the bank will not default $(\tau > t_i)$, and the payoffs of CoCos depend on regulators' discretionary triggers. If regulators do not step in and trigger CoCos ($N_D(t_i) = 0$), then the bondholder gets its full face value CCD. However, if regulators step in and trigger CoCos $(N_D(t_i) = 1)$, the coupon payment stops, and the bond will be used to write off the bank's losses up to $(1-\alpha)CCD$, where α is the remaining ratio of CoCos after write-down and is assumed to be in the range of $0 \leq \alpha < 1$. If $\alpha = 0$, for example, CoCos issued by Credit Suisse are subject to a 100% write-down, converting the par value to zero shares of common equity.

If $kA(t_i) < C^*(t_i) < dA(t_i)$ and the bank defaults before the auditing time t_i- that is, $\tau_D \leq t_i$, the coupon payment stops, and whether the discretionary trigger is activated or not, then the bank leaves the contingent bond of $max[0, A(\tau_D) - D(\tau_D) - (1 - w_1^{CCD}) \times SD]$, because CoCos are junior to SD, and thus the debtholders are paid only after SD recovers 100%, where $A(\tau_D)$ and $D(\tau_D)$ denote the value of the bank's assets and deposits at the defaulting time, respectively.

If the capital ratio of the CoCo is triggered $(0 < C^*(t_i) < kA(t_i))$ and $\tau_D > t_i$, the coupon payment stops and the bond will be used to write off the bank's losses up to the amount of $(R - k)A(t_i)$. Following Glasserman and Nouri (2012), Lo et al. (2015), and Chang and Yu (2018), our setting of the loss absorption is to make the bank's capital position at trigger ratio k, say 5%, back to the required capital standard under Basel III, R, say 8%. The loss absorption feature usually will write down the full face value of CoCos. For the case when a residual amount is remaining, $CCD > (R-k)A(t_i)$, we follow Pennacchi (2011) and Chang and Yu (2018) to assume that this amount will be converted into equity shares at the market equity price.

The payoff of CoCos with discretionary triggers at time t_i in Equation (1) can be further decomposed into three components shown in Equation (2), where the first term, PO_{ccD}^{bond}, is the value of the coupon bond when the CoCos is not triggered. The second term, PO_{ccD}^{dis}, is the value after absorbing the losses when the discretionary trigger is activated before the capital ratio trigger. The third term, PO_{ccD}^{mech}, is the value of new equity shares that the CoCos are converted into when the capital ratio is triggered before the discretionary trigger.

$$PO_{CCD}(t_i) = PO_{ccD}^{bond}(t_i) + PO_{ccD}^{dis}(t_i) + PO_{ccD}^{mech}(t_i),\ i = 1,2,\ldots,h,\ t_h = T. \tag{2}$$

where,

$$PO_{ccD}^{bond}(t_i) = \Bigg[c \times CCD \times 1_{\{C^*(t_i))>kA(t_i)\&C^*(t_i)\geq dA(t_i)\&\tau_D>t_i\}} + CCD \times \Bigg(1_{\{C^*(T)>kA(T)\&\tau_D>T\ \}}$$

$$+1_{\{kA(t_i)<C^*(t_i)<dA(t_i)\&N_D(t_i)=0\&\tau_D>t_i\}}\Bigg)\Bigg] + max\left[0, A(\tau_D) - D(\tau_D) - (1-w_1^{CCD}) \times\ SD\right]$$

$$\times \left(1_{\{C^*(T)>kA(T)\&\tau\leq T\}} + 1_{\{kA(t_i)<C^*(t_i)<dA(t_i)\&\tau_D\leq t_i\}}\right)\Bigg].$$

$$PO_{ccD}^{dis}(t_i) = \left(\alpha \times CCD \times 1_{\{kA(t_i)<C^*(t_i)<dA(t_i)\ \&N_D(t_i)=1\&\ \tau_D>t_i\}}\right).$$

$$PO_{ccD}^{mech}(t_i) = \left[\Big(CCD-(R-k)A(t_i)\Big) \times 1_{\{0<C^*(t_i)<kA(t_i)\&CCD>(q-k)A(t_i)\&\tau_D>t_i\}}\right].$$

3.1.3 Payoffs of CoCos without discretionary triggers

If the CoCos have only one capital ratio trigger, the payoffs of CoCos in Equation (2) reduce to $PO_{CC}(t_i)$, as follows:

$$PO_{CC}(t_i) = PO_{CC}^{bond}(t_i) + PO_{CC}^{mech}(t_i), \quad i = 1,2,\ldots,h,\ t_h = T. \tag{3}$$

where,

$$PO_{CC}^{bond}(t_i) = \left[c \times CCD \times 1_{\{C^*(t_i)>kA(t_i)\&\tau_D>t_i\}} + CCD \times \left(1_{\{C^*(T)>kA(T)\&\tau_D>T\}} + 1_{\{C^*(t_i)>kA(t_i)\&\tau_D>t_i\}}\right)\right]$$

$$+ max\left[0, A(\tau_D) - D(\tau_D) - (1 - w_1^{CC}) \times SD\right] \times \left(1_{\{C^*(T)>kA(T)\&\tau_D\leq T\}} + 1_{\{C^*(t_i)>kA(t_i)\&\tau_D\leq t_i\}}\right)\Bigg].$$

$$PO_{CC}^{mech}(t_i) = \left[\left(CCD - (R-k)A(t_i)\right) \times 1_{\{0<C^*(t_i)<kA(t_i)\&CC>(R-k)A(t_i)\&\tau_D>t_i\}}\right]$$

Equation (3) implies that the payoff of CoCos without discretionary trigger at time t_i, $PO_{CC}(t_i)$, consists of two components. The first term, PO_{CC}^{bond}, is the value of the coupon bond when the CoCo is not triggered. The second term, PO_{CC}^{mech}, is the value of new equity shares when the CoCo is triggered.

3.2 Multi-period Subordinated Debt

If the debt is not loss-absorbing and thus not forced to convert into equity, then it takes the form of traditional subordinated debt (SD). Hence, the payoffs of the subordinated debt, $PO_{SD}(t_i)$, at time t_i are as follows:

$$PO_{SD}(t_i) = \begin{cases} c \times SD, & if \;\; \tau_D > t_i \\ SD, & if \;\; A(T) - D(T) \geq SD \; and \; \tau_D > T \\ A(T) - D(T), & if \;\; 0 \leq A(T) - D(T) < SD \; and \; \tau_D > T \\ min[A(\tau_D) - D(\tau_D), SD], & \begin{cases} if \;\; A(T) - D(T) \geq SD \; and \; \tau_D \leq T \\ if \;\; A(t_i) - D(t_i) \geq SD \; and \; \tau_D \leq t_i \end{cases} \\ 0, & if \;\; otherwise \end{cases} \tag{4}$$

The payoffs of SD depend on whether (1) the bank defaults and (2) there are enough assets for SD or not. If the bank does not default ($\tau_D > t_i$), then the bank continues to make coupon payments $c \times SD$ until the bond matures at date T. At maturity date T, if the bank has enough assets, i.e., $A(T) - D(T) \geq SD(T)$, and $\tau_D > T$, then the bondholder can get the full principal amount, SD. If the bank does not have enough assets at T and $\tau_D > T$, then the bondholder can get back only whatever is left, $0 \leq A(T) - D(T) < SD$.

