EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

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Contingent convertible debt: what is and what should have been

No 3170

Abstract:

This paper develops a model of AT1 CoCos and corporate securities analysing the role of CoCos as replacements of Equity or of Debt. Our results show that, in terms of value creation, CoCos perform better when they replace vanilla corporate debt rather than when they replace common Equity. Moreover, we show as well that although debt increases the probability of bankruptcy, given the coupon suspension possibility, with CoCos the probability of financial distress is higher. Our paper also highlights the considerable complexity of this instrument, something at odds with its role as a potential solution to a financial crisis in part triggered by less complex securities.

JEL Codes: K22, G01, G13, G21, G33

Keywords: CoCo debt, AT1 Capital, Regulatory Uncertainty, Complex Securities.

Non-Technical Summary

CoCos emerged in the aftermath of the 2008 financial crisis as a response to the need for greater financial stability and resilience in the banking sector. The logic behind CoCos is to improve the loss-absorbing capacity of banks without requiring immediate equity issuance. By converting into equity in times of distress, CoCos help to maintain a bank's capital adequacy.

We develop a model that comprises a government and banks in which the government must keep banks operating even if private shareholders decide to abandon the bank. Private shareholders maximize their wealth, do not bear any social responsibilities and are free to abandon the banking business when it is no longer profitable for them.

In turn, the government is a welfare-maximizing agent which take care of the bank when shareholders abandon it due to the bank lack of profitability. Before assuming control of a bank, the government assumes a passive role merely enforcing a symmetrical tax system.

We have carried out some sensitivity analysis and numerical simulations under different scenarios for valuing the different claims used in this paper: equity, debt and CoCo claims. If we sum up the aggregate value of the three claims, the best alternative is equity because it prevents distress and default.

The interesting thing is that the CoCo is better than debt. The reason behind it is simple: even there is more distress with the CoCo, the fact that it is converted in equity to avoid default makes the default less likely and, therefore, increases the value of the bank. A different story is if we include the value for the government. In this case on the one hand, we have the bankruptcy cost and in the other hand we have the financial distress cost.

However, in good times, the equity holders prefer debt, afterwards CoCos and in the last position equity. Since the shareholders are the ones who decide what to issue, in good times they would prefer to issue debt. Nevertheless, if debt is not possible due to solvency regulation, they prefer to issue CoCos because in good times CoCo claims behave like debt.

Due to the increase in financial distress, the worse value for the government is in the scenario with CoCos. In good times the government prefers equity because it delays the abandonment. In bad times it prefers debt.

These results show the role of CoCos in a context where recapitalization becomes difficult. In these cases, the CoCos play their role. Nonetheless, we contrast the application of CoCos as a potential replacement of equity and of debt and we find that CoCos perform better when replacing debt. When CoCos replaces equity, the complexity increases, and it can create regulatory uncertainty.

CoCos have gained increased popularity due to various factors such as (i) need to recapitalize banks; and (ii) the difficulty and cost of increasing capital and (iii) preventing future government interventions such as bailouts. However, our results also highlight the significant complexity of this instrument, something at odds with its role as a potential solution to a financial crisis in part triggered by less complex securities. It is possible that AT1 CoCos were the most appropriate instrument in the context they appeared, nonetheless our results seem to indicate that Tier 2 CoCos have superior performance.

1. Introduction

The emergence of Contingent Convertible Debt (CoCos) is intrinsically linked to the 2007-09 financial crisis and specifically to the difficulties of raising bank capital. CoCos are unique in the sense that they represent an innovative corporate security promoted by both regulators (Basel III and Dodd Frank Act[2]) and by some of the most reputed academics in the field of Financial Economics (Baily et al., 2013). Although its origins can be traced back to Flannery (2002, 2009) and Kashyap et al. (2008), it was not until the financial crisis of 2007-09 that this instrument was seriously considered as presenting real advantages in a bank resolution. In simple terms, CoCos represent debt instruments that are converted into equity (or written down) according to a mechanical trigger (e.g. Regulatory Capital falls below a pre-determined level). The logic behind CoCos is to enhance the loss-absorbing capacity of banks without requiring immediate equity issuance or a public bailout. By incorporating an automatic conversion of debt into equity, CoCos also bypass the well-known coordination problems associated with bankruptcies (Hart, 1995).

Contingent Convertible bonds (CoCos) have gained prominence due to several key factors: (i) the imperative to recapitalize banks post-financial crisis, (ii) the high costs and challenges associated with traditional capital increases, and (iii) the objective of avoiding future government bailouts.

(i). Regulators including the ECB and the Federal Reserve (2009), as well as institutions like the IMF (2010), emphasized the necessity for recapitalization during the 2007-2009 crisis.

(ii). Recapitalization entails significant financial and reputational costs and difficulties, which Oster (2020) identifies as major drivers behind CoCos' development and adoption. Capital adequacy may be achieved via equity issuance, capital retention, or asset liquidation (Hori and Cerón, 2016), all of which impose substantial burdens on existing shareholders, especially amid crisis conditions and debt overhang (Veronesi and Zingales, 2010). Given these constraints, banks faced a binary choice: endure these costs or innovate structurally. The post-crisis period intensified negative market reactions to equity issuance (Botta and Colombo, 2019), thereby prompting innovative solutions such as CoCos and the return of scrip dividends as indirect equity financing mechanisms with fewer reputational drawbacks (Blanco-Alcántara et al., 2022).

(iii). Government bailouts carry significant societal and political costs, often provoking strong political backlash (Hardt and Negri, 2011; Culpepper et al., 2024), are fiscally burdensome, and frequently transfer bank risk to sovereign risk (Cuadros-Solas et al., 2021). The most credible method to reduce moral hazard in banking is to ensure robust capital adequacy, including CoCo issuance, enabling banks to absorb losses and reducing the likelihood of future government interventions (Cordella and Yeyati, 2003; Farhi and Tirole, 2012).

In its beginnings, CoCo debt represented a simple mechanically convertible bond, but there was no effective standard for the security. Not surprisingly, early research focused on different aspects of CoCo design such as their Impact on capital structure decisions, including but not limited to banking institutions, (Albul et al., 2010, Barucci and Del Viva, 2013), on the role alternative conversion

[2] Banking regulation released by the Basel Committee on Banking Supervision in 2010 and translated into EU law via the Capital Requirements Directive IV (CRD IV) and the Capital Requirements Regulation (CRR), which classified Additional Tier 1 (AT1) contingent capital as part of a bank's core capital from 2013/2014 onward. With respect to the US, although the Dodd Frank Act authorized the Federal Reserve to require bank and non-financial holding companies to maintain a minimum amount of contingent capital convertible to equity in times of financial stress, the U.S. Financial Stability Oversight Council reported in 2012 that regulators would not require or include CoCo bonds as regulatory capital for U.S. banks. The US regulatory approach was to let CoCos remain a private sector innovation instead of a mandated capital instrument, as a result, no US bank has ever issued CoCos as AT1, opting to issue preferred shares instead (Wang, 2023).

triggers, including market triggers (Flannery, 2009, McDonald, 2013, Davis et al., 2014, Sundaresan and Wang, 2015) and even exploring more exotic characteristics such as reverse convertible features with pre-specified exercise prices (Bolton and Samama, 2012, Pennacchi et al., 2014). Following Basel III, regulators effectively set a standard for CoCos (Oster, 2020). Emerging from Basel III, we have two different types of CoCos. The first type is defined as an AT1 CoCo, a complex instrument allowed to fill in for Equity Capital3 in Tier 1 and play a going concern role, whereby its exercise aims at preventing a bank resolution. The second type is a Tier 2 CoCo (T2), a more standard contract, and while they incorporate mechanical triggers to force a conversion or a write down, they are similar to a standard vanilla bond with fixed maturities and standard coupons. Tier 2 CoCos are gone concern capital and conversion or write down occurs when the regulator issues a "Failing or Likely to Fail" (FOLTF) declaration. Before Basel III came into force (2013), the market was equally divided between AT1 and T2 CoCos (EUR and USD), in just five years AT1 CoCos dominated the market with more than 90% of the EUR denominated CoCos and more than 80% of the USD denominated CoCos (Godec, 2018). CoCos effectively became Banking Financing instruments mainly used as an alternative to Equity.

Not surprisingly, once a standard was defined, given the complexity of the AT1 CoCos two strands of research developed addressing (i) pricing (Teneberg, 2012, Jung, 2012, Brigo et al., 2013, Wilkens and Bethke, 2014, Cheridito and Xu, 2015) and (ii) financial stability issues (Glasserman and Young, 2015, Gupta et al., 2021, Kremer and Tinel, 2022, Calice et al., 2023, Le Quang, 2024).

CoCos had a stable run until the resolutions of Banco Popular de España (BPE), in 2017, and Credit Suisse (CS), in 2023. These represented the first real tests of AT1 CoCos in terms of their ability to absorb losses, acting as true bail-in instruments, and in terms of their going concern nature. CoCos functioned as intended in terms of loss absorption, both resolutions had zero cost to taxpayers and there was with no immediate market backlash beyond anticipated litigation by investors (CJEU, 2025). However, both the BPE and CS cases highlighted significant concerns regarding CoCos' actual performance. Notably, these instruments did not perform as true going-concern securities. Conversion and the write-down triggered only at the point of resolution rather than preemptively preventing resolution, thereby challenging a fundamental theoretical premise of AT1 CoCos. This issue has generated sustained academic debate, with recent literature increasingly questioning the efficacy of CoCos in their going-concern role (Wu, 2018; Fiordelisi et al., 2020).

Recent research increasingly concludes that contingent convertible bonds (CoCos) have not fulfilled their purpose as going-concern instruments, calling for a fundamental redesign of their structure. Early CoCo issues already favored equity-friendly mechanisms such as principal write-downs while avoiding mandatory conversions that could dilute shareholders, weakening their stabilizing intent (Admati et al., 2012). Despite their classification as AT1 capital, most CoCos operate as gone-concern instruments. Glasserman and Perotti (2017) show that low-trigger AT1 CoCos rarely convert before a bank becomes non-viable, while accounting delays and regulatory discretion further limit the effectiveness of higher triggers. Empirical evidence confirms that most issuances now convert only at the point of non-viability (Wu, 2018). This design failure has also produced market confusion and even sophisticated investors often misinterpret the distinction between going- and gone-concern CoCos (Bolton et al., 2023). Given these persistent flaws, research increasingly argues that CoCos represent a failed experiment in contingent capital and that their conceptual foundation should be reconsidered (Choi and Zhang, 2024).

[3] To be allowed to classify as Tier 1 capital, AT1 CoCos need to present several characteristics of equity such as be perpetual, allow for coupon suspension and have lower priority than subordinated debt.

This paper aims to contribute to this ongoing discussion, by revisiting the capital structure fundamentals of CoCos (Albul et al., 2010) while remaining agnostic with respect to the regulatory classification of AT1 (going concern) and T2 (gone concern) and preserving the convertible features. Based on Dubiel-Teleszynski et al. (2019) and Correia et al. (2019), we develop a model of Equity, Corporate Debt and CoCo debt incorporating the main features of a current standard regulatory CoCo (perpetual, allow for coupon suspension, junior to corporate debt and convertible into equity through a mechanical trigger). Basically, we revisit Albul et al. (2010) capital structure analysis with the current CoCo standard and assess if, in their current form, CoCos may still deliver on their promises.

Our main results, derived in numerical simulation, show that the marginal improvement of the CoCos in terms of Bank value is positive when they replace corporate debt, but it is negative when CoCos replace Common Equity. It is interesting to observe that senior corporate debt always benefits from CoCo issuance, but equity only benefits in good times, because of harsh conversion conditions. For the government, CoCos represent the worst bank financing solution due to the tax treatment of CoCo coupons and their potential to trigger financial distress.

