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**Conference Paper**

## Convert-to-Surrender Bonds: A Proposal of How to Reduce Risk-Taking Incentives in the Banking System

Beiträge zur Jahrestagung des Vereins für Socialpolitik 2011: Die Ordnung der Weltwirtschaft: Lektionen aus der Krise - Session: Board's Risk Taking Incentives, No. C15-V2

**Provided in Cooperation with:**

Verein für Socialpolitik / German Economic Association

*Suggested Citation:* Berg, Tobias; Kaserer, Christoph (2011) : Convert-to-Surrender Bonds: A Proposal of How to Reduce Risk-Taking Incentives in the Banking System, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2011: Die Ordnung der Weltwirtschaft: Lektionen aus der Krise - Session: Board's Risk Taking Incentives, No. C15-V2, ZBW - Deutsche Zentralbibliothek für Wirtschaftswissenschaften, Leibniz-Informationszentrum Wirtschaft

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# Convert-to-Surrender Bonds: A Proposal of How to Reduce Risk-Taking Incentives in the Banking System

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This version: February 2011  
First version: October 2010

## Abstract

We argue that contingent convertible capital (CoCo-Bonds) might have perverse risk-taking incentives for banks (asset substitution problem) and discourage them from investing in positive NPV projects and issuing new equity in times of crisis (debt overhang problem). Whenever the conversion price is set too high - as in the case of the Lloyds CoCo-Bond issuance in November 2009 - a wealth transfer will take place at the time of conversion. This will exacerbate both the asset substitution problem and the debt overhang problem.

We propose a new type of contingent convertible capital for banks - which we label Convert-to-Surrender Bonds (CoSu-Bonds) - which eliminates both the asset substitution and the debt overhang problem. CoSu-Bond convert into equity once the equity ratio falls below a certain threshold and CoSu-Bond holders take over the bank while equity holders are totally wiped out. This instrument makes equity holders naturally risk averse and gives incentives to equity holders to raise new equity and to invest also in slightly negative NPV projects in times of financial distress. Our instrument has a unique price if it is augmented by a simple option for old equity holders to issue equity if the trigger is hit, thereby circumventing the problem of multiple equilibria.

We develop a tractable model to analyze risk-taking incentives in the banking sector and present a detailed analysis of the Lloyds CoCo-Bond issuance. We finally discuss several policy issues associated with this new instrument including robustness and unique equilibria.

**Keywords:** CoCo Bonds, Contingent Capital, banking regulation, Basel II, Basel III, risk taking incentives, credit crunch, asset substitution, debt overhang

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## 1 Introduction

Contingent convertible capital (CoCo-Bonds) has been proposed as an instrument to strengthen the resilience of the financial system and to avoid tax payers picking up financial institutions losses (Flannery (2002, 2009), Squam Lake Working Group on Financial Regulation (2009)). CoCo-Bonds are debt instruments which convert into equity in case of financial distress of a single bank and/or the whole financial system. The appeal of CoCo-Bonds is therefore to provide an additional equity buffer under conditions of distress. CoCo-Bonds do, however, also have an impact on banks' incentive structure. We argue that the analysis of banks' incentives should be one of the key cornerstones in the assessment of contingent capital instruments. We demonstrate that classical CoCo-Bonds - such as the issuance of Lloyds Enhanced Capital Notes<sup>1</sup> - creates perverse incentives for bank managers and might potentially even exacerbate future financial crises.

We argue that CoCo-Bonds might have perverse incentives for bank owners if the conversion price is set wrongly. CoCo-Bonds - like the recently issued Enhanced Capital Notes by Lloyds - increase the incentive for bank owners to take on additional risk (asset substitution problem) by a factor of 5 to 10. The reason is that a wealth transfer from CoCo-Bonds to equities takes place at the time of conversion. Given that misaligned incentives have been identified as one of the causes of the recent financial crisis, this clearly seems to be a wrong path to go. To be precise: CoCo-Bonds will stabilize the financial system as they represent a capital buffer that can be tapped right in the moment when financial distress is imminent. However, this stabilizing effect might be set-off by the risk-taking incentives created by this instrument.