If $A(t_i) - D(t_i) \geq$ SD, and $\tau_D > t_i$, the debtholders will get back the par value of SD because there are enough assets remaining at auditing time t_i. However, if there are not enough assets remaining at auditing time t_i, $A(t_i) - D(t_i) < SD$, and $\tau_D > t_i$, the bondholders receive what's left in the bank, $0 \leq A(t_i) - D(t_i) <$ SD. If the bank defaults before the auditing time t_i or maturity T, no matter whether the bank has enough assets remaining or not, then the bondholders at the defaulting time can get the value of $min[A(\tau_D) - D(\tau_D), SD]$, which is the minimum value of either whatever is left, $A(\tau_D) - D(\tau_D)$, or the full principal amount of SD.

3.3 Original Shareholders' Equity

The bank receives funding from its deposits, bonds in the form of SD and CoCos, and shareholders' equity. The value of the original shareholders' equity at mechanical time, discretionary time, or default time t^* becomes:

$$E_j(t^*) = \begin{cases} A(t^*) - D(t^*) - PO_j(t^*), & if\ A(t^*) > D(t^*) + PO_j(t^*) \\ 0 & if \quad otherwise \end{cases} \tag{5}$$

Here, $PO_j(t^*) = w_1^j \times PO_j(t^*) + (1 - w_1^j) \times PO_{SD}(t^*)$, $PO_j(t^*)$, and $j = CCD\ or\ CC$ is the payoff with or without discretionary trigger, corresponding to each scenario stated in Equations (2) to (4).

3.4 Probability of default (PD): CoCos with and without discretionary triggers

According to Equation (5), the probability of default (PD) is defined as the probability that the shareholders' equity $E(t^*)$ is less than the capital requirement at the time of either mechanical, discretionary, or default. In order to investigate the effect of discretionary triggers of CoCos on the bank's PD, we compute the bank's PD taking CoCos with discretionary triggers as the long-term debt minus the bank's PD taking CoCos without discretionary feature as the long-term debt in order to compare the change of default probability, ΔPD. Hence, we have:

$$\Delta PD = Pr\left(E_{CCD}(t^*) + PO_{CCD}^{mech} < q^* A_{t^*}^{CCD}\right) - Pr\left(E_{CC}(t^*) + PO_{CC}^{mech} < q^* A_{t^*}^{CC}\right), \tag{6}$$

where $q^* A_{t^*}^i$, is the capital requirement, and $i = CCD,\ CC$. Here we set q^* at 5% and the initial asset value at 100.

3.5 Discretionary trigger rules

The maturities of CoCos are generally over ten years. The financial characteristics of the issuing bank may change substantially during such a long period of time. The issuing bank may suffer a loss and become undercapitalized, and then the discretionary trigger may be activated based on the regulator's assessment of the bank's possible insolvency; hence, the discretionary trigger rules matter to the values of CoCos.

In the real world, capital ratio triggers of CoCos are set at around 5% to 8%. In order to compare CoCos with and without discretionary triggers, we set the discretionary threshold for CoCos at the capital ratio trigger of 5%. When the bank's capital position is higher than the capital ratio trigger but lower than the discretionary threshold, the regulator may trigger the loss absorption mechanism.

As mentioned above, the discretionary threshold is higher than the capital ratio trigger and even higher than the required capital ratio. If the discretionary threshold is higher than the required capital ratio, the regulator may activate a discretionary trigger if the regulator deems that a non-undercapitalized bank has reached the PONV. For example, on Sunday, March 19, 2023, the Credit Suisse AT1 bonds were triggered by the regulator rather than the CET1 ratio. Just four days before the Sunday takeover, the regulator (FINMA) confirmed that Credit Suisse met the higher capital and liquidity requirements for systemically important banks. The CET1 ratio is 14.1%, more than double the 7% ratio for the trigger, and it is well above regulatory minimum requirements. However, the regulator stated that Credit Suisse would not have survived Monday. Thus, the regulator decided to trigger the write-down of AT1 bonds and Credit Suisse had to be taken over by UBS Group AG on Sunday.

It is commonly observed that if the discretionary threshold and the probability that a discretionary event occurs is higher, the probability that the discretionary trigger is activated increases. Thus, we expect the discretionary trigger rule to influence the maturities of CoCos and, therefore, their prices. The discretionary trigger rule of CoCos will likely lead to higher funding costs and then increase banks' capital costs because investors will likely demand additional risk premiums. When the discretionary threshold is lower than the capital ratio trigger, the capital ratio trigger determines the maturities and payoffs of CoCos rather than the discretionary threshold.

3.6 Prices of CoCos and SD

Based on the dynamics of the interest rate, assets, and deposits and the payoff structures of CoCos and SD specified above, we can calculate the values of CoCos and SD on the issuing date (i.e., time 0) under the risk-neutralized pricing measure as follows:

$$P_i = \frac{1}{i} \times E^Q\left[\int_0^{T \wedge t^*} e^{-\int_0^{t_i} r_s ds} PO_i(t_i) dt_i\right], i = CCD, CC\ or\ SD \tag{7}$$

where $E^Q[\cdot]$ represents the expectations on the issuing date under the risk-neutral measure Q. t^* denotes the timing of the first trigger or default, which is defined as follows:

$$t^* = inf\left\{t_i \in [0, T]:\ 0 < C^*(t_i) < kA(t_i)\right\} \wedge inf\left\{t_i \in [0, T]: C^*(t_i) < 0\right\}$$

$$\wedge\, inf\left\{\ t_i \in [0, T]:\ kA(t_i) < C^*(t_i) < dA(t_i)\ and\ N_D(t_i) = 1\right\} \tag{8}$$

4. Numerical results

In this section, we evaluate the prices of SD and CoCos with and without discretionary triggers, as well as the value of original shareholders' equity under alternative scenarios using the Monte Carlo method. We conduct the simulation on a semiannual basis with 50,000 sample paths.