In the Section 2 we have presented some concepts related to Basel III capital requirement. Section 3 develops our benchmark and the CoCo models and Section 4 presents a Static Analysis of the models. Section 5 analyses the role of CoCo as replacements of Equity and of Corporate Debt, whereas in Section 6 there is a discussion about the main implications of our results. Finally, Section 7 concludes.

2. Definition of capital in Basel III

Responding to the financial crisis, the Basel Committee on Banking Supervision (BCBS) developed Basel III. This regulation requires improved quality and quantity of capital (BCBS, 2011).

Following BCBS (2019), we can say that Basel III asks for high-quality regulatory capital that can absorb losses. Among the new features of Basel III is the specific classification criteria for the components of regulatory capital. Moreover, an explicit going- and gone-concern framework by clarifying the roles of Tier 1 capital (going concern) and Tier 2 capital (gone concern) is included in Basel III.

Since it absorbs losses when they occur, Common Equity Tier 1 capital (CET1) is the highest quality of regulatory capital. Although additional Tier 1 capital (AT1) instruments do not meet all the criteria for CET1, it also has loss absorption capacity on a going-concern basis. Contrary, Tier 2 capital is gone-concern capital because when a bank fails it must absorb losses before depositors and general creditors. That is the reason why the criteria for Tier 2 inclusion are less strict than for AT1. For example, instruments with a maturity date are eligible for Tier 2, while only perpetual instruments are eligible for AT1.

The sum of these two elements, Tier 1 capital (comprising CET1 and AT1) and Tier 2 capital, represent total available regulatory capital. Capital instruments are required to meet different criteria to the included the respective category. Moreover, Basel III requires banks to keep concrete minimum levels of CET1, Tier 1 and total capital. These minimum levels are set as a percentage of risk-weighted assets (RWA).

In this respect, CET1 is defined as the sum of common stocks, retained earnings, other comprehensive income and qualifying minority interest. AT1 comprises instruments meeting the criteria for AT1 and additional qualifying minority interest. Finally, Tier 2 is the sum of capital instruments meeting the criteria for Tier 2, additional qualifying minority interest and qualifying loan loss provisions.

Finally, Basel II stablishes that CET1 must be higher than 4,5% of RWA, whereas the sum of CET1 and AT1 (that is, Tier 1 capital) must be higher than 6%. Lastly, total capital must be higher than 8%.

3. The model

Our model comprises a government and banks in which the government is committed to keeping banks operating even if private shareholders decide to abandon the bank. Therefore, we model banks operated by private shareholders and banks operated by the government following the abandonment of the private shareholders.

Private shareholders follow a strict wealth maximization objective, do not bear any social responsibilities and are free to abandon the banking business when it is no longer profitable. That is, private shareholders operate the bank and collect dividends if the income is higher than the sum of operating costs and debt coupon payment. However, if the income is lower, shareholders are forced to make the necessary cash injections to avoid defaulting. Therefore, if the income is consistently very low and shareholders are forced to make cash injections regularly, due to a wealth maximization objective, shareholders may want to abandon the bank, even if they lose the capital.

In turn, the government is a welfare-maximizing agent and, therefore, it is assumed that it is forced to take control of the bank when the total income of the bank drops below a given threshold that reflects the abandonment trigger of the private shareholders. In this case, the government takes control of the bank in order to protect depositors and avoid a bank bankruptcy which could affect the system as a whole. Before assuming control of a bank, the government assumes a passive role merely enforcing a symmetrical tax system in which banks pay a rate τ.

Our model assumes full symmetry of information in which the government, private shareholders and the different creditors of the bank possess all relevant information and rationally anticipate each other's actions.

Consider a bank with uncertain total income, x, and operational costs, c_o, both following geometric Brownian motion (*gBm*), that is,

$$dx = \mu x dt + \sigma x dz \quad (1)$$

and

$$dc_o = \mu c_o dt + \sigma c_o dz, \quad (2)$$

where μ is the instantaneous growth rate, σ is the standard deviation, and dz is the increment of a standard Wiener process under the real-world measure $\mathbb{P}$. For the sake of coherence – as otherwise, their values can differ significantly in the long term – we assume that total income, x, and cost, c_o, both follow the exact same *gBm* process (same μ, σ and dz). Furthermore, it is also assumed that

$\mu < r$, with r being the constant and known return on a riskless asset, allowing us to obtain finite solutions.

Following Thijssen (2010), consider the existence of an appropriate exogenous factor Λ_t to discount x and, assume that Λ_t also follows *gBm*, that is, $d\Lambda_t = r\Lambda_t dt + \sigma_\Lambda \Lambda_t dz$ in which the drift term r represents the return on a riskless asset and σ_Λ is the constant standard deviation of Λ_t under the real-world measure $\mathbb{P}$, representing the exogenous price of total income risk.

Assuming complete markets and no-arbitrage, we employ contingent claims analysis to value the different claims on x. As a result, under the risk-neutral measure $\mathbb{Q}$, the dynamics of x and c_o are described by,

$$dx = (\mu - \sigma\sigma_\Lambda) x dt + \sigma x dz \quad (3)$$

and

$$dc_o = (\mu - \sigma\sigma_\Lambda)\, c_o dt + \sigma c_o dz \quad (4)$$

in which the drift parameter is reduced by the market risk premium $\sigma\sigma_\Lambda$ and in which dz now represents an increment of a standard Wiener process under the risk-neutral measure $\mathbb{Q}$. We define the return shortfall with uncertainty as δ and

$$\delta = r + \sigma\sigma_\Lambda - \mu. \quad (5)$$

3.1 The Benchmark Model

Our first model is a benchmark model, in which there is a government and banks with equity and debt (corporate not including depositors) and CoCos are not included. Equity operating the bank represents the "normal" state of the financial system and, in this scenario, the role of the government is simply to collect or 'return' taxes. The role of Equity is crucial because their unwillingness to fund cash flow shortfalls and their consequential abandonment is what triggers default.

Creditors finance the bank through wholesale funding. Debt is assumed to be constant and perpetual paying a continuous coupon "c_d". The bank has constant capital (K) while being run by equity and naturally this capital belongs to equity.

Equity operates the bank and collect dividends as long as $x > (c_o + c_d)$ the dividend is equal to $(x - c_o - c_d)(1 - \tau)$, and we assume a residual dividend policy. Whenever $x < (c_o + c_d)$, shareholders make the necessary cash injections to avoid defaulting for as long as these cash injections do not exceed the market value of equity[4].

Equity can abandon operations at any moment, upon which the government steps in keeping the bank operating or paying the restructuring costs and therefore, depositors are secured. Therefore, its value function does not include any optional features, its position is, in simple terms, one of unlimited liability following a bail in[5].

[4] We assume that neither the government nor equity are financially constrained.

[5] Governmental responsibility takes many forms, such as deposit insurance, debt guarantees and equity injections, among many other forms of ensuring bank solvency. Such interventions reflect an ongoing concern approach for the bank, eliminating uncertainty and calming creditors (depositors and other creditors such as

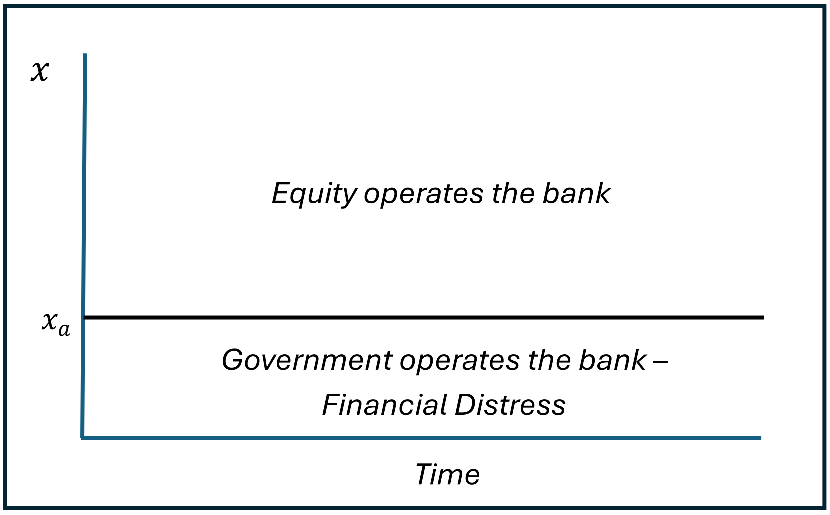
When equity abandons the bank, at an income level x_a, and in line with bail-in regulations, the bank is financially restructured, equity loses its capital (K), following absolute priority and limited liability rules, and debt loses part (or all) of its value. Consequently, when equity abandons, debt gets $\lambda*(c_d/r)$, where $0\leq \lambda\leq 1$. In simple terms, during restructuring, a portion (1- λ) of debt value may be transferred to the government, whenever capital K is not sufficient to compensate the losses assumed. Following restructuring, the bank is not releveled. Moreover, there are financial distress and/or bankruptcy costs equal to $\gamma(K + (1-\lambda)*c_d/r)$, , where $0\leq \gamma \leq 1$. These affect the value for the government that is now $(1-\gamma)(K + (1-\lambda)*c_d/r)$.

Furthermore, following Correia and Poblacion (2015), we consider that when equity abandons, the bank enters financial distress incurring distress costs. The impact of distress is introduced through the growth rates and operational costs. In financial distress the drift rate reduces to $\mu*$ and the operative cost increases until c_o*, naturally, $\mu > \mu*$ and $c_o < c_o*$.

Figure 1 describes the trigger on this model.

Figure 1 The benchmark model

This figure presents the impact of the abandonment trigger (x_a) for the benchmark model, without CoCo debt.



We determine the values of four different claims: the value of equity $E(x)$; the value of debt $D(x)$; the value for the government before abandonment, including the present value of a possible bailout, $G(x)$; and the value of bailout $B(x)$. For simplicity, we briefly describe the value of a general claim A, in which $A = E, D, G, B$ for the cases of the government, debt, equity and bailout costs, respectively.

The following Ordinary Differential Equation - ODE - describes the value of this general claim.

$$0.5\sigma^2 x^2 A_{xx} + (\mu - \sigma\sigma_\Lambda)xA_x - rA + \pi = 0 \tag{6}$$

bondholders), thereby preventing bank runs or the imposition of constraints by debt holders. In our model, the imposition of unlimited liability on the government following the abandonment of the private shareholders encapsulates the effects of all the different types of governmental intervention in a single measure, aiming to reduce the risk of creditors. Naturally, unlimited liability will only be effective, assuming full symmetry of information in which the different stakeholders rationally anticipate that, upon abandonment, the government steps in and ensures that all the bank's financial obligations are fulfilled.

where $\pi = a(x - c_o) + b$ (see Table 1) represents total income and cost flows for each claim, comprising a variable component a associated with the evolution of x and c_o and a fixed component b independent of x and c_o. L_A represents the terminal value at abandonment when $x = x_a$. Table 1 defines a, b and L_A for the different claims considered.

Table 1: Specification of the ODE - Benchmark

This table defines a, b and L_A for the different claims considered in the benchmark model.