We therefore propose a new form of CoCo-Bonds which we label Covert-to-Surrender Bonds (CoSu-Bonds). The unique feature of CoSu-Bonds is that they make bank equity holders naturally risk averse and can therefore align regulators' and banks' incentives. CoSu-Bonds are bonds with two distinct features. First, just like CoCo-Bonds, they convert into equity in case of financial distress.<sup>2</sup> Second, in contrast to classical CoCo-Bonds, equity holders are totally wiped out in case of conversion. Thereby, equity holders lose disproportionately when things go bad. This creates a situation where bank owners are short in volatility and therefore naturally risk averse.

Banks' incentives in the presence of CoCo-Bonds are mainly determined by the conversion price. The conversion price determines the number of shares that CoCo-Bond holders receive in case of conversion. A high conversion price means that CoCo-Bond holders receive only a few shares and therefore only hold a small proportion of the after-conversion outstanding shares. Vice versa, with a low conversion price, CoCo-Bond holders will own a large proportion of the outstanding shares after conversion. The conversion price will therefore determine whether, and in which direction, a wealth transfer takes place at the time of conversion. We analyze two extreme cases: In the first case, CoCo-Bond holders are totally wiped out in case of conversion (i.e. a conversion price of infinity). This effectively means that equity holders bear the first losses until conversion but can

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<sup>1</sup>Lloyds issued GBP 8.3bn of contingent capital in November 2009 which are labelled "Enhanced Capital Notes". These CoCo-Bonds will convert at a 5% Core Tier 1 ratio and thereby immediately increase Lloyds Core Tier 1 ratio by 1.8PP.

<sup>2</sup>If this would be the only benefit of contingent capital, it is questionable whether a higher equity buffer from the beginning on would not be the better solution. Admati, DeMarzo, Hellwig, and Pfleiderer (2010) provide an excellent discussion of the costs and benefits of equity vs. debt in the banking sector.

fully impose these losses on the CoCo-Bond holders in the event of conversion. We label this case the "Convert-to-Steal" case. The other extreme is the case where equity holders are totally wiped out in case of conversion and CoCo-Bond holders take over the bank (i.e. a conversion price of zero). This effectively means equity holders do not only bear the first loss position but are even worse off in case of conversion. CoCo-Bond holders will even pocket a gain in case of conversion in this case. We label this case the "Convert-to-Surrender" case ("CoSu-Bonds").

The analysis of incentives in the corporate finance literature goes back to Jensen and Meckling (1976) and Myers (1977). Jensen and Meckling (1976) pointed out to the asset substitution problem. Equity holders have an incentive to increase risk as they effectively hold a call option on the company's assets. They may even conduct negative NPV projects for the pure purpose of increasing risk. The debt overhang problem goes back to Myers (1977). Under the debt overhang problem, companies in financial distress may reject positive NPV projects because benefits mostly accrue to bond holders. The asset substitution problem therefore predicts excessive risk taking in the financial sector which is further exacerbated by implicit state guarantees. The debt overhang predicts that bank equity holders will be reluctant to provide new funds in times of financial distress as a significant part of these funds will accrue to the bondholders. The debt overhang can also explain a credit crunch in times of financial crisis as banks will be reluctant even to grant loans which are profitable on a stand-alone basis (Holmström and Tirole (1997)).

We show in this paper that Convert-to-Steal-type CoCo-Bonds significantly exacerbates both the asset substitution problem as well as the debt overhang problem over a wide range of reasonable parameters. Convert-to-Surrender CoCo-Bonds have exactly the opposite effect. These effects are highly economically significant. For Convert-to-Steal-type CoCo-Bonds, the equity value will increase by 20% for a 1PP increase in asset risk for reasonable parameters, i.e. there is a significant asset substitution problem. The debt overhang problem is not less severe: It needs 2\$ of NPV per \$1 investment to make the investment worthwhile for equity holders. In the Convert-to-Surrender case, equity value decreases by 10% for each 1PP increase in asset risk and only 0.8\$ NPV are needed per \$1 investment to make the investment worthwhile for equity holders.<sup>3</sup> Equity holders would therefore have a strong incentive to inject own funds even if the expected NPV is slightly negative. We also show that Convert-to-Surrender type CoCo-Bonds are not subject to the multiple equilibria problem (Sundaresan and Wang (2010)) if augmented by a simple option of shareholders to issue new equity before conversion takes place.