4.1 Parameter values

In order to examine how contract specifications influence the values of CoCos and SD, this section specifies a set of benchmark parameters. The parameters' definitions and their base values are shown in Table 1. Most parameter values are adopted from Pennacchi (2011) and Chang and Yu (2018). For the benchmark parameters of the returns on a bank's assets, the Brownian motion uncertainty is σ_A= 2 %. The risk-neutral crisis frequency is λ_A= 0.3 with a mean jump size of $\mu_y = -1\%$ and a standard deviation of σ_y= 2 %. The interest rate elasticity of assets is $\varphi_A = -1$. For the benchmark parameters of bank deposits, we assume that the mean-reversion parameter for bank deposit growth (g) is 0.5 and the bank's target ratio of assets-to-deposits (z) is 1.12. This implies that when the bank's capital ratio deviates from the target capital ratio of 1.12, the expected change in the reduction of deviation for the next year is one-half. For the parameters of the default-free term structure, the initial instantaneous interest rate at time 0, $r(0)$, is set to be 3.5 %, η=11.4 %, γ= 6.9 % and σ_v=7 %. For CoCos (or SD) parameters, the coupon rate c and maturity date T of CoCos (or SD) are 4.23 % and five years, respectively. For the triggers for CoCos, the capital ratio trigger k is set at 5 %, and the discretionary trigger d is set at 10 %. For the parameter of discretionary trigger intensity, regulatory capital threshold R is 8%, and leverage ratio threshold LR is 4.5%. The constant value for the intensity of discretionary trigger is a_0 =5%. The sensitivity to the intensity of discretionary trigger when the capital ratio is lower than R is a_1 =5%. The sensitivity to the intensity of discretionary trigger when the leverage ratio is lower than LR is a_2 =5%. The remaining ratio of CoCos write down is set to be α =50% unless specified otherwise. The initial amount of CoCos (or SD) is 3 % of assets, and the original shareholders' equity is 8 %.

4.2 Prices of CoCos and SD

4.2.1 Comparison of CoCos and SD

Table 2 reports the prices of SD, CoCos without discretionary triggers, and CoCos with discretionary triggers. When the initial capital structure of the bank is low (A/D =1.1 or 1.15), we find that their prices decrease with asset volatility, because asset volatility increases the probability of default and reduces the prices of SD and CoCos. For instance, we can decompose CoCos with the discretionary trigger into three positions: a long position of SD, a short position of a put on CoCos with a strike price at the discretionary trigger and a short position of a put on CoCos with a strike price at the capital ratio trigger. Thus, an increase in asset volatility increases the put value and lowers the price of CoCos further. However, when the initial capital structure of the bank is high (A/D = 1.25), both prices are the same and are insensitive to asset volatility risk.

Consistent with the result of Chang and Yu (2018), we find that the prices of CoCos vary more substantially than those of SD. Furthermore, our results also show that whether we look at capital structure risk, crisis frequency, or crisis size risk, they all have a greater impact on the prices of CoCos with discretionary trigger than they do on CoCos without discretionary trigger. This implies the yield spreads of CoCos with discretionary trigger are a better measure for bank risk than those of CoCos without discretionary trigger.

4.2.2 Comparison of components for CoCos and mixed SD and CoCos

We further show how bank capital, crisis frequency, and crisis size risk affect the decomposed value of mixed SD and CoCos with discretionary triggers in Table 3. When the initial bank capital is low (A/D = 1.1), the capital ratio trigger is activated, and a high crisis frequency and crisis size decreases the bond value of CoCos and increases the new equity value of CoCos. When the initial bank capital is medium (A/D = 1.15), the capital ratio trigger or the discretionary trigger maybe be activated. In a low crisis frequency, the discretionary trigger is activated, whereas the capital ratio trigger is not activated. When the initial bank capital is high (A/D = 1.25), CoCos will not be triggered and crisis frequency and crisis size risk have little impact on CoCos, and CoCos will thus never be triggered. CoCos investors will receive the full coupon and par value of CoCos. If we raise the ratio of CoCos from w_1= 0.8 to w_1=1, though the new equity value of CoCos or the value when the discretionary trigger is activated will be higher, the bond value will be much lower.

4.3 Regulation uncertainty premiums: Size of CoCos, intensity of discretionary event, crisis frequency

We first estimate the case where the bank issues CoCos without discretionary trigger for alternative sets of size of CoCos, intensity of discretionary event, and crisis frequency. The values of CoCos without discretionary trigger minus the values of CoCos with discretionary trigger are the regulatory uncertainty premiums. We investigate the impact of the size of CoCos, intensity of discretionary event, crisis frequency on the regulatory uncertainty premiums in Figure 1 and Figure 2, respectively. For these two figures, we hold the total size of debt at 92 % of the asset value but allow its components of CoCos and deposits to vary.

Figure 1 shows that the regulatory uncertainty premium is positive, implying that CoCos without discretionary trigger has higher value than CoCos with discretionary trigger. Thus, the discretionary feature of CoCos will lead to higher funding costs and then increase banks' cost of capital because investors will likely demand additional risk premiums. Furthermore, observe that the regulatory uncertainty premium increases with the intensity of discretionary trigger. The higher the intensity of discretionary trigger leads to higher likelihood that the discretionary trigger is activated and thus increases write-down the face value of CoCos and the regulatory uncertainty premiums. However, the regulatory uncertainty premiums increase with the decrement of size of CoCos. This occurs because when the discretionary trigger is activated, the potential absorbing losses are too big for a small amount of CoCos, thus the effect of regulatory uncertainty on the price of CoCos is substantially larger. Figure 2 shows that, the regulatory uncertainty premiums decrease with the increment of crisis frequency. In a low-risk environment (λ_A=0.1), the bank's capital ratio usually exceeds the capital ratio trigger, whereas the discretionary trigger maybe be activated, hence, the effect of regulatory uncertainty on price of CoCos increases. In a high-risk environment (λ_A=0.5), the bank's capital risk rises the possibility that the capital ratio trigger is activated before the discretionary trigger, such that the regulatory uncertainty premiums decrease even disappear when the size of CoCos increases.

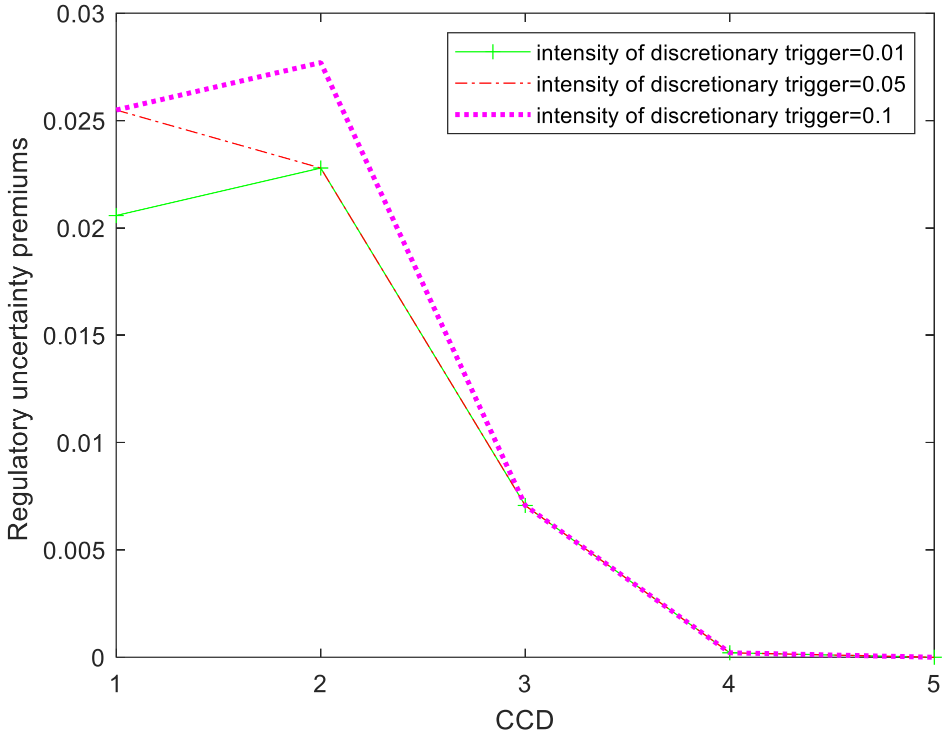


Figure 1: CoCos Size and Intensity of Discretionary Event on Regulatory Uncertainty Premiums. This figure exhibits regulatory uncertainty premiums under alternative combinations of CoCos size and intensity of discretionary event. All estimates are computed using 50,000 sample paths. The capital ratio trigger k is set at 5 %, the discretionary threshold d is at 10%, and other parameter values are specified in Table 1.

