Contingent Debt and Investment

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ABSTRACT

This paper studies the implication of contingent debt (CoCo) on banks' optimal investment policy. CoCo is found to mitigate the standard debt-overhang problem when used to finance investment. On the other hand, having contingent debt outstanding prior to investment leads to the delay of investment via two channels: increased debt-overhang owning to the fact that contingent debt is riskier than standard debt and dilution cost associated with the conversion of contingent debt. The paper argues that CoCo, as a new regulatory tool which is meant to increase banks' stability, can negatively affect banks' incentives to invest.

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1 Introduction

Since 2009 more than 160 banks (primarily from the EU) made about 350 issuances of contingent convertible bonds (CoCos) in the total amount exceeding \$335bn[1]. The introduction of CoCo by regulators (Basel Committe (2010)) aimed at improving banks' stability. However, a potential effect of CoCos on banks' investment seemed not to be considered. By examining the effect of CoCo financing on banks' optimal investment policy, I show that contingent convertibles can negatively affect banks' incentives to invest. Given a special role of banks as fund providers, the decreased incentives to invest may have potentially detrimental effect to the rest of the economy.

The financial crisis of 2007-2009 has demonstrated that banks' capital requirements were inadequately low in order to insure banks' reasonable loss absorption capacity. As a result of such an experience banking regulators turned to significantly higher capital requirements introduced by Basel Committe (2010). In order to lower the cost of meeting these capital requirements and to ensure a swiftly recapitalization of banks without regulatory intervention a new prudential instrument was introduced - contingent debt (a.k.a. CoCo[2]). As an alternative source of regulatory capital, CoCo was first introduced in Flannery (2002) and Flannery (2005), which was later modified by a number of authors as well as practitioners (e.g. Squam Lake (2010)).

CoCo is a hybrid debt instrument issued by a bank that absorbs bank's losses in accordance with their contractual terms once the capital ratio of the issuing bank drops below a prespecified level. The idea behind CoCo is simple: it is meant to provide bank's capital in the state it is mostly needed - when capital is depleting. The two main characteristics of any CoCo is its loss absorption mechanism and trigger level. As far as the loss absorption mechanism is concerned there are two most common kinds: equity conversion (EC) and principal write down. Under the EC loss absorption mechanism, upon reaching a prespecified trigger event the face value of CoCo converts into equity according to a prespecified conversion rate. Alternatively, under the PWD loss absorption mechanism, CoCo face value is written down upon reaching a prespecified trigger event. CoCo's trigger is usually defined in term of the common equity tier 1 (CET1) ratio. The trigger event is the violation of the prespecified trigger level. Depending on a trigger level different regulatory treatment of CoCo is possible[3].

The first issuances of CoCo took place in 2009. Danske Bank A/S issued perpetual PWD CoCos with the face value of about \$4.4bn followed by Lloyds Bank's issuance of both EC and PWD CoCos with various maturities and trigger levels in the total amount of about \$17bn. As of the mid of 2016 159 banks (primarily from the EU) made 347 issuances of CoCo in the total amount of more than \$335bn[4]. Most of CoCo issued are additional T1 capital instruments. The higher growth of CoCo market is projected since banks have to meet new capital requirements by 2018.

As of today in most of the jurisdictions that have seen CoCo issuance the latter is treated

[1]Bloomberg

[2]CoCo stands for contingent convertible. Not all contingent capital instruments are convertibles, some are written down. However, I use the term CoCo as a synonym of contingent debt.

[3]CoCos can count as either additional T1 capital if it is perpetual with trigger level above 5.125 % or T2 capital.

[4]Bloomberg

as debt for tax purposes, that is, the interest payments on CoCo are tax deductible. One of the last countries within the EU that has adopted the debt treatment of CoCos for tax purposes was Ireland in the mid of 2015. However, there is still one jurisdiction that does not treat CoCos as debt, and has not seen any CoCos issuances, which is the US. The paper by Goncharenko and Rauf (2016), analyzing the sample of CoCo issuance in the EU during 2011-2016, argues that the tax deductibility of CoCo was an important factor in whether a given jurisdiction saw CoCo issuances.

To study the effect of CoCos on banks' investment policy I use a dynamic contingent claim model a la Leland (1994) augmented with investment opportunity set similarly to Heckemeyer and de Mooij (2013) and Sundaresan, Wang, and Yang (2014). In my model bank operates in the regulatory environment characterized by the possibility of having its charter withdrawn should it experience severe undercapitalization. The loss of the charter then leads to a costly resolution process. The bank's investment opportunity set is characterized by a growth option. The timing of the growth option exercises is optimally chosen by the bank. The bank's initial (prior to exercising growth option) optimal capital structure consists of senior debt and CoCo. To cover the cost associated with the growth option exercise the bank issues optimal combination of CoCo and subordinated debt. Debt and CoCo have tax-deductible interest payments. Therefore, the bank optimally chooses financing and investment policy that trades off the benefits of tax shields and the cost of regulatory closure.

The impact of CoCo on the investment policy can be disentangled into two effects. The first effect comes from the use of CoCo as a means to raise funds for investment purpose. This effect is found to have positive impact on the bank's investment incentives by mitigating the standard debt-overhang problem. The second effect comes from having CoCo outstanding prior to investment. This effect has a negative impact on the bank's investment incentives via increased debt overhang and the dilution cost of equity associated with CoCo conversion.

Having some debt outstanding induces bank to delay profitable investment due to the standard debt overhang problem. Without CoCo there are only two ways the bank can finance the investment outlay: junior debt or equity. Investing with equity produces no tax shields but at the same time does not directly increase the likelihood of regulatory closure. Investing with equity, hence, will increase the market value of debt the most, and thus, is associated with the highest severity of debt overhang problem. Financing the investment outlay with subordinated debt, on the other hand, will produce tax shields and, at the same time, will positively affect the likelihood of failure. Because junior debt increases the investment payoff via tax shields and at the same time dilutes the market value of senior debt via increased likelihood of failure, it is normally associated with less sever debt-overhang problem. CoCo is a hybrid of debt and equity in that it produces tax shields and does not increase the likelihood of failure. Therefore, investing with CoCo helps to mitigate the standard debt-overhang problem and results in earlier investment than under junior debt financing.

On the other hand, having CoCo outstanding prior to investment has an opposite effect on the timing of investment. There are two channels through which outstanding CoCo can affect the bank's optimal investment policy. First, as any type of debt CoCo creates the standard debt-overhang problem: a payoff from investment is shared among equityholders, debtholders and CoCo holders. In fact, given that CoCo has higher coupons per principal (i.e. riskier) than senior debt, the debt overhang associated with CoCo is even severer than that coming from senior debt. Secondly, if the bank has an EC CoCo outstanding prior to investment then investing with any debt has a negative value on shareholders' equity through the dilution cost associated with CoCo conversion. Issuing subordinated debt, or any debt for that matter, will increase the likelihood of the conversion, and, hence, the dilution cost associated with it. The strength of the effect depends on the conversion rate, of course: for a PWD CoCo, for example, there is no dilution cost at all. The debt overhang problem associated with a PWD CoCo is stronger than that of an EC CoCo because the latter is less risky than the former. However, investment still takes place earlier when the bank has a PWD CoCo outstanding thanks to the absence of the equity dilution cost. Therefore, this paper identifies the superiority of the PWD loss absorption mechanism over the EC one in terms of the effect of CoCo on investment policy.

The robustness of the effect of CoCo on bank's investment policy is examined for different values of the model parameters. I find that the results persist for realistic set of parameter constellation.

The model has also predictions regarding bank's preference over CoCo's loss absorption mechanism. I find that banks with more volatile assets opt for an EC CoCo, whereas their counterparts with lower asset volatility optimally issue a PWD CoCo. Moreover, in the model, the amount of CoCo issued negatively depends on bank's asset volatility. Both facts have been empirically confirmed by Goncharenko and Rauf (2016).

The rest of the paper is organized in the following manner. Next I review literature on CoCo. Section 2 presents the general model. Next, Section 3 discusses the model's assumptions. Section 4 presents the analysis of the simplified model. Finally, Section 5 examines the robustness of the results to different parameter values.

Literature Review

The literature on CoCos, which is surveyed below, has blossomed in a rather short period of time. Initially papers on CoCo focused primarily on two following issues. The first issue being the effect of CoCos upon banks' capital structure, though, without modeling CoCo as the part of the optimal capital structure. In all of the papers analyzing the effect of CoCo on capital structure either the choice of the entire capital structure is not modeled endogenously (e.g. Glasserman and Nouri (2012a),Pennacchi (2010), Pennacchi, Vermaelen, and Wolff (2014), Chen, Glasserman, Nouri, and Pelger (2015)) or the choice of CoCo (Albul, Jaffee, and Tchistyi (2013)). The second issue being the pricing of CoCo (Sundaresan and Wang (2015) and Pennacchi and Tchistyi (2015)). Recently, more attention has been payed to the effect of CoCo on risk incentives (Zeng (2014)).

Glasserman and Nouri (2012a) use Merton (1974)'s framework to study properties of CoCo with accounting-based trigger. They show that whenever the trigger is reached the conversion of

CoCo into equity will occur by the amount just sufficient to meet the capital requirements. Yield spreads are derived in a tractable way assuming that the trigger takes place prior bankruptcy. The calibration shows that the fair yield for contingent capital, in their model, is sensitive to some of the model's inputs such as the size of the convertible tranche, to the volatility of the firm's assets, and to the recovery rates. They argue that this sensitivity as well as overall complexity of the securities can become an obstacle to generating the investor demand.

Albul et al. (2013) (henceforth AJT), employ the model a la Leland (1994) in order to analyze the implication of CoCo financing. The focus, as well as in the previous paper, on capital structure decision. The trigger is assumed to be placed on firm's asset value and the closed form solution for the optimal capital structure including CoCo is derived. AJT show that introducing CoCo into firms De Novo capital structure in an exogenous fashion, increases firms value by the tax shield associated with CoCo, CoCo crowds out adjusted-to-tax-benefit equity one-to-one, and has no effect either on straight debt or on default. AJT demonstrate that under the capital requirement constraints CoCo reduces bankruptcy cost and may even increase firms value. Finally, AJT find that if a leveraged firm replaces a fraction of straight debt with CoCos, the value of equity decreases, firms value may increase , and, bankruptcy cost decreases.

AJT also show that CoCos can increase firm value and reduce the chance of costly bankruptcy or bailout if properly implemented. However, shareholders of overleveraged or too-big-to-fail firms may resist straight-debt-for-CoCo swaps due to the debt-overhang problem or the loss of the government subsidy. The debt in the model is perpetual and, thus, any reduction in bankruptcy cost accrues entirely to the initial debtholders.

Pennacchi (2010) uses a structural approach to model a bank that has short-term deposits, common equity, and CoCo bonds. Banks asset follow a diffusion process with jumps.The short term deposits are priced at par. The trigger is placed on a ratio of the asset value to the combined value of CoCos and equity assuming that bankruptcy is costless. This helps him to get unique equilibrium in stock and CoCo prices because the ratio is independent of the conversion of CoCos.

Pennacchi et al. (2014) adopt the framework by Pennacchi (2010) but propose a different design of CoCo labeling it as COERC. COERC allows the bank's original shareholders to buy back the shares at the par value of the bond. They assume that the MM world holds and, hence, do not model cost of financial distress, which obviously is important for banks.