A(x)	*a*	*b*	L_A
E(x)	$(1-\tau)$	$-(1-\tau)\,c_d$	$-K$
D(x)	0	c_d	$-(1-\lambda)\left(\frac{c_d}{r}\right)+max\left\{\frac{x_a-c_o^*}{\delta^*}+(1-\gamma)\left(K+(1-\lambda)\frac{c_d}{r}\right),0\right\}$
G(x)	τ	$-c_d\,\tau$	$B(x_a)=min\left\{\frac{x_a-c_o^*}{\delta^*}+(1-\gamma)\left(K+(1-\lambda)\frac{c_d}{r}\right),0\right\}$
B(x)	1	$(1-\gamma)[(1-\lambda)c_d+Kr]$ -	

The general solution to ODE (1) is:

$$A(x) = \begin{cases} \frac{ax}{\delta} + \frac{b}{r} + B_1 x^{\beta_1} + B_2 x^{\beta_2} & if\ x > x_a \\ L_A & if\ x \le x_a \end{cases} \quad (7)$$

with a, b and L_A given in Table 1, where $\delta = r + \sigma\sigma_\Lambda - \mu$ and β_1 and β_2 are the roots of the following characteristic polynomial:

$$(0.5\sigma^2\beta^2 + \beta(\mu - \sigma\sigma_\Lambda - 0.5\sigma^2) - r)x^\beta = 0, \quad (8)$$

yielding

$$\beta_1 = \frac{1}{2} - \frac{\mu - \sigma\sigma_\Lambda}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu - \sigma\sigma_\Lambda}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1, \quad (9)$$

$$\beta_2 = \frac{1}{2} - \frac{\mu - \sigma\sigma_\Lambda}{\sigma^2} - \sqrt{\left(\frac{1}{2} - \frac{\mu - \sigma\sigma_\Lambda}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} < 0. \quad (10)$$

Constants B_1 and B_2 are determined given appropriate boundary conditions (see Dixit and Pindyck, 1994). From boundary condition (11), we obtain B_1 equal to zero.

$$\lim_{x\to\infty} A(x) = \frac{ax}{\delta} + \frac{b}{r} \quad (11)$$

Proposition 1: The value of the Equity (E(x)), Debt (D(x)) and the government is the following:

$$E(x) = \begin{cases} \left(\frac{x-c_o}{\delta} - \frac{c_d}{r}\right)(1-\tau) - \left[\left(\frac{x_a-c_o}{\delta} - \frac{c_d}{r}\right)(1-\tau) - L_E\right]\left(\frac{x}{x_a}\right)^{\beta_2} & if\ x \ge x_a \\ L_E = -K & if\ x \le x_a \end{cases} \quad (12)$$

$$G(x) = \begin{cases} \left(\frac{x-c_o}{\delta} - \frac{c_d}{r}\right)\tau - \left[\left(\frac{x_a-c_o}{\delta} - \frac{c_d}{r}\right)\tau - min\left\{\frac{x_a-c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\}\right]\left(\frac{x}{x_a}\right)^{\beta_2} & if\ x \ge x_a \\ L_G = min\left\{\frac{x_a-c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \le x_a \end{cases}$$

(13)

$$D(x)=\begin{cases}\frac{c_d}{r}-\left[(2-\lambda)\frac{c_d}{r}-max\left\{\frac{x_a-c_o^*}{\delta^*}+(1-\gamma)\left(K+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x}{x_a}\right)^{\beta_2} & if\ x\geq x_a\\ L_D=-(1-\lambda)\frac{c_d}{r}+max\left\{\frac{x_a-c_o^*}{\delta^*}+(1-\gamma)\left(K+(1-\lambda)\frac{c_d}{r}\right),0\right\} & if\ x\leq x_a\end{cases}$$

(14)

Following equation (11), we know that absent the possibility of abandonment, the value of equity is equal to,

$$E(x)=\left(\frac{x-c_o}{\delta}-\frac{c_d}{r}\right)(1-\tau). \tag{15}$$

Equity benefits from limited liability and therefore, following a decrease in *x*, it may choose to default and abandon. The earnings level at which equity defaults is defined as x_a, as a residual claim, equity receives nothing and lose their capital (*K*). Constant B_2 considers the value generated by abandonment, and this is reflected in the following abandonment value matching condition:

$$E(x_a)=L_E=-K\Leftrightarrow\left(\frac{x_a-c_o}{\delta}-\frac{c_d}{r}\right)(1-\tau)+B_2x_a^{\beta_2}=L_E. \tag{16}$$

Replacing a, B_1 and B_2 in equation (7), the value equity is given by,

$$E(x)=\begin{cases}\left(\frac{x-c_o}{\delta}-\frac{c_d}{r}\right)(1-\tau)-\left[\left(\frac{x_a-c_o}{\delta}-\frac{c_d}{r}\right)(1-\tau)-L_E\right]\left(\frac{x}{x_a}\right)^{\beta_2} & if\ x\geq x_a\\ L_E=-K & if\ x\leq x_a\end{cases} \tag{17}$$

The second term of equation (17) for $x\geq x_a$ represents the abandonment option that increases the value of equity. Naturally, the symmetrical term in the value equation of the government represents the bailout costs, as we will outline next.

The potential cost of a bailout, defined as $B(x)$, at $x=x_a$, is,

$$B(x_a)=min\left\{\frac{x_a-c_o^*}{\delta^*}+(1-\gamma)\left(K+(1-\lambda)\frac{c_d}{r}\right),0\right\}. \tag{18}$$

Equation (18) represents the value function for the government if/when abandonment occurs. It represents the present value of all future operational revenues ($x-c_o$) and the value of capital and debt received by the government when shareholders abandon the bank. Since the government cannot abandon the bank, its value function does not include any optional features. The minimum operator of equation (18) limits the bail in amount, because not all the creditors' funds are needed to cover the bank losses, as so, $B(x_a)$ varies between $-\infty$ for a potential bailout and 0 for a potential bail in. Equation (18), therefore prevents the government from expropriating creditors and making money with the bailout.

Again, following equation (11), we know that, absent the possibility of abandonment, the value for the government is equal to,

$$G(x)=\left(\frac{x-c_o}{\delta}-\frac{c_d}{r}\right)\tau. \tag{19}$$

Since equity may abandon the bank, we must include the cost of unlimited liability incorporated through the B_2 coefficient. The following abandonment value-matching condition reflects the incorporation of unlimited liability following abandonment.

$$G(x_a) = L_G = min\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} \Leftrightarrow \left(\frac{x_a - c_o}{\delta} - \frac{c_d}{r}\right)\tau + B_2 x_a^{\beta_2} = min\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} \quad (20)$$

In our setting equation (20) is the same as equation (18) because following the bail in, the remaining costs are entirely assumed by the government. Determining B_2 and replacing it in (7) with the appropriate values for a, b_1 and b_2, we have the value for the government,

$$G(x) = \begin{cases} \left(\frac{x - c_o}{\delta} - \frac{c_d}{r}\right)\tau - \left[\left(\frac{x_a - c_o}{\delta} - \frac{c_d}{r}\right)\tau - min\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\}\right]\left(\frac{x}{x_a}\right)^{\beta_2} & if\ x \geq x_a \\ L_G = min\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \leq x_a \end{cases} \quad (21)$$

The value of debt absent equity abandonment is given by,

$$D(x) = \frac{c_d}{r} \quad (22)$$

However, since equity may abandon, debt may be required to bail in the bank. At the abandonment moment x_a the value of debt is L_D. Thus, we have:

$$D(x_a) = L_D = -(1-\lambda)\frac{c_d}{r} + max\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} \Leftrightarrow \frac{c_d}{r} + B_2 x_a^{\beta_2} = -(1-\lambda)\frac{c_d}{r} + max\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} \quad (23)$$

From equation (23), we determine the B_2 parameter and replace it in equation (2) with B_1 equal to zero, and debt value is given by,

$$D(x) = \begin{cases} \frac{c_d}{r} - \left[(2-\lambda)\frac{c_d}{r} - max\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\}\right]\left(\frac{x}{x_a}\right)^{\beta_2} & if\ x \geq x_a \\ L_D = -(1-\lambda)\frac{c_d}{r} + max\left\{\frac{x_a - c_o^*}{\delta^*} + (1-\gamma)\left(K + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \leq x_a \end{cases} \quad (24)$$

The *max* operator here plays the same role as the *min* operator in (18) preventing an expropriation of debt value by the government.

The default spread on a risky bond represents the difference between the required return on the bond, defined as r_d and the risk-free rate as r. The required return of the bond r_d is simply the ratio between the promised coupon c_d and the present value of the bond $D(x)$ ($r_d = c_d/D(x)$). Consequently,

$$Spread = \frac{c_d}{D(x)} - r \quad (25)$$

We now have all of the value equations required for our analysis; however, we still have to determine the abandonment trigger x_a, that is obtained from the following optimization condition.

$$\left.\frac{\partial E(x)}{\partial x}\right|_{x = x_a} = 0 \quad (26)$$

Upon inserting equation (17) into equation (26) and solving for x_a, we have:

$$x_a = \frac{\beta_2}{\beta_2 - 1}\left(c_o + \frac{c_d\delta}{r} - \frac{K\delta}{(1-\tau)}\right) \tag{27}$$

We can easily convert this trigger into abandonment probabilities and an expected time to abandonment. Following Thijssen (2010), the abandonment probability within a period *T*, under the real-world measure $\mathbb{P}$ is,

$$Prob(Sup_{0 \le t \le T}\, x \le x_a) = 1 + \Phi\left(\frac{ln\left(\frac{x_a}{x}\right) + \left(\mu - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right) e^{-\frac{2\left(\mu - \frac{\sigma^2}{2}\right) ln\left(\frac{x_a}{x}\right)}{\sigma^2}} - \Phi\left(-\frac{ln\left(\frac{x_a}{x}\right) - \left(\mu - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right) \tag{28}$$

in which $\varphi(.)$ is the cumulative distribution function of the standard normal distribution.

Following Shackleton and Wajokowski (2002) the expected time to abandonment (θ_a) is,

$$\theta_a = \frac{1}{\mu - 0.5\sigma^2} ln\left(\frac{x_a}{x}\right) = \frac{1}{\mu - 0.5\sigma^2} ln\left(\frac{\frac{\beta_2}{\beta_2 - 1}\left(c_o + \frac{c_d\delta}{r} - \frac{K\delta}{(1-\tau)}\right)}{x}\right) \tag{29}$$

3.2 Contingent Convertible Financing (CoCos)

For contingent convertibles (CoCos) to qualify to Tier 1 (AT1) capital they are required to:

i. Include discretionary coupon suspensions without penalties;

ii. Be perpetual;

iii. Include conversion into equity through trigger mechanism.

Before conversion, the CoCo is perpetual and pays a coupon c_c. Even though there is no direct penalty, the market perceives coupon suspensions as a negative signal, as so, following the coupon suspension the bank enters financial distress and bears distress costs. As before, following Correia and Poblacion (2015), in financial distress the bank drift rate reduces to μ^* and the operative cost increases to c_o^*, naturally, $\mu > \mu^*$ and $c_o < c_o^*$. Equity rationally decides the suspension trigger x_s knowing that following the suspension, the bank enters distress.

This feature of the model aims to capture the unique case of coupon suspension and the resulting expected market backlash. It is a powerful signal that is sent to the market that has no equivalent in plain vanilla corporate debt or even when dividends are suspended.

With respect to the conversion, since we model flows and not asset values, the conversion trigger x_c cannot be associated with the capital level and it is associated with earnings level. In this case we assume that CoCo conversion occurs when earnings are not even sufficient to cover operational costs when not in distress,

$$x_c = c_o. \tag{30}$$

Even though this conversion level is somehow arbitrary, and different levels can be argued, we feel it is reasonable and useful for the purpose of this analysis.

Once CoCos are converted the bank increases its equity and reduces its debt. If conversion naturally follows suspension, there is no impact on cash flows, because the coupons on the CoCo were already suspended.