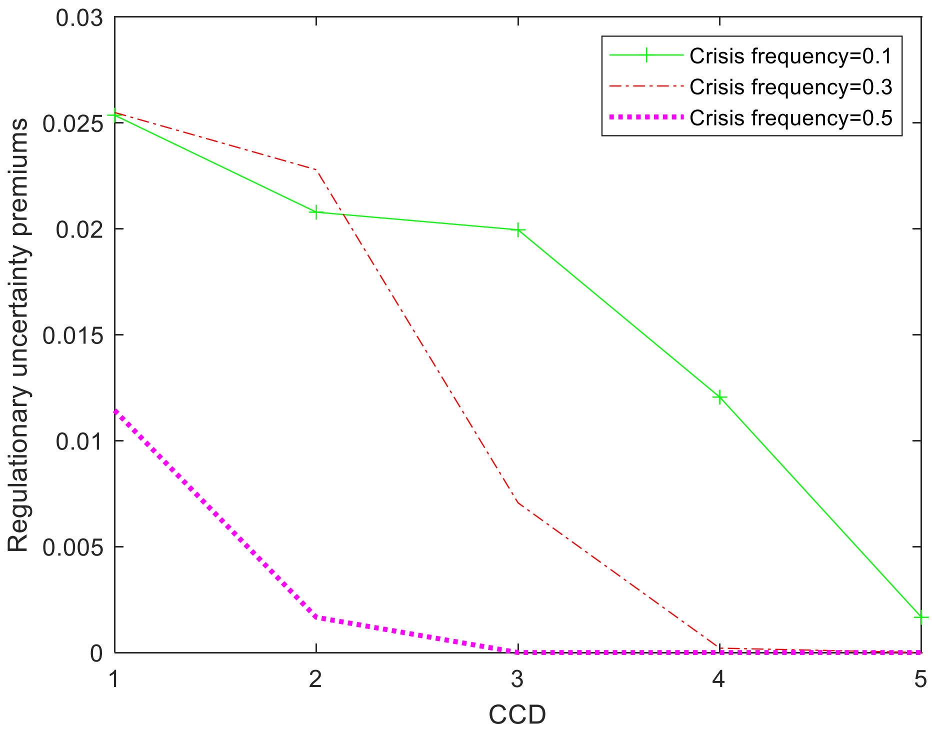
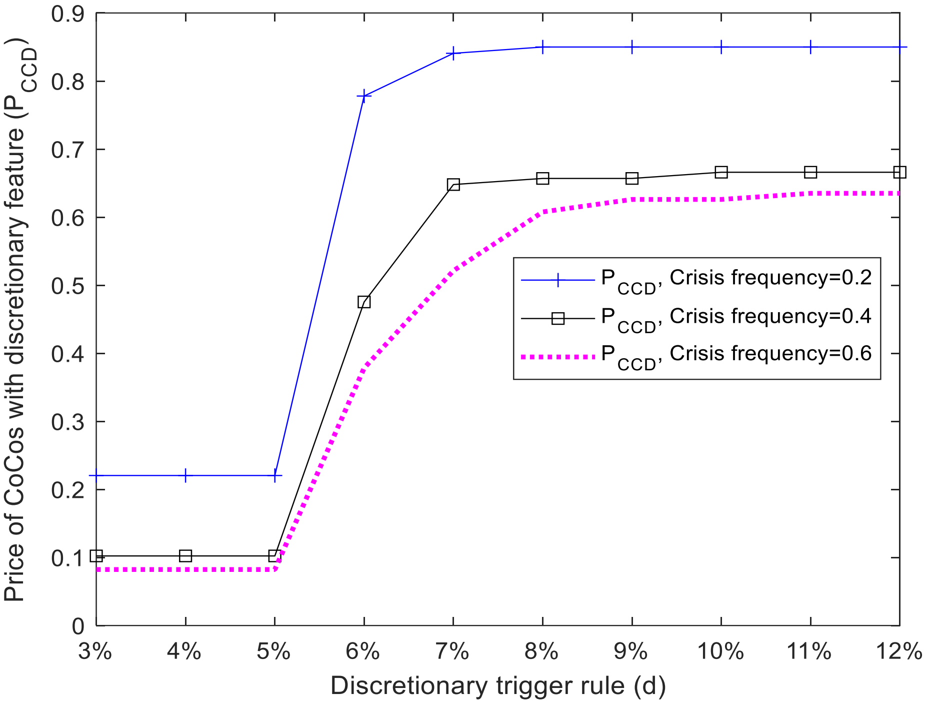


Figure 2: CoCos Size and Crisis Frequency on Regulatory Uncertainty Premiums. This figure exhibits regulatory uncertainty premiums under alternative combinations of CoCos size and crisis frequency. All estimates are computed using 50,000 sample paths. The capital ratio trigger k is set at 5 %, the discretionary threshold d is at 10%, and other parameter values are specified in Table 1.

4.4 Values of CoCos and regulation uncertainty premiums: Discretionary rule and crisis frequency

In Figure 3 and Figure 4, we find that a higher discretionary threshold d increases the value of CoCos and decreases the yields of CoCos. Generally speaking, when the discretionary threshold is lower than the capital ratio trigger (k=5 % here), capital ratio trigger is activated before the discretionary threshold - that is, a lower discretionary threshold will not affect the CoCos price (yield). When the discretionary threshold is higher than the capital ratio trigger, we find that a low-risk (λ_A=0.1) environment still has a high price (low yield spread) and a high-risk (λ_A= 0.5) environment still has a low price (high yield spread) of CoCos.

Furthermore, we find that a higher discretionary threshold (d) decreases the regulation uncertainty premiums shown in Figure 5. When the discretionary threshold is lower than the capital ratio trigger, the capital ratio trigger is activated such that regulation uncertainty premiums is insensitive to the discretionary threshold. However, when the discretionary threshold is higher than the capital ratio trigger, the discretionary trigger is activated such that a high-risk (λ_A=0.5) environment has higher regulation uncertainty premiums than a low-risk (λ_A= 0.1) environment. In other words, the price (yield spread) and risk relationship between CoCos and its issuing banks is linkage, and the price (yield spread) of CoCos with discretionary trigger can reflect the risk information of the banks.