Interestingly, there is a real-life example of CoCo-Bonds coming very close to the extreme of a Convert-to-Steal bond: the Enhanced Capital Notes (ECNs) issued by Lloyds in November 2009. We analyze these ECNs in detail and find that Lloyds bank owners have now an even higher incentive for excessive risk taking than under the old capital rules. The reason is that the contingent capital holders have to bear losses too early, creating perverse incentives for banks to increase risk. In the case of Lloyds, an increase in asset volatility by 1 PP increases the value of equity by approximately GBP 500mn. This effect will be even larger if Lloyds moves closer to the trigger point of a 5% core-Tier-1-ratio. Lloyds will also be severely discouraged by these ECNs to issue new equity in the next financial crisis. This effect can potentially more than offset the positive effect of CoCo-Bonds on the capital supply side.

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<sup>3</sup>Obviously, all these numbers are pre-conversion numbers. If conversion has already taken place, CoCo-Bond holders are the new equity holders and their incentives depend on the new capital structure after conversion.

CoCo-Bonds are on the verge of becoming a regulatory recognized instrument. In fact, Dutch Rabobank issued Senior Contingent Notes (SCNs) in March 2010 which resemble the features of a CoCo-Bond with a rather high conversion price. According to Rabobank these SCNs are not yet recognized as a part of regulatory capital. However, the management expects that this might happen in the future. Another example is a proposal put forward by an expert group implemented by the Swiss Federal Department of Finance. According to their report published by the end of September 2010, UBS and Credit Suisse should increase their total capital ratio up to 19%. Up to 9 PP could be raised via issuing CoCo-Bonds with a trigger set at 7% resp. 5% common equity ratio. According to this proposal, banks are free to choose the details of how to determine the conversion price.

This paper is structured as follows. Section 2 gives a brief literature overview. In section 3, we will explain the driving factors behind the conversion price of CoCo-Bonds and bank owners' incentives based on a simple case in a one period setting. In section 4, we develop general results in a continuous time model for the equity value as a function of the conversion price of CoCo-Bonds. In section 5, we explicitly analyze the CoCo-Bonds issues by Llyods ("Enhanced Capital Notes") in November 2009. Section 6 discusses the policy implications of our proposal and concludes.

## 2 Literature overview

Contingent capital was already proposed by Flannery (2002) including recent updates and further discussions in Flannery (2009). The Squam Lake Proposal (Squam Lake Working Group on Financial Regulation (2009) by 15 U.S. economists also proposes contingent capital.

Flannery (2009) provides an excellent overview of the CoCo-Bond literature and an in-depth analysis of the various features of CoCo-Bonds. Flannery (2002, 2009) proposes Contingent Capital Certificates (CCCs), which convert to equity at a rate implied by the contemporaneous share price. Given continuous price asset values, these CoCo-Bonds are de-facto risk-free because they are either paid back at notional or converted into equity worth exactly the notional value at the trigger event.<sup>4</sup>

Flannery (2009) also notes that "... we must take care that the conversion process does not influences managers to behave in a counter-productive way" (Flannery (2009), p. 13). This acknowledges the two-sided effects on banks: First, CoCo-Bonds can help recapitalizing a bank in times of distress. Second, the existence of CoCo-Bonds themselves can possibly change the way managers behave even before conversion. Flannery (2002, 2009) acknowledges that while his specific proposal for CCCs limits the asset substitution problem, risk-taking incentives for bank managers are still prevalent when CoCo-Bonds convert at the contemporaneous share price.