There are then two possibilities of abandonment, depending on the path of the earnings. If the earnings continue to fall following the conversion into equity, abandonment occurs at an earnings level x_a^*, in this case, following the bail in conditions, the government operates a distressed bank. Nonetheless, we assume that negative signals to the market will dissipate. In this respect we are going to assume that when the bank returns to positive net earnings and is able to distribute dividends once again, the effects of distress also disappear. Therefore, following conversion, the bank continues in distress until $x > x_d$ where,

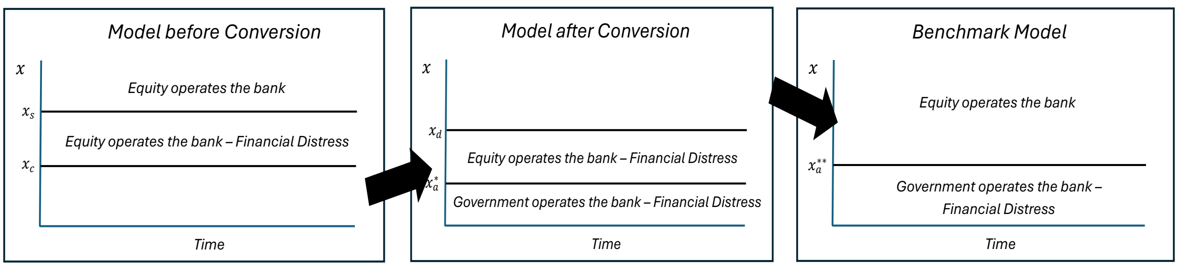
$$x_d = c_o + c_d. \tag{31}$$

Hence, if this happens, we are in the benchmark model. In this case abandonment occurs at x_a^{**} (a lower trigger) and the government operates a bank that is under financial distress as in the benchmark case. Consequently, the trigger levels x_a^{**} and x_a are very similar, since they relate to abandonment of a bank that is not under financial distress. The difference is the capital level, because in the case of the CoCo, the bank was capitalized through the conversion and the opportunity cost of abandoning is naturally higher, as so, ceteris paribus $x_a^{**} < x_a$.

Therefore, in this model we have three different scenarios (model before conversion, model after conversion and benchmark model) as in Figure 2. These three different absorbing scenarios will be incorporated through backward induction.

Figure 2: The model with CoCos

This Figure presents the three different scenarios in the model with CoCos.



All in all, the CoCo model determines the values of six different claims: the value of equity $E(x)$; the value of debt *D(x)*; the value of the CoCos *C(x)*, the value for the government before abandonment, including the present value of a possible bailout, $G(x)$; the value of bailout following conversion $B_1(x)$ and the value of bailout following conversion and exist from distress $B_2(x)$.

As in previous section, Table 2 defines a, b and L_A for the different claims considered.

Table 2: Specification of the ODE – with CoCos

This table defines *a*, *b* and L_A for the different claims considered in the model with CoCos.

A(x)	***a***	***B***	L_A
E(x)+*C*(x)	$(1-\tau)$	$-(1-\tau)c_d$	$-K - \frac{c_c}{r}$

E(x)	$(1-\tau)$	$-(1-\tau)c_d$	$-K$
C(x)	0	c_c	$-\frac{c_c}{r}$
D(x)	0	c_d	$L_D^{**}=-(1-\lambda)\frac{c_d}{r}+max\left\{\frac{x_a^{**}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}$ $3^{er}Sc$ $L_D^{*}=-(1-\lambda)\frac{c_d}{r}+max\left\{\frac{x_a^{*}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}$ $2^{nd}Sc$
G(x)	τ	$-c_d\tau$	$B_2(x_a^{**})=L_G^{**}=min\left\{\frac{x_a^{**}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}$ $3^{er}Sc$ $B_1(x_a^{*})=L_G^{*}=min\left\{\frac{x_a^{*}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}$ $2^{nd}Sc$
B_1(x)	1	$(1-\gamma)[(1-\lambda)c_d+c_c+Kr]$	
B_2(x)	1	$(1-\gamma)[(1-\lambda)c_d+c_c+Kr]$	

Notes: "3er Sc" stands for the third scenario and "2nd Sc" stands for the second scenario.

3.2.1 Equity and CoCos after conversion

We start with the benchmark (the third scenario in Figure 2) in which the CoCo has been converted into equity and capital has increased from K to $K + c_c/r$ which is the face value of the perpetual debt of the CoCo[6] .

Proposition 2: In the last scenario (the benchmark model), following the conversion and exit from distress, the value of equity is given by (equity now includes previous CoCo holders):

$$E^{**}(x)+C^{**}(x)=\begin{cases}\left(\frac{x-c_o}{\delta}-\frac{c_d}{r}\right)(1-\tau)-\left[\left(\frac{x_a^{**}-c_e}{\delta}-\frac{c_d}{r}\right)(1-\tau)-L_E\right]\left(\frac{x}{x_a^{**}}\right)^{\beta_2} & if\ x\geq x_a^{**}\\ L_E=-K-\frac{c_c}{r} & if\ x\leq x_a^{**}\end{cases} \quad (32)$$

Since we are in the benchmark case, the proof of this proposition is exactly the same as Section 3.1. Moreover, we know that:

$$x_a^{**}=\frac{\beta_2}{\beta_2-1}\left(c_o+\frac{c_d\delta}{r}-\frac{\mathrm{K}+\frac{c_c}{r}}{(1-\tau)}\delta\right) \quad (33)$$

$$\theta_a^{**}=\frac{1}{\mu-0.5\sigma^2}ln\left(\frac{x_a^{**}}{x}\right)=\frac{1}{\mu-0.5\sigma^2}ln\left(\frac{\frac{\beta_2}{\beta_2-1}\left(c_o+\frac{c_d\delta}{r}-\frac{\mathrm{K}+\frac{c_c}{r}}{(1-\tau)}\delta\right)}{x}\right). \quad (34)$$

Once the benchmark model is solved, with backward induction we are going to integrate the second scenario in Figure 2.

Proposition 3: In the second scenario (model after conversion), we have three different stages (the first and the third ones are absorbing): bankruptcy, financial distress and the last scenario previously described. Then, the contingent claim for the new shareholders in this second scenario is:

$$E^{*}(x)+C^{*}(x)=\begin{cases}E^{**}(x)+C^{**}(x) & if\ x\geq x_d\\ \left(\frac{x-c_o^*}{\delta^*}-\frac{c_d}{r}\right)(1-\tau)+B_1^{E+C}x^{\beta_1^*}+B_2^{E+C}x^{\beta_2^*} & if\ x_a^*\leq x\leq x_d\\ -K-\frac{c_c}{r} & if\ x\leq x_a^*\end{cases} \quad (35)$$

[6] For the sake of simplicity, it is assumed that the conversion factor is one, i.e., the CoCo face value is incorporated directly into equity.

Being B_1^{E+C} and B_2^{E+C} derived in the Appendix.

Following the same logic as in previous cases we determine when the private shareholders optimally abandon from the following smooth pasting condition $\left(\frac{\partial[E^*(x)+C^*(x)]}{\partial x}\Big|_{x=x_{a^*}}=0\right)$ we derive the following implicit equation for the abandonment trigger,

$$\frac{1-\tau}{\delta^*}+\beta_1^* B_1^{E+C} x_{a^*}^{\beta_1^*}+\beta_2^* B_2^{E+C} x_{a^*}^{\beta_2^*}=0 \qquad (36)$$

Equation (36) doesn´t have a closed form solution and should be solved numerically for x_a*.

As in previous cases, it is easy to convert the abandonment trigger into an expected time to abandonment (θ_{a^*}) since:

$$\theta_{a^*}=\frac{1}{\mu-0.5\sigma^2} ln\left(\frac{x_{a^*}}{x}\right). \qquad (37)$$

3.2.2 Equity and CoCos before conversion

So, once that we have solved the second scenario for the shareholders and the holders of the CoCo, we can solve the first scenario for shareholders and CoCo holders separately. In doing so, the percentage of ownership of the bank of shareholders and CoCo holders once the Contingent Convertible is converted should be defined.

As a notation, let´s call "E_c" the value of Equity after the CoCo conversion and let R be the Contingent Convertible conversion ratio. With this notation, after conversion:

- The ownership stake of initial Equity is $\frac{E_c}{E_c+\frac{c_c}{r}R}$.
- The ownership stake of CoCo holders is $\frac{\frac{c_c}{r}R}{E_c+\frac{c_c}{r}R}$.

Therefore, using this notation:

Proposition 4: Before the conversion the Equity value is going to be:

$$E(x)=\begin{cases}\left(\frac{x-c_o}{\delta}-\frac{c_d+c_c}{r}\right)(1-\tau)+B_{1H}^E x^{\beta_1}+B_{2H}^E x^{\beta_2} & if\ x\geq x_s\\ \left(\frac{x-c_o^*}{\delta^*}-\frac{c_d}{r}\right)(1-\tau)+B_{1M}^E x^{\beta_1^*}+B_{2M}^E x^{\beta_2^*} & if\ x_c\leq x\leq x_s\\ \frac{E_c}{E_c+\frac{c_c}{r}R}[E^*(x)+C^*(x)] & if\ x\leq x_c\end{cases} \qquad (38)$$

B_{1H}^E, B_{2H}^E, B_{1M}^E and B_{2M}^E are derived in the Appendix.

In order to assign values to the variables "E_c" and "R" let´s consider that just after the conversion, assuming that it is not going to be abandoned because in this case the new equity holders (which are the initial shareholders and CoCo holders) will lose their money, the total value of the equity of the bank is $\left(\frac{x_c-c_o^*}{\delta^*}-\frac{c_d}{r}\right)+\frac{c_c}{r}$. Therefore, as a base case it is going to be assumed that once the CoCo is converted, the value of the stocks that the initial shareholders have is $E_c=\left(\frac{x_c-c_o^*}{\delta^*}-\frac{c_d}{r}\right)$ whereas the value of the stocks that the CoCo holders have is $\frac{c_c}{r}$.

In other words, we are going to assume that the conversion ratio (R) is going to be equal to one for the CoCo holders and $E_c = \left(\frac{x_c - c_o^*}{\delta^*} - \frac{c_d}{r}\right)$. Consequently, the percentage of the ownership of the bank that the initial equity holders have after the conversion is $\frac{\left(\frac{x_c - c_o^*}{\delta^*} - \frac{c_d}{r}\right)}{\left(\frac{x_c - c_o^*}{\delta^*} - \frac{c_d}{r}\right) + \frac{c_c}{r}}$ whereas the percentage of the ownership of the bank of the CoCo holders is $\frac{\frac{c_c}{r}R}{\left(\frac{x_c - c_o^*}{\delta^*} - \frac{c_d}{r}\right) + \frac{c_c}{r}}$.

Following the same assumptions as for Equity, CoCo investors have:

Proposition 5: Before the conversion the Equity value is going to be:

$$C(x) = \begin{cases} \frac{c_c}{r} + B_{1H}^C x^{\beta_1} + B_{2H}^C x^{\beta_2} & if\ x \geq x_s \\ B_{1M}^C x^{\beta_1^*} + B_{2M}^C x^{\beta_2^*} & if\ x_c \leq x \leq x_s \\ \frac{\frac{c_c}{r}R}{E_c + \frac{c_c}{r}R}\left[E^*(x) + C^*(x)\right] & if\ x \leq x_c \end{cases} \quad (39)$$

B_{1H}^C, B_{2H}^C, B_{1M}^C and B_{2M}^C are derived in the Appendix.

3.2.3 The Government and the Debt

With the government and with the debt holder we are going to follow the same backward induction procedure, however, since there is no conversion, the contingent claims are simpler.

Proposition 6: In the last scenario (the benchmark model) we have that the government and debt holder contingent claims are the following:

$$G^{**}(x) = \begin{cases} \left(\frac{x - c_o}{\delta} - \frac{c_d}{r}\right)\tau - \left[\left(\frac{x_a^{**} - c_o}{\delta} - \frac{c_d}{r}\right)\tau - min\left\{\frac{x_a^{**} - c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\}\right]\left(\frac{x}{x_a^{**}}\right)^{\beta_2} & if\ x \geq x_a^{**} \\ L_G^{**} = min\left\{\frac{x_a^{**} - c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \leq x_a^{**} \end{cases} \quad (40)$$

$$D^{**}(x) = \begin{cases} \frac{c_d}{r} - \left[(2-\lambda)\frac{c_d}{r} - max\left\{\frac{x_a^{**} - c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\}\right]\left(\frac{x}{x_a^{**}}\right)^{\beta_2} & if\ x \geq x_a^{**} \\ L_D^{**} = -(1-\lambda)\frac{c_d}{r} + max\left\{\frac{x_a^{**} - c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \leq x_a^{**} \end{cases} \quad (41)$$

Since we are in the benchmark case, the proof of this proposition is exactly the same as Section 3.1. Once the last scenario is solved, it is possible to go back to the second stage.