Yield of CoCos with discretionary feature

Figure 3: CoCos Size and Crisis Frequency on Price of CoCos with Discretionary Feature. This figure exhibits price of CoCos with discretionary feature under alternative combinations of CoCos size and crisis frequency. All estimates are computed using 50,000 sample paths. The capital ratio trigger k is set at 5 %, and other parameter values are specified in Table 1.

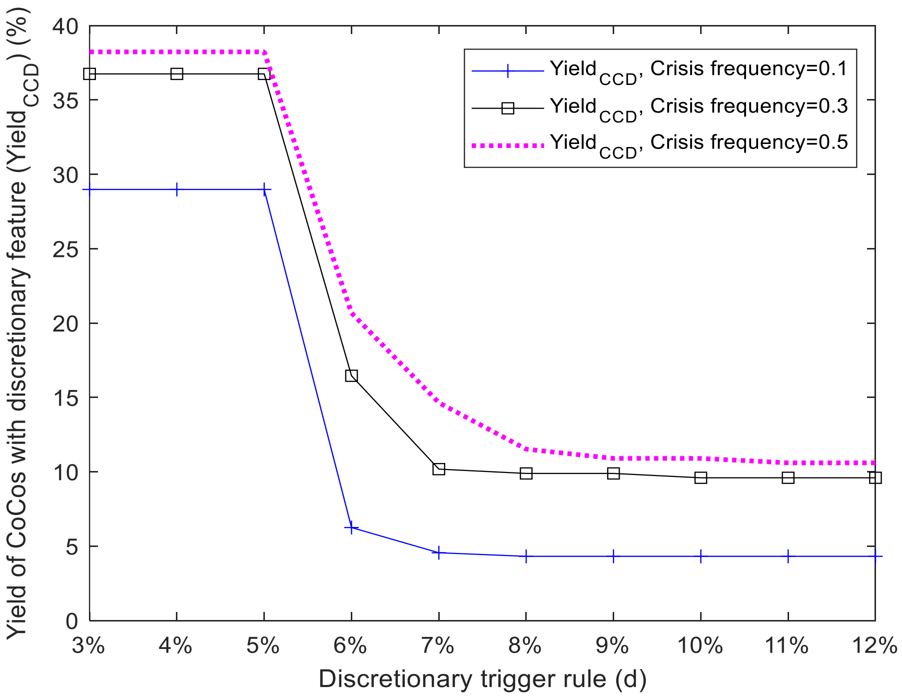


Figure 4: CoCos Size and Crisis Frequency on Yield Spread of CoCos with Discretionary Feature. This figure exhibits yield spread of CoCos with discretionary feature under alternative combinations of CoCos size and crisis frequency. All estimates are computed using 50,000 sample paths. The capital ratio trigger k is set at 5 %, and other parameter values are specified in Table 1.

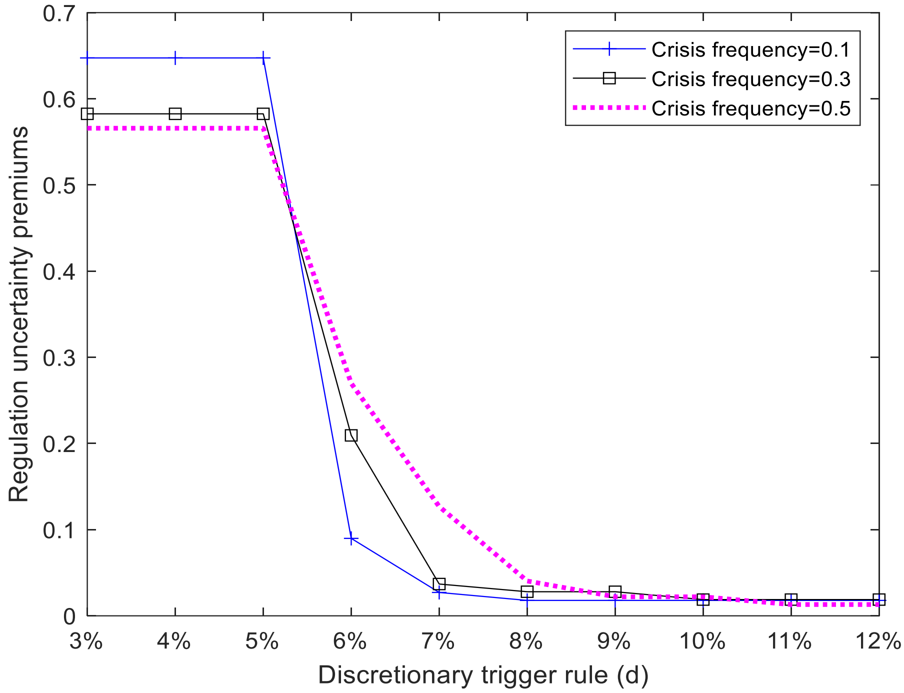


Figure 5: CoCos Size and Crisis Frequency on Yield Spread of CoCos with Discretionary Feature. This figure exhibits yield spread of CoCos with discretionary feature under alternative combinations of CoCos size and crisis frequency. All estimates are computed using 50,000 sample paths. The capital ratio trigger *k* is set at 5 %, and other parameter values are specified in Table 1.

4.5 Original shareholders' equity: Capital trigger and size of CoCos

We examine the impact of the capital ratio trigger and size of CoCos on the original shareholders' equity in Figure 6. Similar to the case of CoCos without discretionary trigger in Chang and Yu (2018), Figures 6 indicates that a capital trigger ratio of around 5 % to 6 % has the highest conversion value and lowest CoCos price to give the highest yield. Furthermore, we also show that the capital ratio trigger is a reverse U-shape function of the value of the original shareholders' equity, whereas the size of CoCos is a decreasing function of the original shareholders' equity. Since that increasing CoCos is regarded as raising new capital, raising new capital makes shifting wealth from original shareholders to creditors leads to the debt overhang and reduces the value of original shareholders' equity. Our result can provide the information to help the bank to determine its optimal size of CoCos and the corresponding capital ratio trigger.