Managers incentives that arise with a given capital structure have been discussed since Jensen and Meckling (1976) and Myers (1977). The agency costs of debt result in asset substitution prob-

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<sup>4</sup>This point is stressed by Flannery (2009); it should be noted that it holds true as long as investors would be able to sell CoCo-Bonds immediately before or after conversion at the conversion price. Flannery (2002, 2009) uses the term "Contingent Capital Certificates". Recently, the term "CoCos" or "Contingent Convertibles" has been used by most papers. We will use the term "CoCos" throughout this paper while still acknowledging that the original proposition goes back to Flannery (2002).

lems as equity holders gain from increasing the riskiness of assets or the leverage of the firm. Debt overhang problems arise because positive NPV projects may be rejected since benefits mostly accrue to bond holders once a company is close to default. Greene (1984) shows that standard convertible bonds reduce the risk-taking incentives for equity holders. With standard convertibles, equity holders have to share part of the upside with convertible bond holders, thereby limiting their interest in increasing asset risk.

There now seems to be a common understanding that perverse incentives have contributed to the recent financial crisis.<sup>5</sup> Surprisingly, the question of bank managers incentives has only gained limited attention in the CoCo-Bond discussion which has so far predominantly focused on the macroeconomic impacts of ensuring capital supply in times of financial distress.

Flannery (2002, 2009), Maes and Schoutens (2010) and Coffee (2010) all acknowledge that the the resulting bank managers incentives should be taken carefully into account in addition to the macroeconomic effects. Coffee (2010) thereby proposes that CoCo-Bonds should not convert into equity but into preferred stock with cumulative dividends and with voting rights. Thereby a class of shareholders is created which are rationally risk averse. Our idea of CoSu-Bonds is similar but differs in one key aspect: While the proposal of Coffee (2010) creates a class of risk-averse shareholders only after conversion, CoSu-Bonds would create naturally risk-averse shareholders also before conversion. An analysis of the impact of the conversion price of CoCo-Bonds on risk-taking incentives can also be found in Albul, Jaffee, and Tchistyi (2010) and Pennacchi (2010). Both papers do, however, not consider the case of CoSu-Bonds which convert at a premium, as we do here.

An important discussion in this context is related to the question whether the conversion price and/or the trigger point is based on book or market values. Sundaresan and Wang (2010) show that if these triggers are based on market prices of stocks, CoCo-Bonds do generally not lead to a unique equilibrium in equity and CoCo-Bond prices. Multiple equilibria can cause problems because market participants might try to manipulate prices to achieve the optimal equilibrium for their holdings (cf. Hillion and Vermaelen (2004)).<sup>6</sup> They find that a unique price can only be achieved if no wealth transfer between equity and CoCo-bond-holders takes place at conversion. These market manipulation concerns might be in particular important for smaller companies where market prices are more prone to manipulation and for companies where a lower share price does not by itself destroy value. If a low share price destroys value by itself - as might be reasonably argued for larger banks because of feedback loops - such market price manipulation would be counterproductive for the CoCo-Bond holders.

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<sup>5</sup>Cf. in particular the detailed discussion in Squam Lake Working Group on Financial Regulation (2009). Fahlenbrach and Stulz (2010) analyze bank managers compensation packages and find no statistically significant link between perverse incentives and the performance during the financial crisis. However, statistically significant evidence may sometimes be hard to find when analyzing short samples and periods (< 100 banks over only 3 years).

<sup>6</sup>Hillion and Vermaelen (2004) study a set of 487 death spiral convertibles issued until 1998. These death spiral convertibles are bonds or preferred equity which could be converted to common equity i) at the investor's option (bond investor, preferred equity investor) and ii) usually at a conversion price below the share's market value on the conversion date (i.e. wealth transfer from stockholders to bond holders as in our proposed case). They find that these bonds and preferred equity encourages short-selling by convertible investors due to contractual flaws. However, they usually analyze smaller issuances which are much more prone to manipulation. In contrast, CoCo-Bonds would only be required by systemically important banks with larger market capitalizations.

Posner (2010) discusses several key issues related to CoCo-Bonds such as making CoCo-Bonds mandatory for systemically important financial institution, prohibiting financial institutions from holding CoCo-Bonds and a discussion of the trigger event. McDonald (2010) also analyzes the trigger event and proposes a dual price trigger similar to Squam Lake Working Group on Financial Regulation (2009).

Finally, Glasserman and Nouri (2010) derive closed-form solutions for CoCos for different choices of conversion triggers and conversion mechanisms. They analyze a general set-up including coupon payments and first-passage time defaults. We build upon their model but use a much simpler version which still allows extracting the main findings from a pure incentive perspective.