Chen et al. (2015) use a contingent model to study the design of CoCo bonds and their incentive effects in a structural model with endogenous default, debt rollover, and tail risk. The low tail risk is modeled by letting banks asset value follow a diffusion process with downward jumps. They show that once the firm issues CoCo the optimally chosen bankruptcy level can be at one of two levels: (1) a lower level with a low default risk and (2) higher level at which default precedes conversion. An increase in the firm's total debt load can move the firm from the first regime to the second, a phenomenon they call debt induced collapse because it is accompanied by a sharp drop in equity value. By setting the trigger sufficiently high allows to avoid such a hazard. Since debt has finite maturity in the model, in contrast to Albul et al. (2013), Chen et al. (2015) find that sometimes the shareholders will want to issue CoCo bonds because the associated reduction in bankruptcy cost will reduce the interest rate required on subsequent debt issues.

Himmelberg and Tsyplakov (2012) use a model of dynamic capital structure choice to analyze how contractual terms of CoCo bonds affect future capital structure incentives. They pay special attention to the loss absorption mechanism. In particular, they find that the principal write-down leads create perverse incentives for banks to pursue higher leverage. On the other hand, conversion to equity creates incentive for banks to pursue lower leverage in order to avoid dilution costs. Finally, they show that banks may choose not to issue CoCos because large fraction of the benefits is captured by existing bondholders. Himmelberg and Tsyplakov (2012)'s model is heavily parametrized: many variables of interest, such as, total debt principal, coupons, default boundaries, are set exogenously in order to calibrate certain ratios.

Hilscher and Raviv (2014) use Merton (1974)'s model to study the effect of contingent securities on risk taking and default probability. They find that there is a reduction in the default probability of a bank issuing a CoCo bond. They also find that appropriate choice of contingent capital terms (such as conversion ratio) can virtually eliminate shareholders' incentives to risk-shift (a problem that is present when banks do not issue CoCos). Only CoCos with conversion-to-equity loss absorption mechanism are analyzed. All securities issued by bank have the same finite maturity (including deposits). The default boundary is specified exogenously.

Hilscher and Raviv (2014), as well as all the models surveyed so far, assume asset in place - there is no investment decisions. These means, that most of the results with regard to debt-overhang and risk-shifting can only be obtained in an implicit way in the style of Leland and Toft (1996), that is to say, this analysis shows the mere potential of the incentive problem. Because of that, no quantitative prediction on this ground can be made (it is important to note that all of the models surveyed are though of as quantitative models).

Other papers deal with equilibrium price issues of CoCos. For example, an early CoCo proposal (Flannery (2005)) specified that bondholders should receive shares worth the band's par value of day's closing price. The idea was that such CoCo would be quite safe since investors would be repaid in dollars or in an equivalent value of shares. Unfortunately, such a conversion mechanism could give to short sellers an unusual opportunity. One then could bid down the share price forcing conversion and increasing the number of shares outstanding. Alternatively, CoCos could be converted into a number of shares implied by the trigger. Although, that fixes the previous problem with conversion, it almost surely guarantees then that the CoCo holders will loose at the conversion making CoCo very expensive (potential too expensive to have any demand at all).

The literature on CoCo with stock market triggers starts from Sundaresan and Wang (2015) (SW henceforth). This paper concludes that if bank issues CoCo with a stock market trigger then its stock price will either have multiple equilibria (if CoCo conversion terms are advantageous to the CoCo holders) or none (if CoCo conversion terms are advantageous to the banks initial shareholders). Later Glasserman and Nouri (2012b) (GN henceforth), using similar setting, confirm the case of no equilibrium, but demonstrate that under conditions which deliver multiple equilibria in SW, the unique equilibrium stock price emerges.

Paper by Pennacchi and Tchistyi (2015) (henceforth PT) contributes to this strand of literature by, first, rationalizing the different predictions of SW and GN regarding CoCos that have conversion terms advantageous to the CoCo holders. In particular, they show a counter example to the proof by SW regarding multiplicity of equilibria and confirm the correctness of GNs unique equilibrium. Secondly, PT show that if one assumes that CoCo is perpetual (papers by SW and GN assumed finite maturity) and most of CoCos are perpetual then under realistic parameter constellation even CoCos with conversion terms advantageous to the banks initial shareholders yield a unique equilibrium of stock price. Moreover, PT identify the exact problem that led both SW and GN to conclude nonexistence of equilibrium this is a lump sum principal payment at maturity that destroys the existence of a unique equilibrium stock price when conversion terms are favorable to initial equityholders.

McDonald (2013) suggests a dual price trigger. In particular, McDonald (2013) argues that a CoCo should convert when two conditions are met: the firm's stock price is at or below a trigger value and the value of a financial institutions index is also at or below some trigger value. Such a structure would potentially protect firms during a crisis, when all firms are doing badly, but at the same time, in good times, it allows a bad bank to go bankrupt.

A paper by Bolton and Samama (2012) propose an alternative instrument to CoCo bond - a capital access bonds (CAB). The basic idea is that a bank issuing a CAB effectively purchasing rights to issue equity in crisis events at a pre-specified price form long term-investors. By doing that, an issuing bank can ensure it will have sufficient regulatory capital when it needs it most - in a crisis. Thus, this bond from the point of view of the issuer is an American option (can be converted prior the maturity). If the bond is not converted it give investors a regular coupon (interest plus put premium). If the bond is converted, then investors get a fixed number of newly issued shares. Thus, this reverse convertible bond is actually a collateralized put option - because the commitment to buy equity will be honored since the money are paid upfront.

To my knowledge, there have only been a few empirical papers analyzing CoCo bonds (Avdjiev, Kartasheva, and Bogdanova (2013), Avdjiev, Bolton, Jiang, Kartasheva, and Bogdanova (2015) and Berg and Kaserer (2015)). Most of the institutional details on CoCos in the first sections of the paper have been borrowed from Avdjiev et al. (2013) and Avdjiev et al. (2015).

Avdjiev et al. (2013) is basically the first paper to present some basic empirical facts about CoCo market. Avdjiev et al. (2015) builds on Avdjiev et al. (2013) by tremendously expanding the sample of CoCo issues. They conduct the first comprehensive empirical study of the bank CoCo issues market between 2009 and 2015. They find that it is the large banks with adequate core capital that are among the earliest adopters of CoCo. Issuance of CoCos is documented to an average of 8 basis point drop in the issuers' CDS spread which indicates that CoCo issuance reduces banks' credit risk. The reduction of the CDS spread is shown to be increasing in the trigger ratio. At the same time no significant impact on equity prices of CoCo issuers is detected. But the trigger threshold is significantly positively (negatively) related to stock returns for principal write down (conversion to equity) CoCos.

Berg and Kaserer (2015) use a simple option-pricing example to illustrate that the issuance of CoCo bonds may increase equity holders' incentive for risk-shifting and decrease incentives to raise new equity during a crisis if there is a wealth transfer from CoCo investors to shareholders at the conversion point. They then consider a relatively small sample of CoCo issuances and argue that (1) almost all CoCo bonds designed in such a way that the above mentioned transfer is present and (2) this contractual design is reflected in traded prices of CoCos (the sensitivity of the CoCo bond total return with respect to a changes in implied volatility is approximately five times larger than the corresponding sensitivity on the straight bond). They conclude, that CoCo bonds, given their current design, may create perverse incentives for banks' equity holders.

Zeng (2014) uses optimal contracting approach to study the effect of CoCo on banks efficiency (*ex post* risk shifting) and the role of CoCo within banking regulation (the minimum capital requirements in particular). Paper argues that CoCo arises naturally in the equilibrium without regulation as means to implement more superior from efficiency point of view contingent capital structure of banks. Moreover, in the equilibrium with regulation (minimum capital requirements) CoCo emerges naturally in order to efficiently implement optimal countercyclical capital requirements.

2 General Model

Bank holds a portfolio of risky assets (loans, securities, etc.) generating cash flows. The value of such a portfolio is given by V_t at time t. The cash flow associated with the portfolio is denoted by Y_t. Under risk-neutral measure the dynamics of the cash flow follows geometric Brownian motion with drift

$$\mathrm{d}Y_t = \mu Y_t \mathrm{d}t + \sigma Y_t \mathrm{dW}^Q \tag{1}$$

where μ denotes a drift of the process under risk-neutral measure, σ is the volatility of the cash flow, W^Q is the Brownian motion under risk-neutral measure Q. Let r denote the risk-free interest rate. Then the after-tax value of the portfolio under risk-neutral measure is given by

$$V(Y_t) = (1-\tau)\,\mathbb{E}^Q\left[\int_t^\infty Y_s e^{-rs}\mathrm{d}s\right] = \frac{1-\tau}{r-\mu}Y_t \tag{2}$$

At $t = 0$, given the initial cash flow Y_0, the bank can issue two types of debt: standard (senior) debt and contingent-convertible (CoCo) debt. Let $D^0(Y_0)$ denote the face value of senior debt and $D_c^0(Y_0)$ the face of CoCo. The interest payment on both types of debt is assumed to be tax-deductible. In most of the jurisdictions that have seen large issuance of CoCo, mostly the EU, the latter is treated as debt for tax purposes by the local fiscal authority. The bank issues senior debt and CoCo trading off tax benefits to both types of debt and the cost of financial distress.

The bank has a growth option. The cost associated with the exercise of the growth option is assumed to be a constant $I > 0$. When the growth option is exercised the bank's assets value, V, is scaled up by a multiplicative factor to $(1+\phi)V$, where $\phi > 0$ measure the profitability of the growth option. For sufficiently large value of I the bank find it optimal to wait before exercising the growth option. Thus, the bank has to optimally decide on when to invest and how to cover the investment outlay I. Suppose that the bank invests at some random time T^i when its cash flow first time riches a certain threshold Y^i, discussed below. The fixed cost I is financed by optimally chosen combination of junior-debt, $D_s^i(Y^i)$, CoCo, $D_c^i(Y^i)$, and equity.

The balance sheet of the bank prior to investment, that is for $t \in [0, T^i]$, is presented in Table 1. Given the value of the bank's assets, $V(Y_t)$ and the book value of the risky debt, $D^0(Y_0)$, and CoCo, $D_c^0(Y_0)$, bank's tangible (regulatory) equity, $CET1$, is defined as the difference between bank's total assets and total debt, $CET1 = V(Y_t) - D - D_c$. Let, $F^0(Y_t)$ denote the total value of bank and $E^0(Y_t)$ denote the market value of bank's equity, both are prior to investment. The charter value of the bank, $CV^0(Y_t)$ can then be defined as the difference between bank's value $F^0(Y_t)$ and the value of the assets $V(Y_t)$.

The balance sheet of the bank after investment has been made, that is for $t \in (T^i, \infty)$, is presented in Table 2. The bank's asset value now is given by $(1+\phi)V(Y_t)$. Since when exercising the growth option bank can issue subordinated debt and CoCo its regulatory equity is defined as the difference between its asset and the total debt (including newly issued one), $CET1 = (1+\phi)V(Y_t) - D^0(Y_0) - D_c^0(Y_0)$. Let, $F^i(Y_t)$ denote the total value of bank and $E^i(Y_t)$ denote the market value of bank's equity, both are after investment. The charter value of the bank, $CV^i(Y_t)$ can then be defined as the difference between bank's value $F^i(Y_t)$ and the value of the assets $(1+\phi)V(Y_t)$.

Asset	Liability
Assets: $V(Y_t)$	Debt: $D^0(Y_0)$
	CoCo: $D_c^0(Y_0)$
	Tangible Equity (CET1): $V(Y_t) - D^0(Y_0) - D_c^0(Y_0)$
Charter Value: $CV^0(Y_t)$	Equity: $E^0(Y_t)$

Table 1 The bank's balance sheet prior to investment. $D^0(Y_0)$ and $D_c^0(Y_0)$ denote the face value of the bank's senior debt and CoCo, respectively. $CV^0(Y_t)$ denotes the charter value of the bank which is define as the dereference the bank's total value and its asset value. CET1 is the bank's regulatory equity defined as the difference between its asset value and its total debt. Finally, $E^0(Y_t)$ denotes the market value of the bank computed as the difference of the bank's total value and the market value of its total debt. The market value of equity includes the value of regulatory equity.