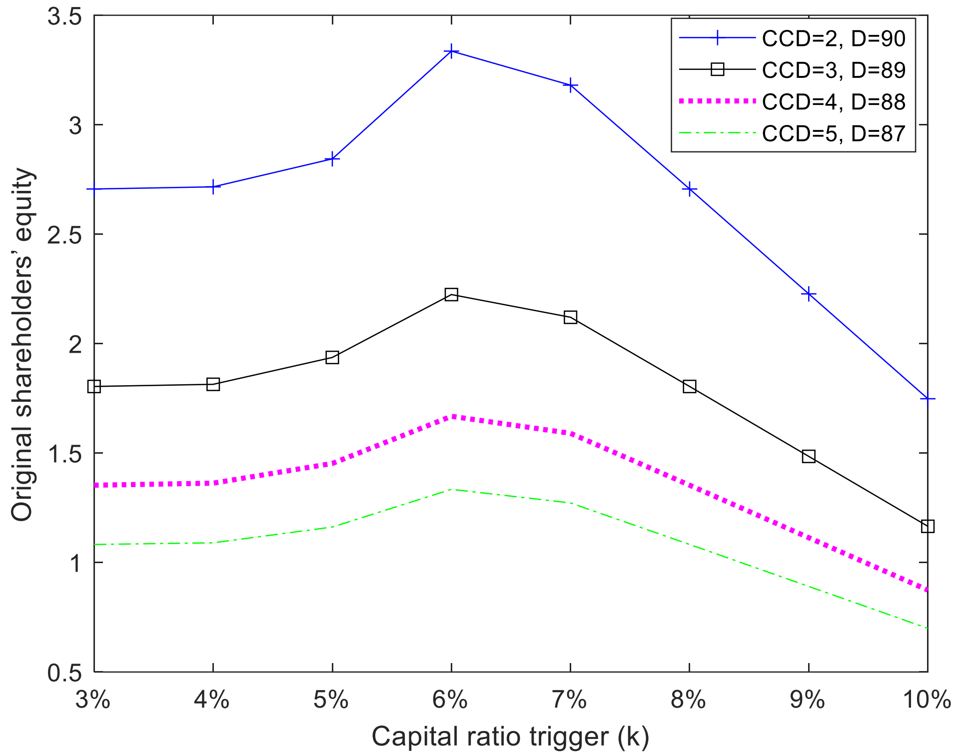


Figure 6: CoCos Size and Capital Ratio Trigger on Original Shareholders' Equity. This figure exhibits original shareholders' equity under alternative combinations of CoCos size and capital ratio trigger. All estimates are computed using 50,000 sample paths. The discretionary threshold *d* is at 10%, and other parameter values are specified in Table 1.

4.6 Change in probability of default (PD): size of CoCos and asset diffusion volatility

We further investigate the effect of discretionary feature of CoCos on the bank's PD. We calculate the change in PD of the bank according to Equation (6). Figure 7 shows that the change in PD varies with the size of CoCos and asset diffusion volatility. We find that the change in PDs decreases with the increment size of CoCos, and there will be little difference in PDs in large size of CoCos. Observe that when asset diffusion volatility is low (σ_A= 0.01), the change in PD is negative, indicating that the bank has lower PD issuing CoCos with discretionary trigger rather than CoCos without discretionary trigger in a low-risk environment. However, when asset diffusion volatility is high (σ_A= 0.09), the change in PD is positive, indicating that the bank has greater PD when issuing CoCos with discretionary trigger in a high-risk environment. This provides the information that although the raising new capital by issuing CoCos can helps to reduce the issuing bank's default risk, the discretionary feature of CoCos causes the regulatory uncertainty such that the bank's default risk is enlarged, especially in a high-risk environment.

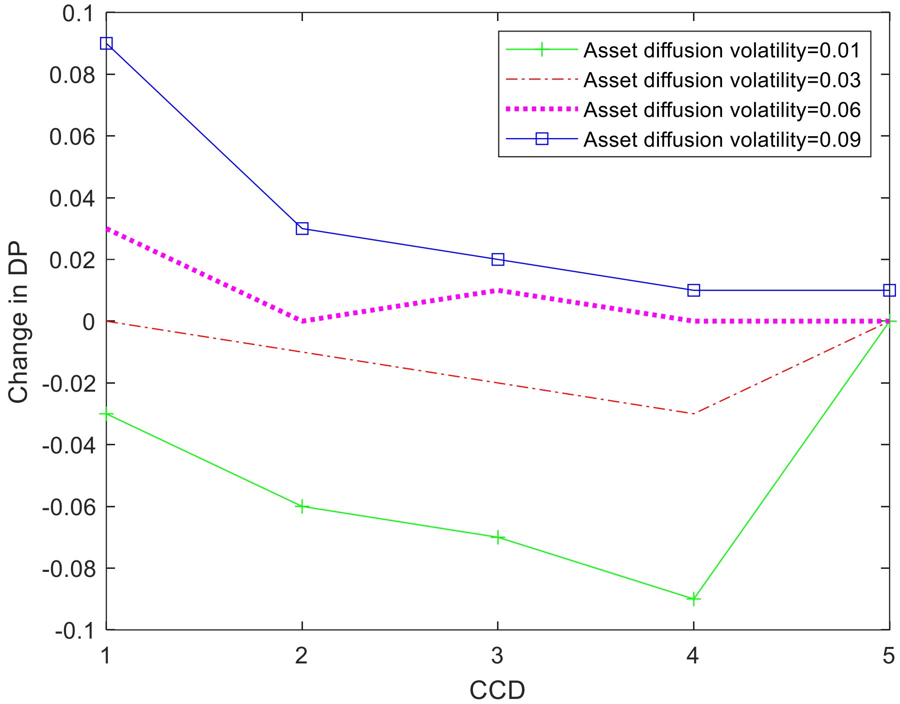


Figure 7: CoCos Size and Asset Diffusion Volatility on Change in DP. This figure exhibits original shareholders' equity under alternative combinations of CoCos size and capital ratio trigger. All estimates are computed using 50,000 sample paths. The capital ratio trigger *k* is set at 5 %, the discretionary threshold *d* is at 10%, and other parameter values are specified in Table 1.

5. Conclusions

Previous models of CoCos valuation have failed to investigate how do the discretionary feature influence the price of CoCos and the bank's default probability. Besides, how do their results differ from models that do not have a discretionary trigger. Our contribution to the literature is to model the discretionary event into a multi-period structural model for CoCos with discretionary feature. Our dynamic model has a fixed default barrier and an additional discretionary threshold rule at specific discrete time points.

Based on the model that incorporates the stochastic interest rate, the crisis event of bank's asset and whereby defaults can happen at any point in time, our simulation findings indicate that whether capital structure risk, crisis frequency, or crisis size risk, they all have a greater impact on the prices of CoCos with discretionary trigger than they do on CoCos without discretionary triggers. The values of CoCos without discretionary triggers minus the values of CoCos with discretionary triggers are the regulatory uncertainty premiums. As expected, the regulatory uncertainty premium increases with the intensity of the discretionary trigger. A higher discretionary threshold increases the price of CoCos and decreases the yields of CoCos and the regulation uncertainty premiums. When the discretionary trigger is higher than the capital ratio trigger, a high-risk environment has higher regulation uncertainty premiums than a low-risk environment. In other words, the price (yield spread) and risk relationship between CoCos and its issuing banks is linkage. Therefore, our model provides an interesting policy implication that the yield spreads of CoCos with discretionary feature are a better measure for bank's risk than those of CoCos without discretionary feature, because the price (yield spread) information of CoCos with discretionary feature is more sensitive to the issuing bank's risk.

The size of CoCos increases the price of CoCos, but decreases the original shareholders' equity. The relationship between CoCos price, original shareholders' equity, the size of CoCos, and capital ratio trigger are consistent with Chang and Yu (2018), which can help the bank to determine its optimal size of CoCos and its corresponding capital ratio trigger. Furthermore, when the bank issues CoCos with discretionary trigger rather than CoCos without discretionary trigger, the issuing bank may increase the default probability in a high-risk environment. This provides the information that although the raising new capital by issuing CoCos can helps to reduce the issuing bank's default risk, the discretionary feature of CoCos causes the regulatory uncertainty such that the bank's default risk is enlarged, especially in a high-risk environment.