### 3 A simple example

To illustrate our point, we will look at a simple example. Bank A has \$100 in assets, financed by demand deposits (\$85), CoCo-Bonds (\$5) and common equity (\$10), as shown in table 1. For reasons of simplicity we assume that no interest is paid on deposits or CoCo-Bonds and that all investors are risk-neutral. The bank has two options for its investment strategy which are depicted in table 2. Strategy I ("Safe gain") yields a profit of \$10 if the economy ends up in the good state and a profit of \$0 if the economy ends up in the bad state. Both states are assumed to occur with the same probability. Strategy II adds an additional "gamble" which yields an extra +\$5 gain in the good state and an extra -\$5 loss in the bad state.

Assets	Liabilities	Description		Good state	Bad state
\$100	\$85	Demand deposits	Strategy I	+\$10	+\$0
	\$5	CoCo-Bonds	("Safe gain")		
	\$10	Equity	Strategy II	+\$15	-\$5
			("Safe gain + gambling")		

Table 1: Left-hand table: Balance sheet structure, right-hand table: Strategy options and payoffs.

We now want to illustrate the effect of the two extreme cases for the conversion price discussed at the beginning. In both cases we assume that conversion takes place once the asset value hits \$95. At the time of the trigger event there is a net asset value of \$10 left which has to be somehow divided between the CoCo-Bond-holders and the equity holders:

- In case A ("Convert-to-Steal"), CoCo-Bond-holders are totally wiped out, i.e., equity holders receive \$15 and CoCo-Bond-holders receive \$0. This is equivalent to saying that the conversion price is infinitely high or that the conversion rate equals 0 shares per \$1 CoCo-Bond-notional.
- In case B ("Convert-to-Surrender"), CoCo bond holders take over the whole company and equity holders are totally wiped out. This is equivalent to saying that the conversion price is \$0 or that the conversion rate is infinitely high, i.e. there is an infinite number of shares granted per \$1 CoCo-Bond-notional. We label CoCo-bonds with this special feature as Convert-to-Surrender bonds (CoSu-Bonds).

This situation is depicted in figure 1.

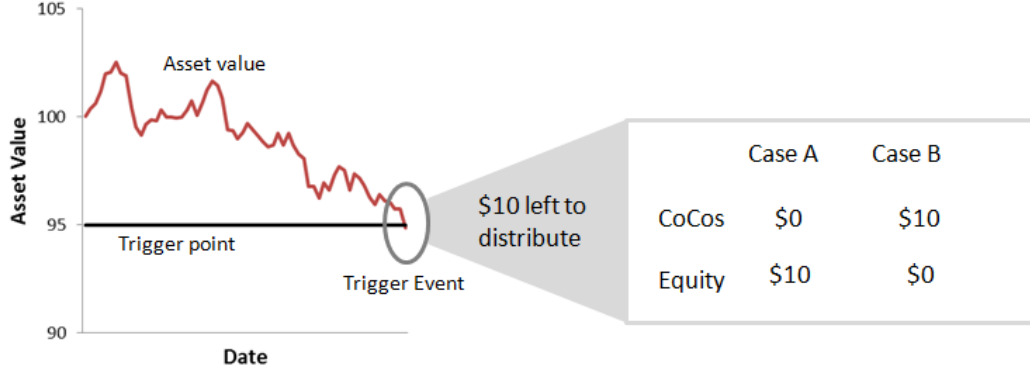


Figure 1: Illustration of trigger event and distribution of remaining \$10 equity (\$10 equity, \$5 converted CoCos, less \$5 losses) to CoCo-Bond-holders and equity holders

How does the payoff to equity holders look like? These payoffs are depicted in figure 2. In case of either strategy I or the good state of strategy II, the trigger will not be hit and equity holders therefore always bear the total gain/loss from the respective strategy. If the economy ends up in the bad state and the bank has chosen strategy II, the conversion of the Coco-Bonds is triggered and the payoff depends on the conversion price. In case A (Convert-to-Steal), the payoff to equity holders will be \$0 (the total loss of \$5 is borne by the CoCo-Bond holders only). In case B (Convert-to-Surrender), the payoff to equity holders is -\$10 as now the CoSu-Bond holders own the total company. Please note that the loss to equity holders in case B is larger than the total loss on strategy II (-\$5). CoSu-Bond-holders therefore even gain from conversion. This is a large incentive for bank owners not to undertake purely risk-shifting projects.