Proposition 7: In the second scenario (the model after conversion), the value for the Government and the value of the Debt is:

$$G^*(x) = \begin{cases} G^{**}(x) & if\ x \geq x_d \\ \left(\frac{x - c_o^*}{\delta^*} - \frac{c_d}{r}\right)\tau + B_1^G x^{\beta_1^*} + B_2^G x^{\beta_2^*} & if\ x_a^* \leq x \leq x_d \\ L_G^* = min\left\{\frac{x_a^* - c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \leq x_a^* \end{cases} \quad (42)$$

$$D^*(x) = \begin{cases} D^{**}(x) & if\ x \geq x_d \\ \frac{c_d}{r} + B_1^D x^{\beta_1^*} + B_2^D x^{\beta_2^*} & if\ x_a^* \leq x \leq x_d \\ L_D^* = -(1-\lambda)\frac{c_d}{r} + max\left\{\frac{x_a^* - c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\} & if\ x \leq x_a^* \end{cases} \quad (43)$$

B_1^G, B_2^G, B_1^D and B_2^D are derived in the Appendix.

Proposition 8: Once the second scenario is solved, we can solve the first scenario (before conversion)

$$G(x) = \begin{cases} \left(\frac{x-c_o}{\delta} - \frac{c_d+c_c}{r}\right)\tau + B_{1H}^G x^{\beta_1} + B_{2H}^G x^{\beta_2} & if\ x \geq x_s \\ \left(\frac{x-c_o^*}{\delta^*} - \frac{c_d}{r}\right)\tau + B_{1M}^G x^{\beta_1^*} + B_{2M}^G x^{\beta_2^*} & if\ x_c \leq x \leq x_s \\ G^*(x) & if\ x \leq x_c \end{cases} \tag{44}$$

$$D(x) = \begin{cases} \frac{c_d}{r} + B_{1H}^D x^{\beta_1} + B_{2H}^D x^{\beta_2} & if\ x \geq x_c \\ D^*(x) & if\ x \leq x_c \end{cases} \tag{45}$$

B_{1H}^G, B_{2H}^G, B_{1M}^G, B_{2M}^G, B_{1H}^D, B_{2H}^D, B_{2M}^D and B_{2M}^D are derived in the Appendix.

It is interesting to notice that in this case shareholders can abandon in two different scenarios (the second and the last one), so there are two different possibilities of bail-out depending on when the abandonment happens (B_1 if the abandon is in the second scenario and B_2 if the abandon is in the third scenario).

$$B_1(x_a^*) = L_G^* = min\left\{\frac{x_a^*-c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\} \tag{46}$$

$$B_2(x_a^{**}) = L_G^{**} = min\left\{\frac{x_a^{**}-c_o^*}{\delta^*} + (1-\gamma)\left(K + \frac{c_c}{r} + (1-\lambda)\frac{c_d}{r}\right), 0\right\} \tag{47}$$

As in the previous case, we can calculate the default spread and the default probability. As in the bail-out case, in the case of the default probability there are two probabilities depending on if the shareholders abandonment is in the second or the last scenario ($Prob_1$ if the abandon is in the second scenario and $Prob_2$ if the abandon is in the third scenario).

$$Spread = \frac{c_d}{D(x)} - r \tag{48}$$

$$Prob_1(Sup_{0\leq t\leq T}\ x \leq x_a^*) = 1 + \Phi\left(\frac{ln\left(\frac{x_a^*}{x}\right)+\left(\mu-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right)e^{-\frac{2\left(\mu-\frac{\sigma^2}{2}\right)ln\left(\frac{x_a^*}{x}\right)}{\sigma^2}} - \Phi\left(-\frac{ln\left(\frac{x_a^*}{x}\right)-\left(\mu-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right) \tag{49}$$

$$Prob_2(Sup_{0\leq t\leq T}\ x \leq x_a^{**}) = 1 + \Phi\left(\frac{ln\left(\frac{x_a^{**}}{x}\right)+\left(\mu-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right)e^{-\frac{2\left(\mu-\frac{\sigma^2}{2}\right)ln\left(\frac{x_a^{**}}{x}\right)}{\sigma^2}} - \Phi\left(-\frac{ln\left(\frac{x_a^{**}}{x}\right)-\left(\mu-\frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}\right) \tag{50}$$

4. Static Analysis

4.1 The Benchmark Model

The benchmark model has eleven parameters (μ, μ^*, σ, σ_Λ, c_o, c_o^*, c_d, K, τ, λ and γ) that drive the eight results of the model: the bailout threshold (x_a), the expected time to bailout (θ_a), the value of the private shareholders claim (E), the value of the creditor claim (D), the value of the government claim (G), the bailout cost (B), the spread and the probability of default.

With respect to our base case parameters, we consider a bank with growth rate (μ) of 2%, a growth rate in distress (μ^*) of 1%, volatility of income (σ) of 30%, an exogenous price of total income risk

(σ_Λ) of 10%. Initial income (x_0) is normalized to 1, with operational costs (c_o) of 0.5, that increase to 0.7 when in distress (c_o*), equity capital (K) is 1.5 and corporate debt receives a perpetual coupon (c_d) of 0.1 with an expected recovery in default (λ) of 20%. With respect to macro parameters, we assume a risk free rate (r) of 6%, a corporate tax rate (τ) of 25% and bankruptcy costs (γ) of 20%. The probabilities are calculated for the period (T) of 1 year.

Table 3 reports how these claims change in response to changes in the parameter values. To be coherent, instead of seeing the change of the claims in response to changes in μ* and c_o*, Table 3 reports how these claims change in response to changes in μ - μ* and c_o* - c_o. In both cases the parameters μ and c_o does not change whereas μ* and c_o* change. Moreover, when there is a change in μ or c_o, μ* and c_o* change accordantly to keep the differences among these parameters constant.

Regarding x_a, increases with μ because total income and costs increase with it. As expected, x_a grows with c_o and c_d and decreases with σ, because if costs or coupon payments increase, the bank is less profitable, and equity has an incentive to abandon early.

With respect to σ, because abandonment is an option for shareholders, the abandonment threshold decreases with volatility; in other words, if volatility increases, the possibility of further profit increases and shareholders wait longer before abandoning. σ_Λ is the discount rate volatility (risk premium) and tends to follow the same direction as σ in almost all cases because both parameters are volatilities.

Because shareholders lose the capital (K) if they abandon the bank, the abandonment point decreases as the capital requirements increase, which is a desirable property in this model. In the case of taxes, because we assume a fully symmetrical tax system, an increase in taxes makes the abandonment less likely since the government bears a higher amount of the pain when the bank has losses.

Table 3: Sensitivity analysis - Benchmark

This table reports how the following claims for the benchmark change in response to changes in the parameter values (μ, μ - μ*, σ, σ_Λ, c_o, c_o – c_o*, c_d, K, τ, λ and γ): the bailout threshold (x_a), the expected time to bailout (θ_a), the value of the private shareholders' claim (E), the value of the creditors' claim (D), the bailout cost (B), the value of the government claim (G), the spread and the probability of default.

	x_a	θ_a	E(x)	G(x)	B(x_a)	D(x)	Spread	Def. Prob.
μ	↑	↑	↑	↑	↓	↑	↓	↑
μ - μ*	-	-	-	↓	↓	-	-	-
σ	↓	↓↑	↓	↓	↓	↓	↑	↑
σ_Λ	↓	↑	↓	↓	↑	↓	↑	↓
c_o	↑	↓	↓	↓	↓	↓	↑	↑
c_o* - c_o	-	-	-	↓	↓	-	-	-
c_d	↑	↓	↓	↑	↑	↑	↑	↑
K	↓	↑	↓	↑	↑	↑	↓	↓
τ	↓	↑	↓	↑	↓	↑	↓	↓
λ	-	-	-	↓	↓	↑	↓	-
γ	-	-	-	↓	↓	-	-	-

Regarding θ_a, in general, as expected, if x_a increases, then θ_a decreases because the higher x_a is, the easier it is for the total income to reach the threshold. The only exceptions are the cases of μ and σ. As explained before, when μ increases, total income moves away from x_a, therefore it makes abandonment less likely, and that increases θ_a.

The role of σ can also be explained following the same logic of option pricing theory: if volatility is higher, on the one hand, x_a decreases, and consequently, it is more difficult for the total income to reach the threshold. However, on the other hand, the underlying asset value moves faster, increasing the likelihood that the exercise threshold will be reached, and that is the reason why there is no obvious change in θ_a when σ increases.

As expected, the value of equity, E(x), grows with μ and decreases with volatility: if volatility is higher, the underlying asset value moves faster, increasing the likelihood that the abandonment trigger will be reached. It is also clear that Equity decreases with costs, taxes or coupon payments since the bank is less profitable. Because equity loses capital (K) if they abandon the bank, if capital requirements increase, then the value of the claim decreases.

The value of all these claims is not affected by changes in μ*, c_o*, λ and γ because these parameters come into play following abandonment. The same applies to the probability of default.

In terms of the bailout cost $B(x_a)$, the first aspect to recall is that it represents a cost; it is a negative number, and consequently, we should analyze the results in Table 3 accordingly. As expected, if c_o increases $B(x_a)$ decreases (it is more negative - the bailout cost increases) because abandonment occurs earlier and the cost after the abandonment increases. The same logic applies when c_o* - c_o increases, $B(x_a)$ decreases because the cost after the abandonment increases.

Concerning volatility, we have to continue following the logic of option pricing theory: if volatility increases, the value of the option for the buyer increases and decreases for the seller. In other words, the bailout cost increases; that is, $B(x_a)$ decreases or becomes more negative. Related to c_d, it is clear that as the government receives part of the debt after the abandonment, so the higher c_d is, the lower the bail-out cost will be ($B(x_a)$ increases). The same logic applies to K; the higher the amount of capital that is transferred from shareholders to the government, the lower the bail-out cost is ($B(x_a)$ increases).

When we increase taxes, this causes x_a to decrease and bail-out occurs at a lower total income level, and, hence, the bail-out cost increases ($B(x_a)$ decreases). For what concerns λ and γ, as expected, the bail-out increases ($B(x_a)$ decreases) because (1- λ) is the percentage of the debt that goes to the government and γ is the percentage of the capital and the debt that government loses due to the financial distress. Finally, the role of μ and μ* are slightly less obvious to see as it affects income and costs and μ also affects μ*; however, the bail-out cost increases with μ and μ*as $B(x_a)$ decreases.

Once the bail-out cost is analyzed, the government claim is straightforward to assess. In all cases except for μ - μ*, σ_Λ and τ, we have the same results as when we analyzed the bail-out cost and for mainly the same reasons. In the case of taxes, the reason for changing the sign is clear: conditional on a bail-out, the fact that banks pay taxes is not included, and the higher the tax rate is, the higher the government benefit is. As stated above, σ_Λ is the discount rate volatility (risk premium) and tends to follow the same direction as σ except in the case of bail-out, which is just one part of the government claim.

However, when we consider the whole government claim, again, σ_Λ and σ follow the same logic. As stated above in the case of μ, it is somewhat more complicated as it affects income and costs and also affects μ*; however, in this case, as the opposite to bail-out costs, G(x) increases with μ as it affects the time to bail-out and it is also associated with the revenue from taxes before the bail-out.