Table 1: Parameter Definition and Base Values

Asset parameters		**Values**
$A(0)$	Bank's assets	100
φ_A	Interest rate elasticity of assets	-1
σ_A	Volatility of bank's assets	2%
λ_A	Crisis frequency	0.3
μ_y	Mean of jump size	-1%
σ_y	Standard deviation of jump size	2%
Deposit parameters		
$D(0)$	Bank's deposits	
g	Growth rate	5%
Interest rate parameters		
$r(0)$	Initial instantaneous interest rate	3.5%
η	Magnitude of mean-reverting force	11.4%
γ	Long-run mean of interest rate	6.9%
σ_v	Volatility of interest rate	7%
CoCos (or SD) parameters		
T	Maturity	5 years
c	Coupon rate	4.23%
k	Capital ratio trigger	5%
d	Discretionary trigger	10%
R	Regulatory capital threshold	8%
LR	Leverage ratio threshold	4.5%
a_0	Constant value for the intensity of discretionary trigger	5%
a_1	The sensitivity to the intensity of discretionary trigger when the capital ratio is lower than R	5%
a_2	The sensitivity to the intensity of discretionary trigger when the leverage ratio is lower than LR	5%
α	The remaining ratio of CoCos write down	50%
Other parameters		
$D(0)/A(0)$	The ratio of initial deposit value to assets	89%
$CCD/A(0)$ Or $SD/A(0)$	The ratio of face value of CoCos or subordinated debt to assets	3% (w_1=1) 3% (w_1=0)
$E(0)/A(0)$	Initial shareholders' equity ratio	8%

Table 2: Prices of Subordinated Debt and Contingent Convertible Bonds

(λ_A, δ)	SD ($w_1 = 0$)			CoCos without discretionary trigger ($w_1 = 1$)			CoCos with discretionary trigger ($w_1 = 1$)		
	σ_A			σ_A			σ_A		
	1.5%	2%	2.5%	1.5%	2%	2.5%	1.5%	2%	2.5%
$A/D = 1.11$									
(0.1, 0.01)	1.003	1.003	1.003	0.444	0.444	0.444	0.430	0.430	0.430
(0.1, 0.03)	1.003	1.003	1.003	0.444	0.444	0.444	0.430	0.430	0.430
(0.1,0.05)	1.003	1.003	1.003	0.444	0.444	0.444	0.430	0.430	0.430
(0.3, 0.01)	0.988	0.988	0.988	0.449	0.449	0.449	0.448	0.426	0.426
(0.3, 0.03)	0.988	0.988	0.988	0.449	0.449	0.449	0.448	0.426	0.426
(0.3,0.05)	0.988	0.988	0.988	0.449	0.449	0.449	0.448	0.426	0.426
(0.5, 0.01)	0.988	0.988	0.988	0.442	0.442	0.442	0.420	0.420	0.420
(0.5, 0.03)	0.988	0.988	0.988	0.442	0.442	0.442	0.420	0.420	0.420
(0.5,0.05)	0.988	0.988	0.987	0.442	0.442	0.442	0.420	0.420	0.420
$A/D = 1.15$									
(0.1, 0.01)	1.003	1.003	1.003	1.003	1.003	1.003	0.990	0.990	0.989
(0.1, 0.03)	1.003	1.003	1.003	0.993	0.993	0.993	0.983	0.981	0.971
(0.1,0.05)	1.003	1.003	1.003	0.993	0.993	0.993	0.971	0.968	0.946
(0.3, 0.01)	1.003	1.003	1.003	0.529	0.529	0.529	0.508	0.481	0.462
(0.3, 0.03)	1.003	1.003	1.003	0.529	0.529	0.529	0.496	0.479	0.459
(0.3,0.05)	1.003	1.003	1.003	0.518	0.518	0.518	0.473	0.458	0.449
(0.5, 0.01)	0.990	0.990	0.990	0.450	0.450	0.450	0.430	0.430	0.430
(0.5, 0.03)	0.990	0.990	0.990	0.450	0.450	0.450	0.420	0.420	0.420
(0.5,0.05)	0.990	0.990	0.990	0.450	0.450	0.450	0.420	0.420	0.420
$A/D = 1.25$									
(0.1, 0.01)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.1, 0.03)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.1,0.05)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.3, 0.01)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.3, 0.03)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.3,0.05)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.5, 0.01)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.5, 0.03)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
(0.5,0.05)	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003

This table reports the prices of SD and CoCos (with single or dual triggers) under alternative combinations of volatility in a bank's assets (σ_A), volatility of jump size (δ), crisis frequency (λ_A), and initial asset-liability structure (*A/D*). The prices of SD and CoCos are presented as a percentage of their par values. All estimates are computed using 50,000 sample paths. The capital ratio trigger k is set at 5%, the discretionary trigger d is set at 10%, and other parameter values are specified in Table 2.

Table 3: Decomposition of Mixed SD and CoCos Price

(λ_A, δ)	CoCos ($w_1 = 1$)				Mixed SD and CoCos ($w_1 = 0.8$)			
	Bond Value	Discretionary Value	Equity Value	Total Value	Bond Value	Discretionary Value	Equity Value	Total Value
$A/D = 1.11$								
(0.1, 0.01)	0.138	0.000	0.292	0.430	0.594	0.000	0.109	0.703
(0.1, 0.03)	0.138	0.000	0.292	0.430	0.592	0.000	0.111	0.703
(0.1,0.05)	0.138	0.000	0.292	0.430	0.592	0.000	0.111	0.703
(0.3, 0.01)	0.000	0.000	0.426	0.426	0.351	0.000	0.189	0.540
(0.3, 0.03)	0.000	0.000	0.426	0.426	0.351	0.000	0.189	0.540
(0.3,0.05)	0.000	0.000	0.426	0.426	0.351	0.000	0.189	0.540
(0.5, 0.01)	0.000	0.000	0.420	0.420	0.243	0.000	0.204	0.447
(0.5, 0.03)	0.000	0.000	0.420	0.420	0.243	0.000	0.204	0.447
(0.5,0.05)	0.000	0.000	0.420	0.420	0.242	0.000	0.205	0.447
$A/D = 1.15$								
(0.1, 0.01)	0.941	0.049	0.000	0.990	0.999	0.005	0.000	1.003
(0.1, 0.03)	0.932	0.049	0.000	0.981	0.999	0.005	0.000	1.003
(0.1,0.05)	0.919	0.049	0.000	0.968	0.993	0.005	0.000	0.998
(0.3, 0.01)	0.119	0.010	0.352	0.481	0.949	0.005	0.004	0.958
(0.3, 0.03)	0.078	0.010	0.391	0.479	0.897	0.005	0.004	0.906
(0.3,0.05)	0.036	0.000	0.422	0.458	0.872	0.000	0.004	0.876
(0.5, 0.01)	0.041	0.000	0.389	0.430	0.638	0.000	0.115	0.753
(0.5, 0.03)	0.011	0.000	0.409	0.420	0.638	0.000	0.115	0.753
(0.5,0.05)	0.006	0.000	0.414	0.420	0.630	0.000	0.115	0.745
$A/D = 1.25$								
(0.1, 0.01)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.1, 0.03)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.1,0.05)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.3, 0.01)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.3, 0.03)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.3,0.05)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.5, 0.01)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.5, 0.03)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003
(0.5,0.05)	1.003	0.000	0.000	1.003	1.003	0.000	0.000	1.003

This table reports the prices of CoCos and a mixture of CoCos and SD under alternative combinations of crisis frequency (λ_A) and initial asset-liability structure (*A/D*). Prices of CoCos are presented as a percentage of their par values. All estimates are computed using 50,000 sample paths. The capital ratio trigger k is set at 5%, the discretionary trigger *d* is set at 10%, and other parameter values are specified in Table 2.