Asset	Liability
Assets: $(1+\phi)V(Y_t)$	Debt: $D^0(Y_0)$, $D_s^i(Y^i)$
	CoCo: $D_c^0(Y_0)$, $D_c^i(Y^i)$
	CET1: $(1-\phi)V(Y_t) - D^0(Y_0) - D_c^0(Y_0) - D_s^i(Y^i) - D_c^i(Y^i)$
Charter Value: $CV^i(Y_t)$	Equity: $E^i(Y_t)$

Table 2 The bank's balance sheet after investment. $D^0(Y_0)$, $D_s^i(Y^i)$, $D_c^0(Y_0)$, and $D_s^i(Y^i)$ denote the face value of the bank's senior debt, subordinated debt, CoCo issued prior to, and after investment, respectively. $CV^i(Y_t)$ denotes the charter value of the bank which is define as the dereference the bank's total value and its asset value. CET1 is the bank's regulatory equity defined as the difference between its asset value and its total debt. Finally, $E^i(Y_t)$ denotes the market value of the bank computed as the difference of the bank's total value and the market value of its total debt. The market value of equity includes the value of regulatory equity.

CoCo is characterized by a conversion trigger. Once this trigger is breached CoCo is either converted into equity (given a conversion rate) or is written down, depending on its loss absorption mechanism. The conversion trigger is typically placed on the CET1 ratio, which is defined as the ratio of CET1 to the bank's assets. This means, that when the CET1 ratio of the issuing bank falls below q^c, the trigger is breached. Because the bank's assets value is the function of the cash flow, it is possible to identify thresholds Y_0^c and Y_i^c that are associated with the breach of trigger prior to and after investment, respectively. When the cash process reaches Y_0^c first time from above the conversion trigger of CoCo with the face value $D_c^0(Y_0)$ will be breached. Similarly, when the cash process reaches Y_i^c first time from above the conversion trigger of CoCo with the face value $D_c^i(Y^i)$ will be breached.

Mathematically, the thresholds Y_0^c and Y_i^c can be obtained in closed from equating the CET1 ratio to the conversion trigger level before investment

$$\frac{V(Y_0^c) - D^0(Y_0) - D_c^0(Y_0)}{V(Y_0^c)} = q^c, \tag{3}$$

after investment, assuming CoCo issued before investment did not convert,

$$\frac{(1+\phi)\, V\left(Y^c_{i|nc}\right) - D^0\left(Y_0\right) - D^0_c\left(Y_0\right) - D^i_s\left(Y^i\right) - D^i_c\left(Y^i\right)}{V\left(Y^c_{i|nc}\right)} = q^c \tag{4}$$

and after investment, assuming CoCo issued before investment converted,

$$\frac{(1+\phi)\, V\left(Y^c_{i|c}\right) - D^0\left(Y_0\right) - D^i_s\left(Y^i\right) - D^i_c\left(Y^i\right)}{V\left(Y^c_{i|c}\right)} = q^c \tag{5}$$

Therefore, Y^c_i can take either value $Y^c_{i|c}$ or $Y^c_{i|nc}$ depending on whether the CoCo issued prior to investment converted or not, respectively. For later use, define index $j \in \{c, nc\}$ which is equal to nc if CoCo issued at date $t = 0$ does not convert prior to investment, and is equal to c, if it does so.

Bank operates in the regulatory environment facing a possibility of being closed by the charter authority. The closure rule is based on the regulatory capital which is measured by the CET1 ratio. For example, in the US the FDIC categorizes a bank as undercapitalized if bank's capital drops below 2 % of asset value. In this case a bank's chartering authority normally closes the bank (unless there is a good reason to believe the bank can be recapitalized) Shibut, Critchfield, and Bohn (2003). Obviously, the bank can be closed either before or after the growth option has been exercised.

Once again, because the bank's assets value is the function of the cash flow, it is possible to identify thresholds $Y^{0,r}$ and $Y^{i,r}_j$ that are associated with the regulatory closure prior to and after investment, respectively. (Note that $Y^{0,r}$ does not have subscript j since by the time the bank fails prior to investment the CoCo issued at time t=0 will have already converted). When the cash process reaches $Y^{0,r}$ for the first time from above prior to investment the bank will be closed. The bank will also be close when its cash flow falls below $Y^{i,r}_j$ for the first time after the growth option has been exercised.

Mathematically, the thresholds $Y^{0,r}$ and $Y^{i,r}_j$ can be obtained in closed from equating the CET1 ratio to the closure trigger level q before investment

$$\frac{V\left(Y^{0,r}\right) - D^0\left(Y_0\right)}{V\left(Y^{0,r}\right)} = q, \tag{6}$$

and after investment

$$\frac{(1+\phi)\, V\left(Y^{i,r}_j\right) - D^0\left(Y_0\right) - D^i_{s,j}\left(Y^i\right)}{V\left(Y^{i,r}_j\right)} = q. \tag{7}$$

The reason there is no CoCo in equations 6 and 7 is because by the time the CET1 ratio reaches q the bank will not hold any CoCo, since $q^c > q$.

In order to be able to write down the valuation formulas for debt, CoCo, and equity, which I need for solving the model, I define the prices of some Arrow-Debreu securities. The first Arrow-

Debreu security pays zero while the cash flow Y_t is strictly above a certain threshold Y^* and pays 1 when this threshold is reached for the first time. which pays 0 if the cash flow Y_t is strictly above a certain threshold Y^* and 1 when this threshold is reached. Let denote the prices of such a security as $A(Y_t, Y^*)$ The price of such a security then is denoted by $A(Y_t, Y^*)$, which functional form can be found in appendix A.

Next define two thresholds Y^* and Y_* such that $Y^* > Y_*$. Consider an Arrow-Debreu security that pays nothing if the cash flow process Y_t stays below Y^* and pays 1 if the process reaches Y^* for the first time from below, conditional that it did not reach Y_* before. Denote the prices of such a security by $\bar{A}(Y_t, Y^*, Y_*)$. The functional form of the price can be found in appendix A.

Finally, consider an Arrow-Debreu security that pays nothing if the cash flow process Y_t stays above Y_* and pays 1 if the process reaches Y_* for the first time from above, conditional that it did not reach Y^* before. Denote the prices of such a security by $\underline{A}(Y_t, Y^*, Y_*)$. The functional form of the price can be found in appendix A.

Having defined the Arrow-Debreu prices of the securities I next present the valuation formulas for debt, CoCo, and equity. I first present the valuation formulas after the growth option has been exercised and then the valuation formulas prior to investment. The valuation formulas are needed to set up the bank's optimization problem.

2.1 Valuations after Investment

The after tax value of assets after the growth option has been exercised, that is for any $t \geq \mathbb{T}_c^i$, is given by

$$V^i(Y_t) = (1-\tau)\,\mathbb{E}_t^Q\left[\int_t^\infty (1+\phi)\,Y_s e^{-rs}\mathrm{ds}\right] = (1+\phi)\,\frac{1-\tau}{r-\mu}Y_t \tag{8}$$

The senior debt has infinite maturity and pays a constant coupon C_0. The payment of the coupon is terminated in the event of bank closure, in which case the debt-holders receive the value of bank's assets at closure minus the cost of the resolution process. If the bank's assets at closure minus the resolution cost exceed the face value of senior debt, senior debtholders enjoy full recovery and the rest is payed to junior-debtholders. The cost of the resolution is assumed to be proportional to bank's asset value $\alpha V^i\left(Y^{i,r}\right)$, where $\alpha \in [0,1]$. Therefore, at any point in time the market value of senior debt after the exercise of the growth option is given by

$$D^{0,i}(Y_t) = \frac{C^0}{r}\left(1 - A\left(Y_t, Y_j^{i,r}\right)\right) + \min\{D^0(Y_0), (1-\alpha)\,V^i\left(Y_j^{i,r}\right)\}A\left(Y_t, Y_j^{i,r}\right) \tag{9}$$

Equation 9 stipulates that senior debtholders receive the value of perpetuity C_c^0/r assuming no regulatory closure and in the case of regulatory closure they receive the value of bank's assets at closure minus the resolution cost or the recover the face value in full.

The CoCo debt is assumed to be perpetual. The vast majority of all outstanding CoCos are perpetual Avdjiev et al. (2015). CoCo pays a constant coupon to a CoCo-holder up until the conversion trigger has been breached. In the case of trigger breach the CoCo converts either into equity or is written down. The conversion rate is such that for each unit of the principal the CoCo-holder receives λ units of shares. Additionally, the total amount of bank's shares is normalized to $V^i\left(Y^i\right)$. This normalization insures the model is homogeneous of degree one in Y_t. Similar approach of modeling conversion rate of CoCo is used in Chen et al. (2015). Therefore, the market value of the CoCo issued after investment at any point in time is given by

$$D_c^i\left(Y_t\right) = \frac{C_{c,j}^i}{r}\left(1 - A\left(Y_t, Y_{i,j}^c\right)\right) + \frac{\lambda D_c^i(Y^i)}{V^i\left(Y^i\right) + \lambda D_c^i(Y^i) + \lambda D_c^0(Y_0)\mathbb{I}_{\{j=nc\}}} E_c^i\left(Y_{i,j}^c\right) A\left(Y_t, Y_{i,j}^c\right) \tag{10}$$

where $j \in \{nc, c\}$ controlling for the fact whether CoCo issued at $t = 0$ converted (c) or did not (nc).

Equation 10 stipulates that assuming no conversion the CoCo holder enjoys the value of perpetuity $\frac{C_c^i}{r}$. Assuming conversion the CoCo-holder receives $\lambda D_c^i(Y^i)$ bank's shares. The total amount of shares outstanding prior to conversion is normalized to $V^i\left(Y^i\right)$, therefore the CoCo-holder owns a fraction $\frac{\lambda D_c^i(Y^i)}{V^i(Y^i)+\lambda D_c^i(Y^i)\lambda D_c^0(Y_0)\mathbb{I}_{j=nc}}$ of the bank after conversion. If CoCo issued at $t = 0$ does not converts prior to investment it converts simultaneously with CoCo issued after investment. The market value of the equity immediately after conversion is denoted by $E_c^i\left(Y_{i,j}^c\right)$.

Similarly, the value of CoCo issued at $t = 0$, assuming it did not convert prior to investment, is given by the following equation

$$D_c^{0,i}\left(Y_t\right) = \frac{C_c^0}{r}\left(1 - A\left(Y_t, Y_{i,nc}^c\right)\right) + \frac{\lambda D_c^0(Y_0)}{V^i\left(Y^i\right) + \lambda D_c^0(Y_0) + \lambda D_c^i(Y^i)} E_c^i\left(Y_{i,nc}^c\right) A\left(Y_t, Y_{i,nc}^c\right) \tag{11}$$

The subordinated debt has infinite maturity and pays a constant coupon C_s. The payment of the coupon is terminated in the event of bank closure, in which case the debt-holders receive the value of bank's assets at closure minus the cost of the resolution process and minus the face value of senior debt provided this value is positive, otherwise they receive nothing. Therefore, at any point in time the market value of subordinated debt is given by

$$D_s^i\left(Y_t\right) = \frac{C_{s,j}}{r}\left(1 - A\left(Y_t, Y_j^{i,r}\right)\right) + \left(\left(1-\alpha\right)V^i\left(Y_j^{i,r}\right) - D^0\left(Y_0\right)\right)^+ A\left(Y_t, Y_j^{i,r}\right) \tag{12}$$

where, $(x)^+ := \max\{x, 0\}$

Intuitively, equation 12 says that the holder of the junior debt receives the value of perpetuity, C_s/r assuming no regulatory closure and assuming closure the junior debtholders receive what is left after the senior debtholders payed. If senior debtholders do not recover the full face value after resolution cost, then junior debtholders receive nothing upon closure.