As expected, the debt claim, D(x), grows in value as c and λ increase and c_o decreases. As in the case of equity, it decreases with volatility because if volatility is higher, the underlying asset value moves faster, increasing the likelihood that the exercise threshold will be reached. However, in this case, we see that the claim value grows with capital requirements and taxes because both make the bail-out less likely. The fact that the value of the debt grows with the capital requirement is an important result. In this case, D(x) increases with μ for the same reason as equity.

Since the spread inversely depends on debt, the spread follows the opposite direction as debt except in the case of the coupon (c_d). The reason is that the spread grows proportionally with c because when the coupon grows the amount of debt grows as well as it's risk.

Finally, the default probability grows with σ, c_o and c_d and decrease with K and τ. Regarding μ, as in previous cases, there are some ambiguous results because total income and costs grow at a rate μ. In this case, the probability of default increases with it.

4.2 The model with CoCos

In the case of the model with CoCos there are sixteen parameters (μ, μ - μ*, σ, σ_Λ, c_o , c_o* - c_o, c_d, c_c, K, τ, λ, γ, x_c, x_d, R and E_c) that drive the fourteen main endogenous claims of the model: the bailout thresholds (x_a^{**} and x_a*), the expected times to bailout (θ_a^{**} and θ_a*), the value of the private shareholders' claim (E), the value of the creditors' claim (D), the bailout costs (B_1 and B_2), the value of the government claim (G), the value of the CoCo claim (C), the CoCo coupon suspension trigger x_s, the debt spread and the probabilities of default.

With respect to our base case parameters, we consider a bank with growth rate (μ) of 2%, a growth rate in distress (μ^*) of 1%, volatility of income (σ) of 30%, an exogenous price of total income risk (σ_Λ) of 10%. Initial income (x_0) is normalized to 2, with operational costs (c_o) of 0.5, that increase to 0.7 when in distress (c_o^*), equity capital (K) is 3.33 and corporate debt receives a perpetual coupon (c_d) of 0.2 with an expected recovery in default (λ) of 20%. With respect to the CoCo parameters, CoCo debt receives a coupon (c_c) of 0.2, a conversion trigger (x_c) equal to c_o, a conversion ratio (R) of 1, a distress trigger (x_d) equal to $c_o + c_d$ and and $E_c = x_0/\delta_1^* - c_o^*/\delta_1^* - c/r$ (being $\delta_1^* = r + \sigma^*\sigma_\Lambda - \mu^*$). With respect to macro parameters, we assume a risk free rate (r) of 6%, a corporate tax rate (τ) of 25% and bankruptcy costs (γ) of 15%. The probabilities are calculated for the period (T) of 1 year.

Table 4: Sensitivity analysis – with CoCos

This table reports how the following claims for the model with CoCos change in response to changes in the parameter values (μ, μ - μ*, σ, σ_Λ, c_e , c_e* - c_e, c, c_c, K, τ, λ, γ, x_c, x_d, R y E_c): the bailout thresholds (x_a and x_a*), the expected times to bailout (θ_a and θ_a*), the value of the private shareholders' claim (E), the value of the creditors' claim (D), the bailout costs (B_1 and B_2), the value of the government claim (G), the value of the CoCo claim (C), the suspension trigger x_s, the debt spread and the probabilities of default.

	x_a^{**}	θ_a^{**}	x_a^{*}	θ_a^{*}	E(x)	G(x)	B_1 (x_a^*)	B_2 (x_a^{**})	D(x)	C(x)	x_s	Spread	Def. Prob. 1	Def. Prob. 2
μ	↑	↑	↑	↑	↑	↑	↓	↓	↑↓	↑	↓	↑↓	↑	↑
μ-μ*	-	-	↑	↓	↑	↑	↓	=	↓	↓	↑	↑	↑	↑
σ	↓	↑↓	↓	↑↓	↓	↓	↑	↑	↓	↓	↑	↑	↑	↑
σ_Λ	↓	↑	↓	↑	↓	↓	↑	↑	↓	↓	↑	↑	↓	↓
c_e	↑	↓	↑	↓	↓	↓	↓	↓	↓	↓	↑	↑	↑	↑
c_e*-c_e	-	-	↑	↓	↑	↓	↓	-	↓	↑	↓	↑	↑	↑
c	↑	↓	↑	↓	↓	↓	↑	↑	↑	↓	↑	↑	↑	↑
c_c	↓	↑	↓	↑	↓	↓	↑	↓	↑	↑	↑	↓	↓	↓
K	↓	↑	↓	↑	↓	↑	↑	-	↑	↓	↓	↓	↓	↓
τ	↓	↑	↓	↑	↓	↑	↓	↓	↑	↑	↓	↓	↓	↓
λ	-	-	-	-	-	↓	↓	↓	↑	-	-	-	-	-
γ	-	-	-	-	-	↓	↓	↓	↓	-	-	↑	-	-
x_c	-	-	-	-	↑	↑	-	-	↑	↑	↓	↓	-	-
x_d	-	-	↑	↓	↓	↓	↑	-	↓	↓	↑	↑	↑	↑

R	-	-	-	-	↑	↓	-	-	-	↓	↑	-	-	-
E_c	-	-	-	-	↓	↑	-	-	-	↑	↓	-	-	-

Table 4 reports how these claims change in response to changes in the parameter values. This model is much more complex because there are more parameters and claims, so there are much more direct and indirect interaction between them. Therefore, it is not always straightforward to explain why each claim evolves in a concrete direction following the movement of a parameter. Many times, the initial values of some parameters influence how a claim evolves with the movement of other parameters. However, comparing Table 4 with Table 3, most of the movements of the claims already included in Table 3 in response to parameters also included in Table 3 go in the same direction.

Focusing on the claims and parameters in Table 4 which are not included in Table 3, as expected, the suspension trigger x_s goes down when μ goes up and goes up when risk (σ or σ_Λ) or costs (c_o, c_d and c_c) goes up. The logic is clear, if the shareholders expect higher income, they do not suspend CoCo coupons, however when the risk or costs are higher, they suspend CoCo coupons earlier.

The opposite happens when c_o* grows because it means that distress times are harsher, so the shareholders try to avoid it decreasing x_s. The same logic applies with K, the higher the cost to the shareholder, the lower x_s. Following the same logic, x_s grows when the conversion ratio increases for the shareholder and goes down when it decreases. It also grows with x_d and decreases with x_c and τ.

As expected, CoCo debt follows a similar dynamic to debt except for c_d, c_o* - c_o and K. If c_d grows the default probability increase and, therefore, CoCo value decreases. In the case of K, it is also easy to explain, if K grows, after conversion the penalty increases, so, CoCo value decreases.

Related to new parameters, it is interesting to notice that the higher is x_d, since the distress after the conversion last more time, it is worse for the claims in the economy. The opposite happens with the conversion (x_c), the sooner the conversion happens the better for the claims in the economy. When R and/or E_c moves, the conversion ratio changes and, consequently, *E* and *C* evolve accordantly.

5. CoCos as Equity and Debt replacements

In this section, we carry out some simulations for valuing the different claims used in this paper: equity, debt and CoCo claims. In this respect, we focus on three different scenarios:

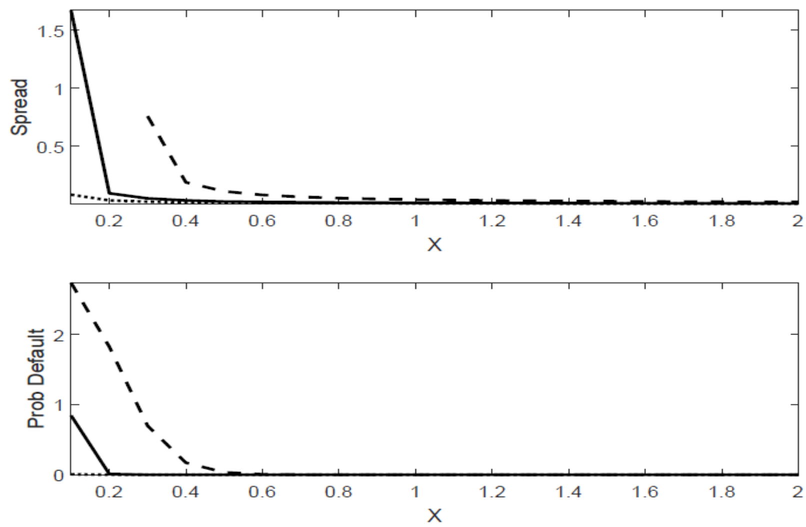
- In the first scenario we have the same amount of equity, debt and CoCo claim,
- In the second scenario we switch the CoCo claim for equity,
- In the third scenario we switch the CoCo claim for debt.

In all these three scenarios we are going to show the evolution of the value of all claims when we change the value of the total income (x). In this case the values that we are going to use for the parameters are: $\mu = 2\%$, $\mu^* = \mu - 1\%$, $\sigma = 30\%$, $\sigma_\Lambda = 10\%$, $c_o = 0.5$, $c_o^* = 0.7$, $c_d = 0.2$, $c_c = 0.2$, K = 3.3333, τ = 25%, λ = 0, γ = 0.5, $x_c = c_o$, $x_d = c_o + c$, R = 1, r = 6%, T =1 and $E_c = x_0/\delta_1^* - c_o^*/\delta_1^* - c/r$ (being $\delta_1^* = r + \sigma^* \sigma_\Lambda - \mu^*$).

The purpose of these scenarios is to check what is the best option (equity, CoCo and debt) and what is the option chosen by shareholders, who are the ones who decide on it. The first thing to notice is the fact that, as expected, the higher is the amount of debt, the higher is the probability of default and the spread (see Figure 3).

Figure 3: Spread and Default Probability under the three scenarios of the simulated results

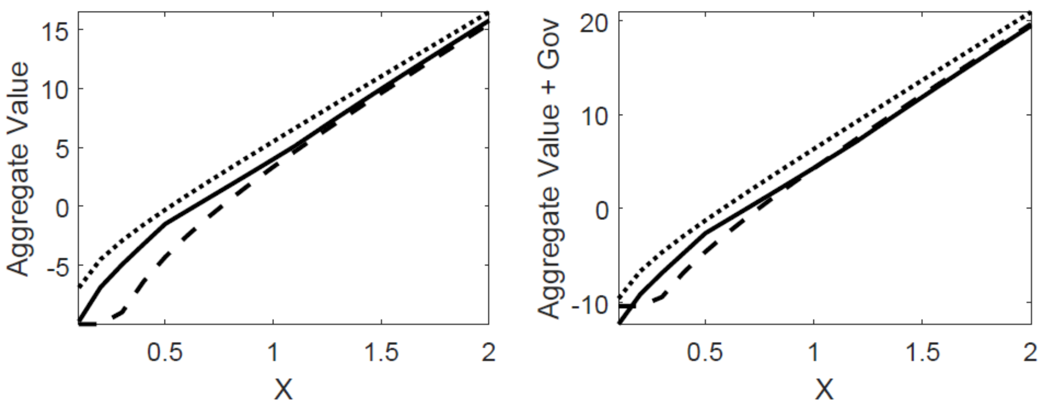
This figure represents the spread and the default probability under the three scenarios of the simulated results: In the first scenario we have the same amount of equity, debt and CoCo claim (solid line), in the second scenario we switch the CoCo claim for equity (dotted line) whereas in the third scenario we switch the CoCo claim for debt (dash line).



Clearly, increases in equity financing the lower are spreads and default probabilities. The reason for this is the fact that with the CoCo claim, financial distress is more likely and, therefore, the default probability is more likely as well. Somewhat surprisingly, CoCo issuance benefits debt, in terms of lower spreads and default probabilities. The recapitalization feature of CoCos and their subordinated nature with respect to vanilla corporate bonds can explain this result.

Figure 4: Aggregate under the three scenarios of the simulated results

This figure represents the aggregate value of the three claims (equity, debt and CoCo) and the value for the government under the three scenarios of the simulated results: In the first scenario we have the same amount of equity, debt and CoCo claim (solid line), in the second scenario we switch the CoCo claim for equity (dotted line) whereas in the third scenario we switch the CoCo claim for debt (dash line).