References

1. Adrian, T., and Shin, H. S. (2010). Liquidity and leverage. *Journal of Financial Intermediation*, 20, 418-437.
2. Albul, B., Jaffee, D. M., and Tchistyi, A. (2010). Contingent convertible bonds and capital structure decisions, Working Paper.
3. Avdjiev, S., Bogdanova, B., Bolton, P., Jiang, W. and Kartasheva, A. (2020). CoCo issuance and bank fragility. *Journal of Financial Economics*, 138(3), 593–613.
4. Bolton, P., Jiang, W., Kartasheva, A. (2023). The Credit Suisse CoCo wipeout: Facts, misperceptions, and lessons for financial regulation. *Journal of Applied Corporate Finance*, 35, 66-74.
5. Brigo, Damiano, João Garcia, and Nicola Pede. (2015). Coco bonds pricing with credit and equity calibrated first-passage firm value models. *International Journal of Theoretical and Applied Finance*, 18, 1550015.
6. Chang, C. C., and Yu, M. T. (2018). Bank contingent capital: Valuation and the role of market discipline. *Journal of Financial Services Research*, 54, 49-80.
7. Chen, N., P. Glasserman, B. Nouri, and M. Pelger, 2017, Contingent Capital, Tail Risk, and Debt-Induced Collapse. *Review of Financial Studies,* 30, 3921–3969.
8. Cheridito, P., and Xu, Z. (2015). A reduced-form contingent convertible bond model with deterministic conversion intensity. *Journal of Risk*,17, 18.
9. Chung, T.-K., and Kwok, Y.-K. (2016). Enhanced equity-credit modeling for contingent convertibles. *Quantitative Finance*,16, 1511-1527.
10. Corcuera, J. M., de Spiegeleer, J., Fajardo, J., Jönsson, H., Schoutens, W., and Valdivia, A. (2014). Close form pricing formulas for coupon cancellable CoCos. *Journal of Banking and Finance*, 42, 339-351.
11. Cox, J., Ingersoll, J., and Ross, S. (1985). The term structure of interest rates. *Econometrica* 53, 363-384.
12. De Spiegeleer, J., W. Schoutens. (2012a). Pricing Contingent Convertibles: A Derivatives Approach. *Journal of Derivatives*, 20, 27-36.
13. Duan, J.-C., and Yu, M.-T. (1994). Forbearance and pricing deposit insurance in a multiperiod framework, stochastic interest rate and catastrophe risk. *Journal of Risk and Insurance*, 61, 575-591.
14. Duan, J.-C., and Yu, M.-T. (2005). Fair insurance guaranty premia in the presence of risk-based capital regulations, stochastic interest rate and catastrophe risk. *Journal of Banking*

and Finance, 29, 2435-2454.

15. Flannery, M. J. (2014). Contingent capital instruments for large financial institutions: A review of the literature. *Annual Review of Financial Economics.* 6, 225-240.
16. Flannery, M., and Rangan, K. (2008). What caused the bank capital build-up of the 1990s?, *Review of Finance*, 12, 391-429.
17. French, K., M. Bailey, J. Campbell, J. Cochrane, D. Diamond, D. Duffie, A. Kashyap, F. Mishkin, R. Rajan, D. Scharfstein, and others, 2010, The squam lake report: Fixing the financial system. *Journal of Applied Corporate Finance*, 22, 8-21.
18. Glasserman, P., and Nouri, B. (2012). Contingent capital with a capital-ratio trigger, *Management Science*, 58, 1816-1833.
19. Javadi, S., Li, W., and Nejadmalayeri, A. (2023) Contingent capital conversion under dual asset and equity jump–diffusions. *International Review of Financial Analysis*, 89, 102798.
20. Kund, A.-G. and Petras, M. (2023). Can CoCo-bonds mitigate systemic risk?. *International Review of Financial Analysis*, 89, 102686.
21. Leung, C. M., and Kwok, Y. K. (2015). Numerical pricing of CoCo bonds with Parisian trigger feature using the Fortet method. Working paper, Hong Kong Baptist University.
22. McDonald, R. (2013). Contingent capital with a dual price trigger. *Journal of Financial Stability,* 9, 230-241.
23. Memmel, C. and P. Raupach, 2010, How do banks adjust their capital ratios? *Journal of Financial Intermediation* 19, 509-528.
24. Mendes, L. dos S., Leite, R. de O., and Fajardo, J. (2022). Do contingent convertible bonds reduce systemic risk? *Journal of International Financial Markets, Institutions and Money*, 78, 101554.
25. Merton, R. (1974). On the pricing of corporate debt: The risk structure of interest rates. *Journal of Finance,* 29, 449-470.
26. Pennacchi, G., 2011, A Structural Model of Contingent Bank Capital, Working Paper.
27. Pennacchi, G., and Tchistyi, A. (2019a). On equilibrium when contingent capital has a market trigger: A correction to Sundaresan and Wang Journal of Finance (2015). *Journal of Finance*, 74, 1559-1576.
28. Pennacchi, G., and Tchistyi, A. (2019b). Contingent convertibles with stock price triggers: The case of perpetuities. *Review of Financial Studies*, 32, 2302-2340.
29. Pennacchi, G., Vermaelen, T., and Wolff C. (2014). Contingent capital: The case of COERCs, *Journal of Financial and Quantitative Analysis*, 49, 541-574.
30. Sundaresan, S., and Wang, Z. (2015). On the design of contingent capital with a market

trigger. *Journal of Finance*, 70, 881-920.

31. Vasicek, O. A. (1977). An equilibrium characterization of the term structure. *Journal of Financial Economics*, 5, 177-188.
32. Von Furstenberg, G. M. (2011). Contingent capital to strengthen the safety net for financial institutions: Cocos to the rescue? Paper 01/2011, Deutsche Bundesbank, Frankfurt am Main, Germany.
33. Wilkens, S., and Bethke, N. (2014). Contingent convertible bonds: A first empirical assessment of selected pricing models. *Financial Analysts Journal*, 70, 59-77.
34. Yang, Z., and Zhao, Z. (2015). Valuation and analysis of contingent convertible securities with jump risk. *International Review of Financial Analysis*, 41, 124-135.