The value of the equity after investment is given by

$$
\begin{aligned}
E_j^i(Y_t) = & \left(V^i(Y_t) - (1-\tau)\frac{C^0 + C_{s,j} + C_c^0 \mathbb{I}_{\{j=nc\}} + C_{c,j}^i}{r} \right) \\
& + \left((1-\tau)\frac{C_c^0 + C_{c,j}^i}{r} - \frac{\lambda D_c^0(Y_0)}{V^i(Y^i) + \lambda D_c^0(Y_0) + \lambda D_c^i(Y^i)} E_c^i\left(Y_{i,nc}^c\right) \mathbb{I}_{\{j=nc\}} \right. \\
& \left. - \frac{\lambda D_c^i(Y^i)}{V^i(Y^i) + \lambda D_c^i(Y^i) + \lambda D_c^0(Y_0)\mathbb{I}_{j=nc}} E_c^i\left(Y_{i,j}^c\right) \right) A\left(Y_t, Y_{i,j}^c\right) \\
& + \left((1-\tau)\frac{C^0 + C_{c,j}^i}{r} - V^i\left(Y_j^{i,r}\right) \right) A\left(Y_t, Y_j^{i,r}\right).
\end{aligned} \tag{13}
$$

The first term in equation 13 is perpetuity of after-tax levered equity value if there is neither conversion nor closure. The second term takes into account conversion. When conversion happens equity holders gain from discontinuing CoCo payments but at the same time the value of equity is reduced by dilution (if $\lambda > 0$). The third term takes into account bank's closure. When closure happens shareholders forgo future cash flows, gaining from terminating debt payments at the same time.

Finally, I define the payoff from exercising growth option which is equal to the combined value of equity, newly issued CoCo, junior debt, which is given by the following equation

$$
\begin{aligned}
F_j^i(Y_t) &= E_j^i(Y_t) + D_{c|j}^i(Y_t) + D_{s|j}^i(Y_t) \\
&= V^i(Y_t) + \tau\frac{C_c^i}{r}\left(1 - A(Y_t, Y^c)\right) + \tau\frac{C_{s,j}^i}{r}\left(1 - A\left(Y_t, Y_j^{i,r}\right)\right) \\
&- (1-\tau)\frac{C^0}{r}\left(1 - A\left(Y_t, Y_j^{i,r}\right)\right) \\
&- (1-\tau)\frac{C_c^0}{r}\left(1 - A\left(Y_t, Y_{nc}^c\right)\right)\mathbb{I}_{j=nc} \\
&- \frac{\lambda D_c^0(Y_0)}{V^i(Y^i) + \lambda D_c^0(Y_0) + \lambda D_c^i(Y^i)} E_c^i\left(Y_{i,nc}^c\right)\mathbb{I}_{\{j=nc\}} A\left(Y_t, Y_{i,j}^c\right) \\
&- \min\{\alpha V^i\left(Y_j^{i,r}\right) + D^0(Y_0), V^i\left(Y_j^{i,r}\right)\} A\left(Y_t, Y_j^{i,r}\right)
\end{aligned} \tag{14}
$$

The first term in equation 14 is the after-tax value of the bank's assets. The second and third terms are the values of tax shield associated with newly issued CoCo and junior debt. The fourth term is the net value of the coupon payments associated with senior debt. The fifth term is the net value of the coupon payments associated with initial CoCo. The sixth term is the cost of equity dilution associated with CoCo issued at $t = 0$. Finally, the last term captures the loss of future cash flow due to regulatory closure.

2.2 Valuations prior to investment

The value of senior debt issued at date prior to investment, that is for all $t < \mathbb{T}_i$, is given by the following equation

$$\begin{aligned} D^0(Y_t) = \frac{C^0}{r} \Big(1 - \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \left(\underline{A}\left(Y^c_0, Y^i_c, Y^{0,r}\right) + \bar{A}\left(Y^c_0, Y^i_c, Y^{0,r}\right) A\left(Y^i_c, Y^{i,r}_c\right)\right) \\ -\bar{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) A\left(Y^i_{nc}, Y^{i,r}_{nc}\right)\Big) \\ + (1-\alpha) V^0\left(Y^{0,r}\right) \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \underline{A}\left(Y^c_0, Y^i_c, Y^{0,r}\right) \\ + (1-\alpha)\Big(V^i\left(Y^{0,r}_c\right) \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \bar{A}\left(Y^c_0, Y^i_c, Y^{0,r}\right) A\left(Y^i_c, Y^{i,r}_c\right) \\ + V^i\left(Y^{0,r}_{nc}\right) \bar{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) A\left(Y^i_{nc}, Y^{i,r}_{nc}\right)\Big) \end{aligned} \tag{15}$$

The first term in equation 15 is the value of the perpetuity of debt payments assuming no closure prior to or post investment regardless of whether the initial CoCo converted. The second term is what debtholders receive if closure takes place prior to investment. Finally, the third term is debtholders payoff if bank is closed after it has exercised its growth option accounting for the fact that the initial CoCo could either convert or not prior to investment.

Next consider the value of CoCo issued at $t = 0$. This value is given by the following equation

$$\begin{aligned} D^0_c(Y_t) = \frac{C^0_c}{r} \left(1 - \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) - \bar{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) A\left(Y^i_{nc}, Y^c_{i|nc}\right)\right) \\ + \frac{\lambda D^0_c(Y_0)}{V^i(Y^i) + \lambda D^0_c(Y_0)} E^0\left(Y^c_0\right) \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \\ + \frac{\lambda D^0_c(Y_0)}{V^i(Y^i) + \lambda D^0_c(Y_0) + \lambda D^i_c(Y^i)} E^0\left(Y^c_0\right) \bar{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) A\left(Y^i_{nc}, Y^c_{i|nc}\right) \end{aligned} \tag{16}$$

Equation 16 stipulates that assuming no conversion either prior to or post investment the CoCo holders of CoCo issued at $t = 0$ enjoy the perpetuity value associated with the security's coupon payments. Assuming that conversion takes place prior to investment the CoCo holders receive $\lambda D^0_c(Y_0)/\left(V^i\left(Y^i\right) + \lambda D^0_c(Y_0)\right)$ fraction of the equity. Assuming that conversion take place after the investment has been made the CoCo holders receive $\lambda D^0_c(Y_0)/\left(V^i\left(Y^i\right) + \lambda D^0_c(Y_0) + \lambda D^i_c(Y^i)\right)$ fraction of the equity, which is smaller than the previous one since now equity is also diluted with the conversion of the CoCo issued at $t = T^i$.

Finally, I present the value of equity prior to investment which is given by the following equation

$$
\begin{aligned}
E^0(Y_t) = &\left(V^0(Y_t) - (1-\tau)\frac{C^0 + C^0_c}{r}\right) \\
&+ \left((1-\tau)\frac{C^0_c}{r} - \frac{\lambda D^0_c(Y_0)}{V^i(Y^i) + \lambda D^0_c(Y_0)} E^0(Y^c_0)\right) \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \\
&+ \left((1-\tau)\frac{C^0}{r} - V^0\left(Y^{0,r}\right)\right) \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \underline{A}\left(Y^c_0, Y^i_c, Y^{0,r}\right) \\
&+ \left(F^i\left(Y^i_{nc}\right) + \left((1-\tau)\frac{C^0_j}{r} - V^0\left(Y^i_{nc}\right)\right)\right. \\
&+ \left.\left((1-\tau)\frac{C^0_c}{r} - \frac{\lambda D^0_c(Y_0)}{V^i(Y^i) + \lambda D^0_c(Y_0)} E^0(Y^c_0)\right) - I\right) \bar{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) A\left(Y^i_{nc}, Y^{i,r}_{nc}\right) \\
&+ \left(F^i\left(Y^i_c\right) + \left((1-\tau)\frac{C^0_j}{r} - V^0\left(Y^i_c\right)\right) - I\right) \underline{A}\left(Y_t, Y^i_{nc}, Y^c_0\right) \bar{A}\left(Y^c_0, Y^i_c, Y^{0,r}\right).
\end{aligned}
\tag{17}
$$

The first term in equation 17 is the perpetuity of after-tax levered equity assuming no closure, no investment, and no CoCo conversion. The second term takes into account CoCo conversion prior to investment. In this case the shareholders' equity is diluted by new shares issued upon conversion, but at the same time the shareholders gain from terminating the coupon payments. The third term takes closure prior to investment into account. By this time CoCo has already converted, therefore, the shareholders gain from discontinuing senior debt payments but forgo the future cash flow. Finally, the fourth and fifth terms take investment into account. The fourth term assumes that CoCo does not convert prior to investment, whereas, the fifth term assumes the opposite. Upon investment, the shareholders receive the newly maximized value of the bank, $F^i\left(Y^i_j\right)$, incur costs I, and loose the perpetuity of the after-tax levered equity prior to investment.

Finally, the value of the bank prior to investment, $F^0(Y_t)$, is then given by the sum of the value of senior debt, CoCo, and equity for all $t \leq \mathbb{T}^i_j$

$$
F^0(Y_t) := E^0(Y_t) + D^0(Y_t) + D^0_c(Y_t). \tag{18}
$$

2.3 Model's Solution

The model is solved backwards. Given the initial capital structure which is characterized by senior debt $D^0(Y_0)$ and initial CoCo $D^0_c(Y_0)$, the shareholders decide on how when to exercise the growth option, that is, the optimal threshold Y^i_j, and how to finance it, that is, the shareholders decide on optimal level of subordinated debt, $D^i_s\left(Y^i_j\right)$, and new CoCo, $D^i_c\left(Y^i_j\right)$.

Since the shareholders cannot commit to when they exercise the growth option, the optimal time to invest is characterized by the smooth-pasting condition (see Hackbarth and Mauer (2011) and Sundaresan et al. (2014)). The smooth-pasting condition equates the marginal value of equity prior to investment evaluated at the optimal investment threshold to the marginal payoff from investment evaluated at the same threshold. Mathematically,

$$
\begin{aligned}
\frac{\partial}{\partial Y_t} E^0(Y_t)|_{Y_t=Y_{nc}^i} &= \frac{\partial}{\partial Y_t} F_{nc}^i(Y_t)|_{Y_t=Y_{nc}^i} \\
\frac{\partial}{\partial Y_t} E^0(Y_t)|_{Y_t=Y_c^i} &= \frac{\partial}{\partial Y_t} F_c^i(Y_t)|_{Y_t=Y_c^i}
\end{aligned} \tag{19}
$$

Solving the system of two nonlinear equations with two unknowns in equation 19 produces the optimal investment thresholds Y_{nc}^i, when initial CoCo does not convert, and Y_c^i, when it does.

Simultaneously with choosing when to exercise the growth option, the shareholders decide on how the investment outlay I is going to be financed. Given Y_j^i, decide on optimal amount of junior debt, $D_{s|j}^i\left(Y_j^i\right)$, and CoCo, $D_{c|j}^i\left(Y_j^i\right)$, raised solving the following optimization problem

$$
\begin{aligned}
\max_{\left(D_{s|j}^i\left(Y_j^i\right), D_j^i\left(Y_j^i\right)\right)\geq 0} \quad & F_j^i\left(Y_j^i\right) \\
\text{s.t.} \quad & D_{s|j}^i\left(Y_j^i\right) + D_j^i\left(Y_j^i\right) \leq I \\
& E_j^i\left(Y_j^i\right) \geq 0 \\
& Y_j^i \text{ is given}
\end{aligned} \tag{20}
$$

The constraint $D_{c|j}^i\left(Y_j^i\right) + D_j^i\left(Y_j^i\right) \leq I$ is important because it is possible that the shareholders will find it optimal to raise CoCo/subordinated debt with the face value larger than the fixed cost I. For low value of σ the optimal bank's leverage is high. The bank cannot lever up prior to exercising the growth option in this model. Therefore, the bank will use the exercise of growth option as an opportunity to lever up to the optimal level. Hence, this intrinsic to the model capital structure effect will interact with the investment decision. In fact, for low values of σ the constrained will likely bind.