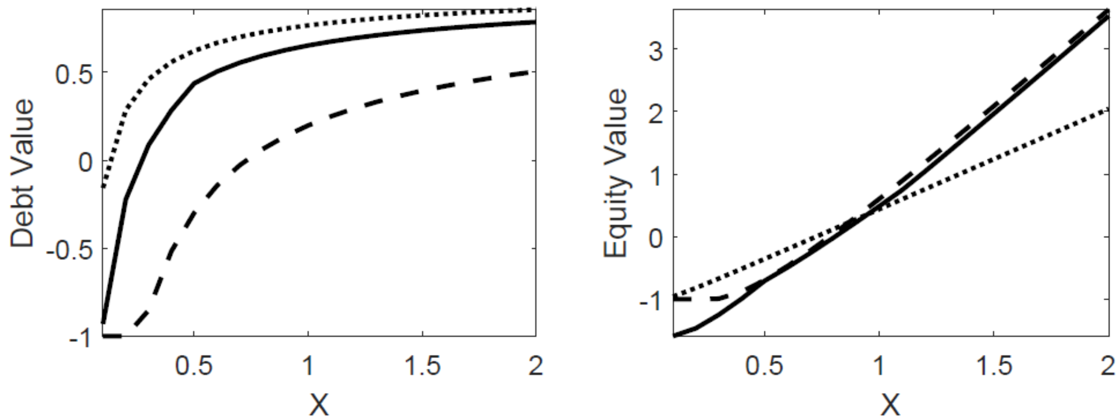


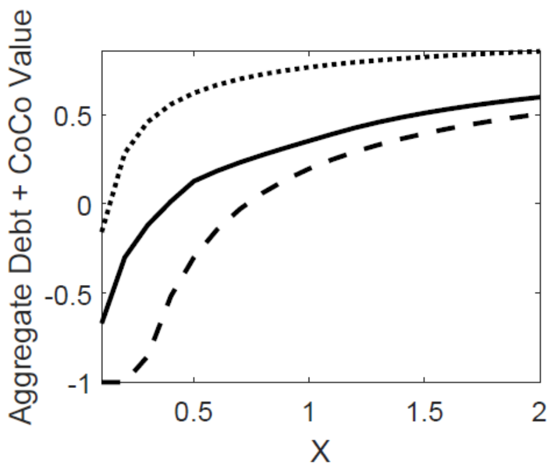
If we sum up the aggregate value of the three claims (CoCo, equity and debt) for all the three scenarios, as we can see in Figure 4, we have that, as expected, the best alternative is equity because it prevents distress and default. The interesting thing is the comparison between debt and CoCo and, in this respect, considering the overall value of the company, it is clear that the CoCo is better. The reason behind it is simple: even though the effects of distress are more pronounced with the CoCo (due to coupon suspension), the fact that it is eventually converted into equity to prevent default makes default less likely and, therefore, increases the value of the bank.

A different story is if we include the value for the government. In this case on one hand, we have the bankruptcy cost and in the other hand we have the financial distress cost. In the scenario with CoCos the abandon, and therefore the bankruptcy cost, is less likely but the probability of the financial distress situations increases with respect to the scenario with debt. So, comparing both cost (bankruptcy and financial distress) we have which option is the best. As expected, it depends on total income (x) because the higher the total income the less likely is the default.

Figure 5: Debt value and equity value under the three scenarios of the simulated results

This figure represents the equity value, the debt value and the aggregate CoCo plus debt value under the three scenarios of the simulated results: In the first scenario we have the same amount of equity, debt and CoCo claim (solid line), in the second scenario we switch the CoCo claim for equity (dotted line) whereas in the third scenario we switch the CoCo claim for debt (dash line). Since the face value is not the same under the three scenarios considered, in this case the result are presented normalized by the face value.





However, even it is interesting to see what it is the best alternative, it is worth notice to mention that are the shareholders who decide among the three alternatives: to increase capital, to issue debt or to issue CoCo. Therefore, in Figure 5 we have the value of the equity value (normalized) under the three scenarios[7]. It is interesting to notice that, as expected, when the bank is in difficulties (equity value is very low), the best scenario for equity holders is the equity one because when a bank is close to bankruptcy the most effective measure is an increase of capital.

On the other hand, in good times, the equity scenario is the one less valuable for equity due to the dilution effect. In good times equity prefers debt, afterwards CoCos and in the last position equity. The reason is clear, due to limited liability, equity holders prefer debt. If debt is not possible due to solvency regulation, they prefer to issue CoCos because in good times CoCos behave like debt. However, they would prefer debt because debt cannot be converted into equity in bad times, and this avoids the dilution effect.

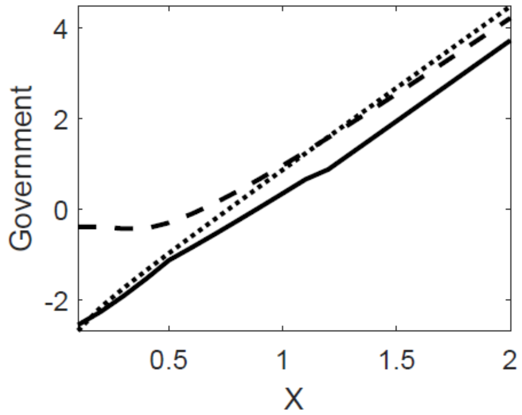
We can find as well in Figure 5 that, as expected, the debt value and the aggregate value of debt plus CoCos is higher in the equity scenario. The reason for this is, again, that the higher is equity the less likely is default and, consequently, debt and CoCos claims value increases. As before, since in the CoCo scenario there is the possibility to convert into equity, debt and CoCo values are higher than in the debt scenario.

Therefore, even on aggregate terms the best for a bank is to issue equity, equity holders, the ones who decide, prefer to issue debt due to limited liability. However, due to solvency regulation, banks are not allowed to issue all the debt that they wanted. Under these circumstances banks issue CoCos instead of equity even if this action leads to a situation in which financial distress is more likely.

Figure 6: Government value under the three scenarios of the simulated results

This figure represents the government value under the three scenarios of the simulated results: In the first scenario we have the same amount of equity, debt and CoCo claim (solid line), in the second scenario we switch the CoCo claim for equity (dotted line) whereas in the third scenario we switch the CoCo claim for debt (dash line).

[7] Since the face value is not the same under the three scenarios considered, in this case the results are presented normalized by the face value.



Finally, in Figure 6 we have the value for the government under the three scenarios. Due to the increase in financial distress probabilities and the tax treatment of CoCo coupons, the Governmental stake loses with the issuance of CoCos. In good times the government prefers equity financing because it delays abandonment. In bad times it prefers debt.

6. Discussion

The significant and far-reaching impacts of the 2007-2009 financial crisis should be carefully prevented. Financial regulators worked on ensuring that these events would not repeat itself by enforcing new regulations aiming at strengthening the banks' ability to absorb shocks arising from financial and economic stress, improve risk management and governance, and strengthen banks' transparency and disclosures (e.g. Basel III).

The 2007-2009 crisis had many causes that needed to be addressed, amongst which the complexity of financial securities (Schwartz, 2011, Blinder, 2013) and regulatory failures (Blinder, 2013, Shoen, 2017), are commonly highlighted8.

Paradoxically, in terms of complexity, Asset Backed Securities and Securities generated by Securitizations pale in comparison with the securities that emerged in the aftermath and, as a result, of the financial crisis. CoCos (Bolton et al., 2023) are highly complex securities9 that present obvious challenges in terms of valuation and consequently price efficiency. When we started the model presented in Section 2, we were unaware of the length and complexity of what would follow. It is important to highlight that our model is incomplete in what respects AT1 CoCos (does not include discretionary triggers) and considers market values instead of book values10. Any attempt at

[8] As additional causes of the financial crisis Schoen (2017) presents housing and bond bubbles, excessive leverage, disgraceful banking practices, abysmal rating agency; Schwarcz (2011) presents conflicts of interest, complacency of market participants and a type of tragedy of the commons; Blinder (2013) presents inflated asset prices and perverse compensation systems.

[9] To be fair, CoCos are not the only complex security coming out of the 2007-09 financial crisis, cryptocurrencies and particularly Tokens are very complex securities. There is however a fundamental difference between Tokens and CoCos, while the former was developed by private investors with the purpose of avoiding regulation, the latter was actively promoted by regulators.

[10] To model book values within an earnings model would necessarily require the introduction of an additional stochastic process for Capital with an arbitrarily defined correlation between the two stochastic processes.

developing a more accurate model of Pricing CoCos would increase the complexity of the model manifold.

In terms of regulation and specifically in terms of regulatory uncertainty, it also appears that we made little headway. In the run up to the financial crisis there was uncertainty with respect to the legal rights of Asset Backed Securities (Landsman et al., 2008) or even Preferred Shares (Zunzunegui, 2014), currently there is considerable uncertainty with CoCos (Choi and Zhang, 2024).

With respect to CoCos, Bolton et al. (2023) highlights the considerable ambiguity introduced by discretionary triggers, by the interpretation of different regulators, and the unclear framing of write-down CoCos within absolute priority rules. Apart from the uncertainty created by triggers, we add the role of the discretionary coupon suspension. The simple coupon suspension of an AT1 write-down CoCo leads to an effective wipe out of the security, in an apparent violation of absolute priority rules.

7. Conclusions

This paper models an AT1 CoCo debt with conversion features. We have carried out some simulations under different scenarios for valuing the different claims used in this paper: equity, debt and CoCo claims.

If we sum up the aggregate value of the three claims, the best alternative is equity because it prevents distress and default. However, CoCo financing is preferred to standard debt. Even if distress is triggered earlier with CoCos, the fact that it is converted to equity and coupons are suspended makes the default less likely and, therefore, increases the value of the bank. A different story is if we include the value for the government. Given the tax treatment of CoCo coupons and the higher likelihood of distress the value of this security for the government is clearly negative.

It is worth notice to mention that the shareholders are the ones who decide. In this respect: (i) When the bank is in difficulties, the best scenario for equity holders is equity, however, (ii) In good times equity holders prefer debt, followed by CoCos and lastly equity. If debt cannot be issued due to solvency regulation, equity prefers to issue CoCos because in good times CoCo claims behave like debt.

Our results highlight the role in CoCo debt in alleviating the pain of equity in a context of pressing need to recapitalize banks and CoCos performed their role adequately. Nonetheless, when we contrast the application of CoCos as a potential replacement of Equity or of Debt the results show that CoCos perform better when replacing debt.

Our results have implications for bank managers, investors and regulators. With respect to the latter, having overcome the period of debt overhang, it is possible that given its simpler nature and superior performance Tier 2 CoCos should be promoted instead of AT1 CoCos. Another aspect that theoretical analyses of CoCos, such as ours, highlight is the difficulties in modelling Book Value triggers, given the fact that they represent path dependency problems. In this sense, we believe there is scope for further evolution of this type of contracts and for further innovations.

Our paper contrasts the role of AT1 CoCos as replacements of debt or equity financing. In reality, a CoCo aimed at replacing debt does not require the characteristics of an AT1 CoCo, and future research on the topic should contrast two instruments in two scenarios and not simply one instrument in two scenarios. We also believe that reversive convertibles should also be explored as potential replacements or complements for CoCo debt. Although very similar in structure, reverse convertibles avoid the problems associated with Book Value triggers.