Solving optimization problem in equation 20, delivers the vector of the optimal investment thresholds and the optimal allocation of junior debt and CoCo $\Theta^* := \left(\{Y_j^i, D_{s|j}^i\left(Y_j^i\right), D_j^i\left(Y_j^i\right)\}_{j\in\{nc,c\}}\right)$ as a function of the initial capital structure characterized by vector $\Gamma := \left(D^0(Y_0), D_c^0(Y_0)\right)$.

Given Θ^*, the optimal vector of the initial capital structure, Γ^* is obtained from maximizing the *ex-ante* total value of the bank. Formally, the following optimization problem is solved

$$
\begin{aligned}
\max_{\Gamma\geq 0} \quad & F^0(Y_0) \\
\text{s.t.} \quad & E^0(Y_0) \geq 0 \\
& Y_0 \text{ and } \Theta^*(\Gamma) \text{ are given}
\end{aligned} \tag{21}
$$

Finally, it is assumed that at any point in time no cash outflow (coupon payment) should exceed the cash inflow. That is, the shareholders cannot top up the difference between outflows and inflows of cash.

3 Discussion of the Model Assumptions

In this section I discuss the major assumptions of the model. Some of the assumptions are crucial for the results whereas others are not as important as it may seem at first glance.

3.1 Deposits

In the model the main part of the bank's liability is the senior debt which is modeled as a standard risky debt. In reality, of course, the main bulk of banks' liabilities are deposits. A way to incorporate deposits into the model is to follow Sundaresan and Wang (2016)'s approach. They model deposits as risk-free debt. Specifically, assume that the total amount of deposits is D. Since deposits are risk-free they pay the risk-free rate r. But deposits also generate non-interest profits (e.g. service fees). Suppose that the instantaneous cash-flow generated by deposits is proportional to its face value ηD. Then the net payment to deposits is $(r - \eta) D$. Therefore, bank issues deposits not only to maximize the tax shields associated with it, but also because it generates some additional cash flow.

In order to justify risk-free nature of deposits, Sundaresan and Wang (2016) assume that deposits are insured. Specifically, the assume that the instantaneous insurance fee is a constant and given by I^0 and satisfies the following equality

$$(1 - A(Y_t, Y^r)) \frac{I^0}{r} = A(Y_t, Y^r)(D - V(Y^r)) \tag{22}$$

where Y^r is the threshold at which the bank is closed by the regulator, and $A(Y_t, Y^r)$ is the Arrow-Debreu price of regulatory closure. Equation 22 stipulates that under the fair insurance the regulators gain from receiving insurance premium), the left-hand side of the equation (is equal to the cost of paying deposits in case of the bank's closure (the right-hand side of the equation).

Introducing deposits into the model either instead of senior debt or together with it, although, will result in quantitative predictions, it will not change the main results. With deposits instead of senior debt the bank will select optimally higher leverage since deposits generate additional cash flow.

3.2 Regulatory Closure

In my model I do not permit endogenous default. Although, endogenous defaults are presumably common among non-banking corporations, it hardly ever happens in banking industry. It is unusual for a bank to file bankruptcy. On the other hand, it is very common for a bank to have its license withdrawn by its regulator when the former find itself severely undercapitalized. Therefore, instead of allowing for endogenous default I assume a regulatory closure rule. The rule is such that the bank is shut down once its capital ratio drops bellow a certain threshold q^c, which is consistent with the regulatory practice, for example, in the US (Shibut et al. (2003)).

However, having regulatory closure instead of endogenous default requires an assumption that shareholders cannot inject equity. The ability of shareholder to inject equity, on the other hand, hinges on the assumption that the shareholders have "long pockets", and therefore, can easily top up the difference between the bank's outflows and inflows of cash, provided it is profitable. But in reality economic agents either face budget constraints or some funds may simply not be readily available. Thus, it is important to understand that the opposite assumption to the one I make, that is, the assumption of shareholders' "long pockets", is even less realistic. Either assumption is a strong one, in reality the shareholders most likely can top up the difference between the outflows and inflows to some extend. I could relax my assumption of no equity injection, and instead assume that some injection is possible (bot not unlimited). In this case the result will change quantitatively but not qualitatively. What is crucial for my results, is that the shareholders do not have an unlimited ability to inject equity, and, hence, face some constraints on the total outflow of cash.

3.3 Dynamic Capital Structure

In the model the bank optimally selects its capital structure at date $t = 0$ and is not allowed to readjust it prior to investment. In reality, of course, firms do not wait till they invest to lever up. Therefore, a potentially interesting modification of the model is to allow the bank to re-adjust the capital structure prior to exercising the growth option. However, as Hackbarth and Mauer (2011) argue, for a wide range of the model's parameter values it is optimal for the shareholders to issue new debt when investing, not prior to it, since that helps to fully exploit the tax advantage of debt without worsening the debt overhang problem. The increase in debt coupon payments caused by earlier issuance of new debt reduces post-investment equity value, thereby making underinvestment problem more severe. Moreover, issuing additional debt prior to investment does not fully exploit the incremental tax shield value inherent in the growth option because the optimal coupon and, hence, the tax shield associated with it, is smaller than if the firm could wait and time the debt issue with the investment decision.

In their analysis Hackbarth and Mauer (2011) assume that asset volatility, σ, varies between 0.2 and 0.4, which is a standard range for corporates. Banks' asset volatility is much lower that that, ranging from 0.04 to 0.15. The lower volatility of assets implies higher leverage. This means, that on the one hand, if the bank waits sufficiently long before the exercise of the growth option the bank's leverage will deviate substantially from its optimal level, and hence the bank might find it optimal to readjust its capital structure earlier. On the other hand, because the bank has high leverage it might not find it optimal to readjust its capital structure before investment since that would lead to a large reduction in equity value brought about by the increase in coupon payments, and, hence, worsened underinvestment problem.

3.4 CoCo

In the model I assume that the characteristics of CoCo, the loss absorption mechanism and the trigger level, are not the choice variables of the bank. In practice, banks have full discretion on both of the type of loss absorption mechanism and partially discretion on the trigger level.

As far as the regular is concerned either a PWD CoCo or an EC CoCo both receive the same treatment. Still, empirically we see that CoCo with different loss absorption mechanisms are issued. Therefore in the last section I endogenize the choice of the loss absorption mechanism and examine how it depends on bank's characteristics (e.g. asset volatility, etc).

The trigger level is not bounded from above but it is so from below. For example, a common practice in the EU is that for CoCo to be qualified as T1 capital its trigger level should not be lower 5.125% in terms of CET1 ratio. The idea is that the higher the trigger level the better its loss absorption ability is.

Although, the question of the optimal design of CoCo (from banks' perspective) is very interesting one, this is beyond the scope of this paper, which does not aim at rationalizing the bank's choice the trigger level. The aim of this paper is to analyze the effect of CoCos (as a new type of security) on banks' optimal (joint) financing and investment policy. Bringing the choice over the CoCos' characteristics will only make the analysis too complex without providing additional benefits.

4 Analysis

In the model from section 2 the bank issues CoCo prior to investment and when investing. Having some debt outstanding induces bank to delay profitable investment due to the standard debt overhang problem. Without CoCo there are only two ways the bank can finance the investment outlay: junior debt or equity. Investing with equity produces no tax shields but at the same time does not directly increase the likelihood of regulatory closure. Investing with equity, hence, will increase the market value of debt the most, and thus, is associated with the highest severity of debt overhang problem. Financing the investment outlay with subordinated debt, on the other hand, will produce tax shields and, at the same time, will positively affect the likelihood of failure. Because junior debt increases the investment payoff via tax shields and at the same time dilutes the market value of senior debt via increased likelihood of failure, it is normally associated with less sever debt-overhang problem. CoCo is a hybrid of debt and equity in that it produces tax shields and does not increase the likelihood of failure. Therefore, one could expect that investing with CoCo should help to mitigate the standard debt-overhang problem and result in earlier investment.

On the other hand, having some CoCo outstanding could have the opposite effect on the timing of investment. There are two channels through which outstanding CoCo can affect the bank's optimal investment policy. First, as any type of debt CoCo creates the standard debt-overhang problem. In fact, given that CoCo has higher coupons per principal (i.e. riskier) than senior debt, the debt overhang associated with CoCo may well be more severe. Secondly, if the bank has some EC CoCo outstanding prior to investment then investing with subordinated has a negative value on shareholders' equity through the dilution cost associated with CoCo conversion. Issuing subordinated debt, or any debt for that matter, will increase the likelihood of the conversion, and, hence, the dilution cost associated with it. The strength of the effect depends on the conversion rate: for a PWD CoCo, for example, there is no dilution cost at all.

The model from section 2 allows me to study the two effects of CoCos on tha bank's optimal investment policy. To simplify the analysis, I study the two effects separately. First, I assume that initially bank issues no CoCo, that is using the notation from the previous section, $D_c^0(Y_0) = 0$, and finances the investment outlay either by CoCo or by subordinated debt. This allows me to isolate the effect of investing with CoCo from the effect of having some CoCo outstanding. Moreover, I it enables me to contrast the debt-overhang implications of CoCo and junior debt.

To study the implications of having CoCo outstanding on the optimal investment policy, I assume that the investment outlay can only be financed by subordinated debt, that is, $D_c^i(Y^i) = 0$, but initially the bank issues both senior debt and CoCo. This approach allows me to isolate the effect of having CoCo outstanding on the optimal investment policy without being distorted by the effect of CoCo issued to financing the investment outlay.

The model from section 2 cannot be solved in closed from and, thus, the numerical solution is obtained. To solve the model numerically I assign value to the model parameters discussed in the next subsection.

4.1 Exogenous Parameters

In order to solve the model numerically it needs to be parametrized. The model has in total 9 parameters which are summarized by the vector $(\alpha, \mu, \sigma, \lambda, \tau, r, q, q^c, Y_0)$. The risk of debt, CoCo, and equity is connected to the risk of assets via parameter σ - the volatility of the assets. Using Moodys KMV estimates of firm's asset volatility across many industries, Sundaresan and Wang, 2016, find that the mean volatility of bank's asset during the period of 2001-2012 was about 8%. Therefore, at the baseline value I set σ to 0.08 and then examine the sensitivity of optimal capital structure to the volatility level.

The cost of resolution is basically a special type of the bankruptcy cost. The estimation of the bankruptcy cost is a challenge in general. One of the first and highly cited references on the estimation bankruptcy costs is Altman (1984), who finds that in a sample of 19 industrial firms bankruptcy cost are about 20% of a firm's value. Relatively recently, Bris, Welch, and Zhu (2006) find that the cost of bankruptcy range from 0% to 20% within a comprehensive sample of small and large corporate bankruptcies in Arizona and New York from 1995 to 2001.

In general, one could expect the cost of bank's bankruptcy be larger than the one of an industrial firm. Occasionally, when industrial firms go bankrupt they are still continuing their manufacturing process without big changes. In contrary, a bankruptcy process for a financial firm often implies a complete withdrawal from any business operations. This is mostly due to the stigma of failure: a financial firm that is thought to experience some problems will face challenges with its creditors and can become a subject of a bank run.

One of the first papers to reexamine the question of bankrupts cost in banking industry is James (1991). Using the sample of the FDIC-regulated commercial banks failed during 1982-1988, James (1991) finds that the cost of bank's bankruptcy is about 30% of failed bank's assets. Recently, Flannery (2011) estimates bank's bankruptcy cost to be about 26.6% of asset value. Given the estimates of the bankruptcy cost, at the baseline value I set α to 0.25 and then examine the sensitivity of the optimal capital structure to the cost.

The marginal tax rate is a parameter of crucial importance in capital structure, since one of the main benefits of debt is the tax-deductibility of interest on it. Corporate tax rate differs among jurisdiction. The federal tax rates on corporate taxable income vary from 15% to 39% in the US. In the UK the corporate tax rate is a flat rate of 20% and Switzerland it ranges between 18% and 21%.

The US department of Treasury (2007) reports that on average the effective marginal tax rate on investment in business is 25.5%, though, varying across industries. Graham (2000) estimates the effective corporate tax rate for non-financial US firms to be around 10%. Heckemeyer and de Mooij (2013) estimates the effective corporate tax rate for US commercial banks at about 30%. Therefore, at the baseline value I set τ to 0.25 and then examine the sensitivity of the optimal capital structure to this rate.

One of the main functions of the banking regulators is to monitor bank's capital. Violating the minimum capital requirement constraints usually leads to different sort of penalties imposed on banks by their regulators. At some point bank's capital can be so small that it is no longer viable for the regulator to let bank continue its operations. Then bank's charter authority may close the bank. Particularly in the US, the FDIC categorizes bank as critically undercapitalized if bank's tangible equity-to-asset ratio hits 2 % level. In that case bank's charter authority is likely to close the bank appointing the FDIC as a receiver Shibut et al. (2003).

The CoCo security has two main characteristics: the trigger threshold q^c and the conversion rate λ. In the benchmark model I set the trigger threshold $q^c = 0.05125$ which corresponds to high-conversion CoCo. It is interesting to focus on high conversion CoCo since it has higher loss absorption capacity. The conversion rate λ takes values in $\{0, 2\}$, where 2 is for a EC CoCo and 0 is for a PWD CoCo. This allows me to study the effect of the loss absorption mechanism on the optimal investment decision.

The risk-free rate, r, is set to 5% and the risk-neutral drift of the cash flow, μ, is set to 2%. The initial value for the cash flow process, Y_0, is calibrated such, that the asset value at $t = 0$, $V(Y_0)$ is equal 1.

I set the investment outlay $I = 0.5$ and the profitability of the option growth $\phi = 0.65$. This implies that the NPV of the project at $t = 0$ is $\phi \frac{(1-\tau)}{(r-\mu)} Y_0 - I = 0.15 > 0$. The growth option is parametrized such that if the bank issues nether senior debt nor CoCo it will invest at $t = 0$. This implies that the only reason the bank delays its investment is the debt overhang.

Table 3 presents the benchmark parameter values.

	parameter	value
Resolution cost	α	0.25
Risk-neutral drift	μ	0.02
Asset volatility	σ	0.08
Conversion rate	λ	$\{0, 2\}$
Marginal corporate tax rate	τ	0.25
Risk-free rate	r	0.05
Closure threshold	q	0.02
Trigger threshold	q^c	0.05125
Initial asset value	$V(Y_0)$	1.00
Cost of investment	I	0.50
Size of growth option	ϕ	0.65

Table 3 The benchmark parameter values.

4.2 Investing with CoCo vs Junior Debt

Table 4 summarizes bank's optimal financing and investment policy, and its implication on bank's characteristics, under four scenarios: when exercising its growth option bank issues (i) junior debt, (ii) a PWD CoCo ($\lambda = 0$), (iii) a an EC CoCo ($\lambda = 2$), and (iv) equity. The coco-issuing bank invests earlier than the junior-debt-issuing bank. This difference is economically significant. If the bank raises funds by issuing a PWD CoCo, an EC CoCo, a junior debt, or equity, then the investment is expected to take place in about four years, two years, eight years, and 17 years, respectively. The probability of investment conditional on not being shut down prior to investing, $\Pi_j^i(Y_0)$, is higher for a CoCo financing (it the highest for a EC CoCo-issuing bank) and is the lowest for equity financing. Although a CoCo-issuing bank tends to have higher initial leverage, its conditional probability of investment is still higher due to a lower investment threshold.

Variable	junior debt	PWD	EC	Equity
$D_j^0(Y_0)$	0.6418	0.6117	0.6680	0.6441
$D_j^i(Y_j^i)$	0.5000	0.5000	0.5000	0.0000
Y_j^i	0.0479	0.0437	0.0421	0.0579
$F_j(Y_0)$	1.4143	1.4240	1.4296	1.3460
$RC_j(Y_0)$	0.0099	0.0030	0.0041	0.0072
$\text{CS}_{D_j^0}$	0.04%	0.02%	0.03%	0.05%
$\text{CS}_{D_j^i}$	0.06%	0.22%	0.20%	NaN
$\Pi_j^f(Y_0)$	0.1273	0.0366	0.0425	0.0971
$\Pi_j^i(Y_0)$	0.9308	0.9671	0.9646	0.9040
$\bar{T}^i$	8.2490	4.1368	2.1641	17.4594

Table 4 compares bank's optimal financing and investment policy, and its implication on bank's characteristics, under four scenarios: when exercising its growth option bank issues (i) junior debt, (ii) a PWD CoCo ($\lambda = 0$), (iii) a an EC CoCo ($\lambda = 2$), and (iv) equity. $RC_j(Y_0)$ denotes the value of the resolution cost. $TB_j^0(Y_0)$ and $TB_j^i(Y_0)$ denote the value of tax shields from senior and CoCo/subordinated debt, respectively. $\text{CS}_{D_j^0}$ and $\text{CS}_{D_j^i}$ denote the credit spread in percentage points for senior and CoCo/subordinated debt, respectively. $\Pi_j^f(Y_0)$ denotes the unconditional probability of failure (the sum of the probability of failure prior to and after investment). $\Pi_j^i(Y_0)$ denotes the conditional probability of investment; the conditional probability of failure is then given by $1 - \Pi_j^i(Y_0)$. The model is parametrized with benchmark parameter values from Table 3.

Under both CoCo and subordinated-debt financing the bank raises the investment outlay, I, solely by debt. In order to understand why the growth option is exercised earlier under CoCo financing than under junior-debt financing one needs to examine the smooth pasting condition given in equation 19. At the optimal investment threshold the marginal value of equity is exactly equal to the marginal value of the payoff $\frac{\partial}{\partial Y_t} E_j^0(Y_t)|_{Y_t=Y_j^i} = \frac{\partial}{\partial Y_t} F_j^i(Y_t)|_{Y_t=Y_j^i}$. If the bank under subordinated debt financing scenario is forced to exercise the growth option earlier - at the same time that the CoCo-issuing banks does - then the marginal value of equity of the bank is smaller than the marginal value of payoff, $\frac{\partial}{\partial Y_t} E_s^0(Y_t)|_{Y_t=Y_c^i} < \frac{\partial}{\partial Y_t} F_s^i(Y_t)|_{Y_t=Y_c^i}$, implying a convex kink at the investment boundary. It can be shown numerically that the marginal value of equity under both scenarios are roughly the same. Therefore, to understand why it is optimal for a subordinated-debt issuing bank to invest later one needs to examine the the marginal value of the payoff closer.

The partial derivative of the payoff for a CoCo issuing bank is given by

$$\begin{aligned}\frac{\partial}{\partial Y_t} F_c^i(Y_t)|_{Y_t=Y^*} := (1+\psi)\frac{(1-\tau)}{(r-\mu)} - \tau\beta_2 \frac{C_c^i}{r}\frac{A(Y^*, Y^c)}{Y^*} \\ + (1-\tau)\beta_2 \frac{C_c^0}{r}\frac{A\left(Y^*, Y_c^{i,r}\right)}{Y^*} - \beta_2 V^i\left(Y_c^{i,r}\right)\frac{A\left(Y^*, Y_c^{i,r}\right)}{Y^*}\end{aligned} \tag{23}$$

and for a junior-debt issuing bank it is given by

$$\begin{aligned}\frac{\partial}{\partial Y_t} F_s^i(Y_t)|_{Y_t=Y^*} := (1+\psi)\frac{(1-\tau)}{(r-\mu)} - \tau\beta_2 \frac{C_s^i}{r}\frac{A\left(Y^*, Y_s^{i,r}\right)}{Y^*} + (1-\tau)\beta_2 \frac{C_s^0}{r}\frac{A\left(Y^*, Y_s^{i,r}\right)}{Y^*} \\ - \beta_2 \min\{\alpha V^i\left(Y_s^{i,r}\right) + D_s^0(Y_0), V^i\left(Y_s^{i,r}\right)\}\frac{A\left(Y^*, Y_s^{i,r}\right)}{Y^*}.\end{aligned} \tag{24}$$

The first term is the direct marginal benefit from waiting - as you wait assets grow bigger. The second term is the marginal value of tax shield associated with new debt. Postponing investment increases the value of this tax shield by decreasing the likelihood of loosing it. The third term is the marginal value of the net payment to the senior debtholders. This term is increasing in Y^* due to convexity of the Arrow-Debreu price, thus, inducing to invest earlier. The last term is the value of the marginal benefit from reducing the loss in closure. This term is decreasing in Y^* due to convexity of the Arrow-Debreu price, thus, inducing later investment.

The first two effects happen to have roughly similar magnitude for both scenarios. The third effect is stronger for junior-debt financing because $Y_s^{i,r} > Y_c^{i,r}$, and hence, $A\left(Y^*, Y_s^{i,r}\right) > A\left(Y^*, Y_c^{i,r}\right)$, since CoCo does not contribute to the likelihood of closure directly. Thus, the effect from the third term - the reduction in the value of the net payment to the senior shareholders - actually incentivizes a junior-debt issuing bank to invest earlier. However, the opposite effect that comes from the fourth term - the reduction in the value of the loss in closure - has a large magnitude offsetting the previous effect and inducing later investment. The reason the marginal benefit from reduction in the value of loss in closure is larger under junior-debt financing is again because the likelihood of failure is quite larger comparing to that under CoCo financing.

CoCo is a hybrid of debt and equity. But it is a kind of a hybrid that takes the best from the two types of securities. Similar to equity it does not contribute to the likelihood of bankruptcy. Similar to debt it generates the tax shield. As a result, investment financed by CoCo suffer less from debt-overhang problem.

The ex-ante value of the bank, $F_j(Y_0)$, is higher under CoCo financing scenario and the lowest under equity financing. Under CoCo financing the value of tax-shields is higher and the value of resolution cost is lower rationalizing a high ex-ante total value.

The total probability of bank's failure, $\Pi_j^f(Y_0)$, is given by the sum of the probability of bank's failure prior to investing and the probability of bank's failure after investing. The probability of bank's failure is the highest under subordinate-debt financing; it is lower under equity financing. The probability is even lower for CoCo financing with the lowest value for a PWD-CoCo financing.

The credit spread associated with the senior debt under both subordinated-debt and equity financing than under CoCo financing. When the growth option is financed by equity the credit spread of senior debt are the highest partially because the initial leverage is slightly higher than under subordinated debt, but mostly because the probability of failure prior to investing, $1-\Pi_j^i(Y_0)$, is the highest. The lower senior-debt credit spreads under CoCo financing are explained by very small probabilities of failure prior to investing despite the fact that initial leverage is somewhat higher.

When investing with a PWD CoCo the bank issues less senior debt in order to be able to make the coupon payments (recall that no equity injections are allowed in the model). Since a PWD CoCo has higher coupon per face value than an EC CoCo, the bank optimally lowers the amount of senior debt and, hence, the total coupon payment associated with it. In fact, given the benchmark parameter values it is optimal for bank to opt for an EC CoCo.