Appendix

Proof of Proposition 3:

Since the higher and the lower stages are absorbing stages, we only have the two "value matching" conditions to infer B_1^{E+C} and B_2^{E+C}. This value matching conditions are:

$$\left(\frac{x_d - c_o}{\delta} - \frac{c_d}{r}\right)(1-\tau) - \left[\left(\frac{x_a^{**} - c_o}{\delta} - \frac{c_d}{r}\right)(1-\tau) + K + \frac{c_c}{r}\right]\left(\frac{x_d}{x_a^{**}}\right)^{\beta_2} = \left(\frac{x_d - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + B_1^{E+C} x_d^{\beta_1^*} + B_2^{E+C} x_d^{\beta_2^*} \quad \text{(A1)}$$

$$-K - \frac{c_c}{r} = \left(\frac{x_a^* - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + B_1^{E+C} x_a^{*\beta_1^*} + B_2^{E+C} x_a^{*\beta_2^*} \quad \text{(A2)}$$

Multiplying equation (A2) by $\left(\frac{x_d}{x_a^*}\right)^{\beta_1^*}$ and subtracting it from equation (A1) we have that:

$$B_2^{E+C} = \frac{1}{\left(x_d^{\beta_2^*} - x_d^{\beta_1^*} x_a^{*(\beta_2^* - \beta_1^*)}\right)}\left\{\left(\frac{x_d - c_o}{\delta} - \frac{x_d - c_o^*}{\delta^*}\right)(1-\tau) - \left[\left(\frac{x_a^{**} - c_o}{\delta} - \frac{c_d}{r}\right)(1-\tau) + K + \frac{c_c}{r}\right]\left(\frac{x_d}{x_a^{**}}\right)^{\beta_2} + \left[\left(\frac{x_a^* - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + K + \frac{c_c}{r}\right]\left(\frac{x_d}{x_a^*}\right)^{\beta_1^*}\right\} \quad \text{(A3)}$$

In the same way, multiplying equation (A2) by $\left(\frac{x_d}{x_a^*}\right)^{\beta_2^*}$ and subtracting it from equation (A1) we have that:

$$B_1^{E+C} = \frac{1}{\left(x_d^{\beta_1^*} - x_d^{\beta_2^*} x_a^{*(\beta_1^* - \beta_2^*)}\right)}\left\{\left(\frac{x_d - c_o}{\delta} - \frac{x_d - c_e^*}{\delta^*}\right)(1-\tau) - \left[\left(\frac{x_a^{**} - c_e}{\delta} - \frac{c_d}{r}\right)(1-\tau) + K + \frac{c_c}{r}\right]\left(\frac{x_d}{x_a^{**}}\right)^{\beta_2} + \left[\left(\frac{x_a^* - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + K + \frac{c_c}{r}\right]\left(\frac{x_d}{x_a^*}\right)^{\beta_2^*}\right\} \quad \text{(A4)}$$

Proof of Proposition 4:

As usual in this kind of problems, to avoid explosive solutions $B_{1H}^E = 0$. So we have three coefficients to infer and three equations: two value matching and one contact condition in x_s.

$$\left(\frac{x_I - c_o}{\delta} - \frac{c_d + c_c}{r}\right)(1-\tau) + B_{2H}^E x_s^{\beta_2} = \left(\frac{x_I - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + B_{1M}^E x_s^{\beta_1^*} + B_{2M}^E x_s^{\beta_2^*} \quad \text{(A5)}$$

$$\beta_2 B_{2H}^E x_s^{(\beta_2 - 1)} = \beta_1^* B_{1M}^E x_s^{(\beta_1^* - 1)} + \beta_2^* B_{2M}^E x_s^{(\beta_2^* - 1)} \quad \text{(A6)}$$

$$\left(\frac{x_c - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + B_{1M}^E x_c^{\beta_1^*} + B_{2M}^E x_c^{\beta_2^*} = \frac{E_c}{E_c + \frac{c_c}{r}R}\left[\left(\frac{x_c - c_o^*}{\delta^*} - \frac{c_d}{r}\right)(1-\tau) + B_1^{E+C} x_c^{\beta_1^*} + B_2^{E+C} x_c^{\beta_2^*}\right] \quad \text{(A7)}$$

Equations (A5) to (A7) can be solved as done in the proof of Proposition 3. For the sake of brevity we are not going to present the results here, however they are available upon reader request.

Additionally, since x_s is chosen by the shareholders, we need to use a super-contact condition,

$$\beta_2(\beta_2 - 1) B_{2H}^E x_s^{(\beta_2 - 2)} = \beta_1^*(\beta_1^* - 1) B_{1M}^E x_s^{(\beta_1^* - 2)} + \beta_2^*(\beta_2^* - 1) B_{2M}^E x_s^{(\beta_2^* - 2)} \quad \text{(A8)}$$

This equation is not linear and, therefore, needs to be solved numerically.

Proof of Proposition 5:

As in the case of E(x), to avoid explosive solutions we have $B_{1H}^{Coco}=0$ and there are three equations with three unknowns.

$$\frac{c_c}{r}+B_{2H}^{C}x_I^{\beta_2}=B_{1M}^{C}x_I^{\beta_1^*}+B_{2M}^{C}x_I^{\beta_2^*} \quad \text{(A9)}$$

$$\beta_2 B_{2H}^{C}x_I^{(\beta_2-1)}=\beta_1^* B_{1M}^{C}x_I^{(\beta_1^*-1)}+\beta_2^* B_{2M}^{C}x_I^{(\beta_2^*-1)}$$
(A10)

$$B_{1M}^{C}x_c^{\beta_1^*}+B_{2M}^{C}x_c^{\beta_2^*}=\frac{\frac{c_c}{r}R}{E_c+\frac{c_c}{r}R}\left[\left(\frac{x_c-c_o^*}{\delta^*}-\frac{c_d}{r}\right)(1-\tau)+B_1^{E+C}x_c^{\beta_1^*}+B_2^{E+C}x_c^{\beta_2^*}\right]$$
(A11)

Equations (A9) to (A11) can be solved as done in the proof of Proposition 3. For the sake of brevity we are not going to present the results here, however they are available upon reader request.

Proof of Proposition 7:

As in the case of equity plus CoCo, since the higher and the lower stages are absorbing stages, we only have the two “value matching” conditions to infer the coefficients. Following the same procedure as before we have that:

$$B_2^D=\frac{1}{\left(x_d^{\beta_2^*}-x_d^{\beta_1^*}x_a^{*(\beta_2^*-\beta_1^*)}\right)}\left\{-\left[(2-\lambda)\frac{c_d}{r}-max\left\{\frac{x_a^{**}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x_d}{x_a^{**}}\right)^{\beta_2}+\left[(2-\lambda)\frac{c_d}{r}-max\left\{\frac{x_a^{*}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x_d}{x_a^{*}}\right)^{\beta_1^*}\right\} \quad \text{(A12)}$$

$$B_1^D=\frac{1}{\left(x_d^{\beta_1^*}-x_d^{\beta_2^*}x_a^{*(\beta_1^*-\beta_2^*)}\right)}\left\{-\left[(2-\lambda)\frac{c_d}{r}-max\left\{\frac{x_a^{**}-c_o^*}{\delta^*}+(1-\gamma)\left(\mathrm{K}+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x_d}{x_a^{**}}\right)^{\beta_2}+\left[(2-\lambda)\frac{c_d}{r}-max\left\{\frac{x_a^{*}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x_d}{x_a^{*}}\right)^{\beta_2^*}\right\}$$
(A13)

$$B_2^G=\frac{1}{\left(x_d^{\beta_2^*}-x_d^{\beta_1^*}x_a^{*(\beta_2^*-\beta_1^*)}\right)}\left\{\left(\frac{x_d-c_o}{\delta}-\frac{x_d-c_o^*}{\delta^*}\right)\tau-\left[\left(\frac{x_a^{**}-c_o}{\delta}-\frac{c_d}{r}\right)\tau-min\left\{\frac{x_a^{**}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x_d}{x_a^{**}}\right)^{\beta_2}+\left[\left(\frac{x_a^{*}-c_o^*}{\delta^*}-\frac{c_d}{r}\right)\tau-min\left\{\frac{x_a^{*}-c_o^*}{\delta^*}+(1-\gamma)\left(K+\frac{c_c}{r}+(1-\lambda)\frac{c_d}{r}\right),0\right\}\right]\left(\frac{x_d}{x_a^{*}}\right)^{\beta_1^*}\right\} \quad \text{(A14)}$$

$$B_1^G = \frac{1}{\left(x_d^{\beta_1^*} - x_d^{\beta_2^*} x_a^{*(\beta_1^*-\beta_2^*)}\right)} \left\{ \left(\frac{x_d - c_o}{\delta} - \frac{x_d - c_o^*}{\delta^*} \right) \tau \right.$$

$$- \left[\left(\frac{x_a^{**} - c_o}{\delta} - \frac{c_d}{r} \right) \tau \right.$$

$$\left. - \min \left\{ \frac{x_a^{**} - c_o^*}{\delta^*} + (1-\gamma) \left(K + \frac{c_c}{r} + (1-\lambda) \frac{c_d}{r} \right), 0 \right\} \right] \left(\frac{x_d}{x_a^{**}} \right)^{\beta_2}$$

$$\left. + \left[\left(\frac{x_a^* - c_o^*}{\delta^*} - \frac{c_d}{r} \right) \tau - \min \left\{ \frac{x_a^* - c_o^*}{\delta^*} + (1-\gamma) \left(K + \frac{c_c}{r} + (1-\lambda) \frac{c_d}{r} \right), 0 \right\} \right] \left(\frac{x_d}{x_a^*} \right)^{\beta_2^*} \right\}$$

(A15)

Proof of Proposition 8:

As usual in this kind of problems, to avoid explosive solutions $B_{1H}^G = B_{1H}^D = 0$.

In the case of the government, the third ($if\ x_a \leq x \leq x_c$) and the fourth ($if\ x \leq x_a$) are absorbing levels which are already solved. So we have three coefficients to infer and three equations: two value matching and one contact condition in x_I.

$$\left(\frac{x_I - c_o}{\delta} - \frac{c_d + c_c}{r} \right) \tau + B_{2H}^G x_I^{\beta_2} = \left(\frac{x_I - c_o^*}{\delta^*} - \frac{c_d}{r} \right) \tau + B_{1M}^G x_I^{\beta_1^*} + B_{2M}^G x_I^{\beta_2^*} \quad \text{(A16)}$$

$$\beta_2 B_{2H}^G x_I^{(\beta_2 - 1)} = \beta_1^* B_{1M}^G x_I^{(\beta_1^* - 1)} + \beta_2^* B_{2M}^G x_I^{(\beta_2^* - 1)} \quad \text{(A17)}$$

$$B_{1M}^G x_c^{\beta_1^*} + B_{2M}^G x_c^{\beta_2^*} = B_1^G x_c^{\beta_1^*} + B_2^G x_c^{\beta_2^*} \quad \text{(A18)}$$

Equations (30) to (32) can be solved as done in the proof of Proposition 3. For the sake of brevity we are not going to present the results here, however they are available upon reader request.

In the case of the debt holder, we have just one equation for one coefficient, so, it is easy to solve:

$$B_{2H}^D = B_1^D x_c^{(\beta_1^* - \beta_2)} + B_2^D x_c^{(\beta_2^* - \beta_2)} \quad \text{(A19)}$$

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Acknowledgements

We thank Jérôme Henry, Katrin Assenmacher, Samuele Scaglioni, Marián Ruiz Martin and Nadya Wildmann for their very helpful comments. Ricardo Correia acknowledges financial support from the Spanish Ministry of Science, Innovation and Universities (grants PID2023-149010NB-I00) and the Madrid Regional Government (grant PHS-2024/PH-HUM-294).
This paper should not be reported as representing the views of the Banco de España (BdE) or the European Central Bank (ECB). The views expressed are those of the authors and do not necessarily reflect those of the BdE or ECB. All errors remain entirely the authors.

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PDF ISBN 978-92-899-7614-5 ISSN 1725-2806 doi:10.2866/8490831 QB-01-26-002-EN-N