4.3 CoCo Outstanding

In this subsection I present the results of the analysis of CoCo outstanding on the bank's optimal capital structure. I solve the model from section 2 with a restriction that the bank does not issue CoCo when financing the investment outlay I, that is, $D_c^i(Y_j^i) = 0$. The model's parameters assume the values from Table 3.

Table 5 summarizes bank's optimal financing and investment policy, and its implication on bank's characteristics, under three scenarios: (i) the benchmark scenarios under which the bank does not issue CoCo at $t = 0$, (ii) the bank issues a PWD CoCo, and (iii) the bank issued an EC CoCo.

As in the analysis from the previous subsection, the bank that has no CoCo outstanding is expected to make the investment within about 8 years. In contrary, the bank that issues CoCo at time $t = 0$ invests later, despite the fact that it actually has less senior debt. Although, a CoCo issuing bank issues less senior debt, its total leverage is higher than that of non-issuing CoCo one. Given that CoCo is riskier than senior debt - its coupon per face value is larger than that of senior debt - it creates even more sever debt-overhang problem than senior debt.

Conditional on CoCo converting prior to investment a CoCo-issuing bank invests earlier than non-issuing CoCo one. This can be seen from the values of the optimal investment thresholds Y_c^i of the CoCo issuing bank: 0.0466 for a PWD CoCo and 0.0473 for an EC CoCo versus 0.0479 for the bank that does not have CoCo outstanding. This is because a CoCo-issuing bank does not issues as much senior debt as the bank that does not issue CoCo. However, conditional on CoCo not converting prior to investment, a CoCo-issuing bank invests much later, such that the unconditional expected time before investment, $\bar{T}^i$, is larger when there is CoCo outstanding.

The bank issuing a PWD CoCo is expected to invest earlier than that issuing an EC CoCo: about 10 years for the PWD CoCo issuing bank and about 13 years for the EC CoCo issuing bank. This is because an EC CoCo is associated with the dilution cost of equity due to the CoCo's conversion. The larger the conversion rate λ, the higher the dilution cost. The dilution cost, assuming that CoCo does not convert prior to investment, lowers the payoff from investment resulting in the delay of the latter.

Variable	No CoCo	PWD	EC
$D^0(Y_0)$	0.6418	0.5958	0.6033
$D^0_c(Y_0)$	0.0000	0.1473	0.1684
$D^i_s(Y^i_j)$	0.5000	0.5000	0.5000
Y^i_j	0.0479	0.0486/0.0473	0.0521/0.0475
$F(Y_0)$	1.4143	1.4483	1.4458
$RC_j(Y_0)$	0.0099	0.0066	0.0061
CS_{D^0}	0.04%	0.03%	0.03%
$\text{CS}_{D^0_c}$	NA	1.01%	0.79%
$\text{CS}_{D^i_s}$	0.06%	0.02%/0.04%	0.02%/0.04%
$\Pi^f_j(Y_0)$	0.1273	0.0951	0.0938
$\Pi^i_j(Y_0)$	0.9308	0.9550	0.9434
$\bar{T}_j$	8.2490	9.1704	11.7656

Table 5 compares bank's optimal financing and investment policy, and its implication on bank's characteristics, under three scenarios: (i) the benchmark scenarios under which the bank does not issue CoCo at $t = 0$, (ii) the bank issues a PWD CoCo, and (iii) the bank issued an EC CoCo. $RC_j(Y_0)$ denotes the value of the resolution cost. $\text{CS}_{D^0_j}$, $\text{CS}_{D^0_c}$, and $\text{CS}_{D^i_s}$ denote the credit spread in percentage points for senior, CoCo and subordinated debt, respectively. $\Pi^f_j(Y_0)$ denotes the unconditional probability of failure (the sum of the probability of failure prior to and after investment). $\Pi^i_j(Y_0)$ denotes the conditional probability of investment; the conditional probability of failure is then given by $1-\Pi^i_j(Y_0)$. The model is parametrized with benchmark parameter values from Table 3.

To better understand the implications of CoCo outstanding on the bank's optimal investment policy it is useful to examine the payoff from investment from equation 14. I rewrite this equation under assumption that bank does not issue CoCo when exercising the growth option. For the bank that issues CoCo initially, this payoff is given by the following equation

$$
\begin{aligned}
F^i_j(Y_t) = {} & V^i(Y_t) + \tau\frac{C^i_{s,j}}{r}\left(1 - A\left(Y_t, Y^{i,r}_j\right)\right) \\
& - (1-\tau)\frac{C^0}{r}\left(1 - A\left(Y_t, Y^{i,r}_j\right)\right) \\
& - (1-\tau)\frac{C^0_c}{r}\left(1 - A\left(Y_t, Y^c_{nc}\right)\right)\mathbb{I}_{\{j=nc\}} \\
& - \frac{\lambda D^0_c(Y_0)}{V^i\left(Y^i_{nc}\right) + \lambda D^0_c(Y_0)} E^i_c\left(Y^c_{i,nc}\right)\mathbb{I}_{\{j=nc\}} A\left(Y_t, Y^c_{i,j}\right) \\
& - \min\{\alpha V^i\left(Y^{i,r}_j\right) + D^0(Y_0), V^i\left(Y^{i,r}_j\right)\} A\left(Y_t, Y^{i,r}_j\right)
\end{aligned}
\tag{25}
$$

where, recall, index $j \in \{c, nc\}$, indicates whether the CoCo issued at $t = 0$ has converted prior to investment, $j = c$, or has not, $j = nc$. The payoff from the investment of the bank that issues no

CoCo at date $t = 0$, on the other hand, is given by the following equation

$$\begin{aligned} F^i(Y_t) = {} & V^i(Y_t) + \tau \frac{C_s^i}{r}\left(1 - A\left(Y_t, Y^{i,r}\right)\right) \\ & - (1-\tau)\frac{C^0}{r}\left(1 - A\left(Y_t, Y^{i,r}\right)\right) \\ & - \min\{\alpha V^i\left(Y^{i,r}\right) + D^0(Y_0), V^i\left(Y^{i,r}\right)\} A\left(Y_t, Y^{i,r}\right) \end{aligned} \tag{26}$$

The payoff from investment of the bank with CoCo outstanding (equation 25) has two more terms than the corresponding payoff of the bank that has no CoCo outstanding (equation 26). These terms are the value of the net payments to CoCo holders - the fourth term in equation 25 - and the cost of equity dilution - the fifth term in equation 25. Both of these terms have negative effect on the payoff resulting in larger benefits from waiting before making investment. Even when the conversion rate, λ, is zero, that is, when the bank has a PWD CoCo outstanding, the value of the net payments to CoCo holders reduces the payoff substantially to induce later investment.

Table 5 shows that, although, the bank that has CoCo outstanding is expected to invest later than the one that has no CoCo outstanding, the probability of investing is actually larger for the former one. This has to do with the fact that the bank with CoCo outstanding optimally issues less senior debt and, thus, faces lower likelihood of regulatory closure prior to investment.

The total probability of failure is the highest for the bank that issue no CoCo at date $t = 0$ since this is the bank with the highest level of senior debt. The PWD CoCo issuing bank has the lowest total probability of failure thanks to relatively low level of senior debt issued. As a result the ex-ante value of the bank is higher if it issues CoCo at date $t = 0$. This means that a value maximizing bank optimally issues CoCo at date $t = 0$ despite the fact that CoCo forces the bank to suffer from severer debt overhang resulting in later investment. The losses associated with later investment are well offset by decreased total probability of failure and increase total value of the total tax shields.

5 Sensitivity Analysis

This section examines robustness of the results obtained in section 4 by assuming alternative to benchmark parameters' values. In particular, I examine how the effect of CoCo on the bank's investment policy varies with bank's asset volatility σ. I assume that the value of σ takes value in the interval $[0.05, 0.12]$ which is consistent for its empirical estimates (Sundaresan and Wang (2016)).

5.1 Investing with CoCo vs Junior Debt

In this subsection I reexamine the analysis from subsection 4.2 given alternative values of model parameters. Tables 6, 7, and 8 summarize the bank's optimal liability structure and optimal investment policy for different values of asset volatility, σ, when the bank finances the exercise of the growth option with junior debt, a PWD CoCo, and an EC CoCo, respectively.

Examining the tables reveals that CoCo's ability to mitigate the debt overhang problem, leading to earlier investment, is independent of the bank's asset volatility. However, as asset volatility becomes larger the relative difference in average time before investment under junior debt and CoCo decreases. For example, when the bank's asset volatility is 5% the investment under CoCo financing is expected to happen at least 3 times earlier than under junior debt, whereas for the bank with asset volatility of 12% only 1.3 times earlier. Therefore, CoCo's ability to mitigate the debt overhang problem is especially pronounced for banks with low asset volatilities.

σ	$D_s^0(Y_0)$	$D_s^I(Y^i)$	Y_s^i	$\Pi^f(Y_0)$	$\Pi^I(Y_0)$	$\bar{T}_s^i$	$F_s(Y_0)$
0.05	0.7920	0.5000	0.0421	0.0381	0.9777	2.4059	1.4600
0.06	0.7361	0.5000	0.0442	0.0592	0.9642	4.6844	1.4431
0.07	0.6872	0.5000	0.0460	0.0893	0.9486	6.5486	1.4279
0.08	0.6418	0.5000	0.0479	0.1273	0.9308	8.2490	1.4143
0.09	0.5995	0.5000	0.0498	0.1730	0.9110	9.8100	1.4022
0.1	0.5603	0.5000	0.0518	0.2258	0.8896	11.2348	1.3917
0.11	0.5238	0.5000	0.0539	0.2850	0.8672	12.5278	1.3826
0.12	0.4898	0.5000	0.0560	0.3501	0.8440	13.6929	1.3748

Table 6. The bank's optimal capital structure and investment policy as a function of the bank's volatility when the growth option is financed by subordinated debt. $D_s^0(Y_0)$ denotes the face value of senior debt. $D_s^I(Y^i)$ denotes the face value of junior debt. Y_s^i is the optimal investment threshold. $\Pi^f(Y_0)$ is the unconditional probability of failure. $\Pi^I(Y_0)$ is the probability of investment. $\bar{T}_s^i$ is the expected time before investment. $F_s(Y_0)$ is the bank's ex-ante value.

Examining the bank's ex-ante value reveals that the bank's preference over the loss absorption mechanism depends on its asset volatility. The model predicts that the banks with low asst volatility prefer a PWD CoCo over an EC CoCo, whereas banks with higher volatility have the opposite preferences. Higher asset volatility implies riskier senior debt and CoCo, which in turn makes it harder to satisfy the liquidity constraints. Therefor, a bank with higher asset volatility is more liquidity constrained and this forces bank to opt for safer kind of CoCo - an EC one. It is important

σ	$D_c^0(Y_0)$	$D_c^I(Y^i)$	Y_c^i	$\Pi^f(Y_0)$	$\Pi^I(Y_0)$	$\bar{T}_c^i$	$F_c(Y_0)$
0.05	0.7384	0.5000	0.0401	0.0008	0.9992	0.1834	1.4594
0.06	0.7161	0.5000	0.0402	0.0026	0.9976	0.2636	1.4534
0.07	0.6748	0.5000	0.0418	0.0207	0.9807	1.9903	1.4399
0.08	0.6117	0.5000	0.0437	0.0366	0.9671	4.1368	1.4240
0.09	0.5437	0.4940	0.0454	0.0491	0.9589	6.1181	1.4080
0.1	0.5036	0.4613	0.0475	0.0762	0.9408	8.0873	1.3928
0.11	0.4626	0.4291	0.0497	0.1095	0.9216	10.1861	1.3792
0.12	0.4275	0.3917	0.0523	0.1537	0.8987	12.3074	1.3670

Table 7. The bank's optimal capital structure and investment policy as a function of the bank's volatility when the growth option is financed by a PWD CoCo. $D_c^0(Y_0)$ denotes the face value of senior debt. $D_c^I(Y^i)$ denotes the face value of CoCo. Y_c^i is the optimal investment threshold. $\Pi^f(Y_0)$ is the unconditional probability of failure. $\Pi^I(Y_0)$ is the probability of investment. $\bar{T}_c^i$ is the expected time before investment. $F_c(Y_0)$ is the bank's ex-ante value.

σ	$D_c^0(Y_0)$	$D_c^I(Y^i)$	Y_c^i	$\Pi^f(Y_0)$	$\Pi^I(Y_0)$	$\bar{T}_c^i$	$F_c(Y_0)$
0.05	0.7251	0.5000	0.0406	0.0022	0.9978	0.7711	1.4550
0.06	0.7085	0.5000	0.0410	0.0088	0.9914	1.1939	1.4482
0.07	0.6862	0.5000	0.0416	0.0216	0.9800	1.7525	1.4389
0.08	0.6680	0.5000	0.0421	0.0425	0.9646	2.1631	1.4296
0.09	0.6179	0.5000	0.0445	0.0760	0.9380	4.4193	1.4162
0.1	0.5513	0.5000	0.0466	0.0971	0.9261	6.6301	1.4039
0.11	0.4771	0.5000	0.0485	0.1133	0.9220	8.7709	1.3914
0.12	0.4172	0.4801	0.0506	0.1415	0.9125	10.9342	1.3780

Table 8. The bank's optimal capital structure and investment policy as a function of the bank's volatility when the growth option is financed by an EC CoCo ($\lambda = 2$). $D_c^0(Y_0)$ denotes the face value of senior debt. $D_c^I(Y^i)$ denotes the face value of CoCo. Y_c^i is the optimal investment threshold. $\Pi^f(Y_0)$ is the unconditional probability of failure. $\Pi^I(Y_0)$ is the probability of investment. $\bar{T}_c^i$ is the expected time before investment. $F_c(Y_0)$ is the bank's ex-ante value.

to highlight that without liquidity constraints the bank would always prefer a PWD CoCo since in that case the bank will maximize the tax shields associated with it. However, without liquidity constraints CoCo's total coupon would require a lot of cash injection from the shareholders, which is a very unrealistic scenario.

Interestingly, the model also predicts that the bank with asset volatility of 5% will not finance its investment with CoCo but instead will issue junior debt, since the ex-ante value is larger under the junior-debt financing than that under the CoCo one, despite the fact that this will result in later investment. Although, the conditional probability of investment is higher and unconditional probability of failure is lower under the CoCo scenario for all values of σ considered, the ex-ante value is till higher for the junior-debt scenario thanks to much higher initial leverage for very small value of σ. The higher initial leverage is due to later investment and relatively small cost of resolution due to low asset volatility. Also, issuing more senior debt under CoCo scenario will negatively affect the value of tax shields associated with the latter since CoCo converts prior to closure, whereas tax shields from subordinated debt remain till closure.

5.2 CoCo Outstanding

In this subsection I reexamine the analysis from subsection 4.3 given alternative values of model parameters. Tables 9, 10, and 11 summarize the bank's optimal liability structure and optimal investment policy for different values of asset volatility, σ, when the bank invests with junior debt, and initially issues no CoCo, a PWD CoCo, and an EC CoCo, respectively.

Examining the tables reveals that having CoCo's outstanding prior to investment induces later investment regardless of the bank's asset volatility. However, as asset volatility becomes larger the relative difference in the average time before investment of the bank that issues CoCo prior to investing and the bank that does not decreases. For example, when the bank's asset volatility is 5% the investment of the bank that initially issues CoCo is expected to take place at least 2 times later than that of the bank not issuing CoCo, whereas for the bank with asset volatility of 12% only 1.1 times later. Therefore, the negative effect of outstanding CoCos is more pronounced for banks with lower volatilities.

The expected time before investment is larger under EC CoCo than under PWD CoCo owning to the presence of the equity dilution cost that comes with EC CoCo. However, the difference between the expected times before investment under two types of CoCo decreases with asset volatility.

Examining the bank's ex-ante value reveals that, as in the previous subsection, the bank's preference over the loss absorption mechanism depends on its asset volatility. The model predicts that the banks with low asset volatility prefers a PWD CoCo over an EC CoCo, whereas banks with higher volatility have the opposite preferences. The intuition of this results is the same as for the case when CoCo is issued to finance investment. Higher asset volatility implies riskier senior debt and CoCo, which in turn makes it harder to satisfy the liquidity constraints. Therefor, a bank with higher asset volatility is more liquidity constrained and this forces bank to opt for safer kind of CoCo - an EC one. Once again, it is important to highlight that without liquidity constraints the

σ	$D^0(Y_0)$	Y^i	$\Pi^f(Y_0)$	$\Pi^I(Y_0)$	$\bar{T}^i$	$F(Y_0)$
0.05	0.7920	0.0421	0.0381	0.9777	2.4059	1.4600
0.06	0.7361	0.0442	0.0592	0.9642	4.6844	1.4431
0.07	0.6872	0.0460	0.0893	0.9486	6.5486	1.4279
0.08	0.6418	0.0479	0.1273	0.9308	8.2490	1.4143
0.09	0.5995	0.0498	0.1730	0.9110	9.8100	1.4022
0.1	0.5603	0.0518	0.2258	0.8896	11.2348	1.3917
0.11	0.5238	0.0539	0.2850	0.8672	12.5278	1.3826
0.12	0.4898	0.0560	0.3501	0.8440	13.6929	1.3748

Table 9. The bank's optimal capital structure and investment policy as a function of the bank's volatility when the bank does not issue any CoCo at time $t = 0$ and the growth option is financed by junior debt. $D^0(Y_0)$ denotes the face value of senior debt. Y^i is the optimal investment threshold. $\Pi^f(Y_0)$ is the unconditional probability of failure. $\Pi^I(Y_0)$ is the probability of investment. $\bar{T}^i$ is the expected time before investment. $F(Y_0)$ is the bank's ex-ante value. The bank fully finances the exercise of the growth option by junior debt for all values of σ.

σ	$D^0(Y_0)$	$D_c^0(Y_0)$	Y_{nc}^i	Y_c^i	$\Pi^f(Y_0)$	$\Pi^I(Y_0)$	$\bar{T}^i$	$F(Y_0)$
0.05	0.7141	0.1682	0.0443	0.0419	0.0101	0.9938	4.5841	1.4873
0.06	0.6695	0.1649	0.0448	0.0437	0.0304	0.9905	5.3791	1.4787
0.07	0.6411	0.1517	0.0452	0.0455	0.0616	0.9712	6.1757	1.4630
0.08	0.5958	0.1473	0.0486	0.0473	0.0951	0.9550	9.1704	1.4483
0.09	0.5508	0.1408	0.0496	0.0492	0.1357	0.9385	10.3394	1.4344
0.1	0.5185	0.1294	0.0517	0.0512	0.1916	0.9151	11.9062	1.4216
0.11	0.4832	0.1192	0.0537	0.0532	0.2512	0.8932	13.3360	1.4100
0.12	0.4522	0.1086	0.0558	0.0554	0.3191	0.8691	14.5817	1.3997

Table 10. The bank's optimal capital structure and investment policy as a function of the bank's volatility when the bank issues a PWD CoCo at time $t = 0$ and the growth option is financed by junior debt. $D^0(Y_0)$ denotes the face value of senior debt. $D_c^0(Y_0)$ denotes the face value of CoCo issued at time $t = 0$. Y_{nc}^i is the optimal investment threshold assuming no conversion prior to investment. Y_c^i is the optimal investment threshold assuming conversion prior to investment. $\Pi^f(Y_0)$ is the unconditional probability of failure. $\Pi^I(Y_0)$ is the probability of investment. $\bar{T}^i$ is the expected time before investment. $F(Y_0)$ is the bank's ex-ante value. The bank fully finances the exercise of the growth option by junior debt for all values of σ.

σ	$D^0(Y_0)$	$D_c^0(Y_0)$	Y_{nc}^i	Y_c^i	$\Pi^f(Y_0)$	$\Pi^I(Y_0)$	$\bar{T}^i$	$F(Y_0)$
0.05	0.7335	0.1713	0.0464	0.0420	0.0140	0.9902	5.6589	1.4822
0.06	0.7181	0.1710	0.0460	0.0440	0.0470	0.9691	6.0769	1.4725
0.07	0.6540	0.1684	0.0504	0.0457	0.0634	0.9582	9.9460	1.4582
0.08	0.6033	0.1684	0.0521	0.0475	0.0938	0.9434	11.7656	1.4458
0.09	0.5606	0.1607	0.0536	0.0493	0.1362	0.9248	13.0857	1.4335
0.10	0.5190	0.1506	0.0551	0.0513	0.1859	0.9062	14.2459	1.4218
0.11	0.4830	0.1383	0.0566	0.0533	0.2459	0.8852	15.2015	1.4109
0.12	0.4500	0.1255	0.0581	0.0554	0.3133	0.8632	16.0559	1.4009

Table 11. The bank's optimal capital structure and investment policy as a function of the bank's volatility when the bank issues an EC CoCo ($\lambda = 2$) at time $t = 0$ and the growth option is financed by junior debt. $D^0(Y_0)$ denotes the face value of senior debt. $D_c^0(Y_0)$ denotes the face value of CoCo issued at time $t = 0$. Y_{nc}^i is the optimal investment threshold assuming no conversion prior to investment. Y_c^i is the optimal investment threshold assuming conversion prior to investment. $\Pi^f(Y_0)$ is the unconditional probability of failure. $\Pi^I(Y_0)$ is the probability of investment. $\bar{T}^i$ is the expected time before investment. $F(Y_0)$ is the bank's ex-ante value. The bank fully finances the exercise of the growth option by junior debt for all values of $\{}sigma$.

bank would always prefer a PWD CoCo since in that case the bank will maximize the tax shields associated with it.

The ex-ante value of the bank is higher when the latter issues CoCo prior to investment regardless of the value of the asset volatility. Therefore, the value maximizing bank is expected to issue CoCo prior to investment even though this leads to delayed investment.

Finally, the model predicts that it is the lower volatility banks that issue more CoCo than their higher volatility counterparts. This model's prediction is consistent with the empirical finding by Goncharenko and Rauf (2016) who analyzing the sample of the EU banks from 2010-2016 confirm that among the banks issuing CoCo the ones with lower asset volatility issue more CoCo as a percentage of the total assets.

A Arrow-Debreu Security Prices (incomplete)

$$A(Y_t, Y^*) := \mathbb{E}_t^Q\left[e^{-r(\mathbb{T}^*-t)}\right] = \left(\frac{Y_t}{Y^*}\right)^{\beta_2} \tag{27}$$

where $\mathbb{T}^* := \inf\{s : Y_s \leq Y^*\}$ is the first time the process Y_t hits the threshold Y^* from above and

$$\beta_2 := -\frac{1}{\sigma^2}\left(\left(\mu - \frac{\sigma^2}{2}\right) + \sqrt{\left(\mu - \frac{\sigma^2}{2}\right)^2 + 2r\sigma^2}\right) < 0 \tag{28}$$

is the negative root of the fundamental quadratic equation.

B Derivation of the Valuation Equations (incomplete)

C The Smooth Pasting Condition for the Model from Subsection 4.2 (incomplete)

D The Smooth Pasting Condition for the Model from Subsection 4.3 (incomplete)

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