		Good state	Bad state	Average
Case A	→ Strategy I	10	0	5
	→ Strategy II	15	0	7.5
Case B	→ Strategy I	10	0	5
	→ Strategy II	15	-10	2.5

Figure 2: Payoffs for different conversion prices (case A vs. case B) for the two different strategies. Case A assumes that equity holders are wiped out in case of conversion, case B assumes that CoCo-Bond holders are wiped out in case of conversion.

Assuming equal probabilities therefore results in an NPV of \$5 for strategy I for both case A and case B. In case of strategy II, the NPV is \$2.5 in case of Convert-to-Steal and \$7.5 in case of



Convert-to-Surrender (cf. figure 2). Under Convert-to-Steal, equity holders therefore have a strong incentive to increase risk. The average payoff from the risky strategy II is \$2.5 higher than the average payoff from strategy I. Such an asset substitution incentive cannot be in the interest of regulators and tax payers. Although this example is extreme, it clearly shows how CoCo-Bonds might increase the incentives for the equity holders to take on more risk.

Of course, prudential banking regulation would require banks to hold more equity if it is following strategy II. However, the financial crisis has certainly demonstrated that most banks are able to drive trucks through each loophole of such regulations. Current regulatory reform aims at closing these loopholes. However, regulation will never be 100% waterproof. Actually, with a CoSu-Bond, banks will have an explicit incentive not to invest in risky projects just because risks can be shifted towards debtholders or taxpayers. This is an especially important feature for systemically relevant financial institutions, because their debt is effectively guaranteed by the government ("too-big-too-fail"). A CoSu-Bond could interrupt these perverse risk-shifting incentive making the financial sector more resilient.

## 4 A general solution

### 4.1 Basic model

In this section, we provide a general solution for the risk-taking incentives for banks with CoCo-Bonds on the liability side. In particular, our framework uses the following notations and assumptions:

- Both standard debt and CoCo-Bonds are assumed to be zero bonds with the same maturity  $T$  and notionals  $N_{Debt}$  and  $N_{CoCo}$ .
- Conversion of the CoCo-Bonds takes place if the asset value  $V_T$  has fallen below a certain threshold  $TP$  ("trigger point") at maturity  $T$ .
- Convert-to-Steal vs. Convert-to-Surrender:
  - Convert-to-Steal-Type: If conversion takes place at  $T$ , equity holders receive the remaining net asset value ( $V_T - N_{Debt}$ )
  - Convert-to-Surrender-Type: If conversion takes place at  $T$ , CoCo-Bond holders receive the remaining net asset value ( $V_T - N_{Debt}$ )
  - No CoCo-Bonds: Standard debt is issued instead of the CoCo-Bonds. If the asset value is below the debt notional, equity holders receive nothing.

This simple Merton-type framework allows for a straightforward derivation of the main effects of CoCo-Bonds on banks incentives. Deviations from the main assumptions will be discussed in the next subsection, in particular a first-passage-style trigger and different debt and CoCo-Bond maturities.

*The payoff profile:*

The payoff to equity holders in all three cases ("Convert-to-Steal", "Convert-to-Surrender", "No

CoCo-Bonds") is depicted in figure 3. The crucial feature is the payoff function at the trigger point. In the Convert-to-Steal-case equity holders receive the remaining net wealth, i.e. they bear the first losses up to the trigger point. Once the trigger is breached, losses are therefore transferred from equity holders to the CoCo-Bond holders. Therefore, equity holders are better off for a time-T-asset-value of  $TP - \epsilon$  than for a time-T-asset-value of  $TP + \epsilon$ . In the Convert-to-Surrender-case equity holders are totally wiped out at conversion. Equity holders are better off for a time-T-asset value of  $TP + \epsilon$  than for a time-T-asset-value of  $TP\epsilon$ .

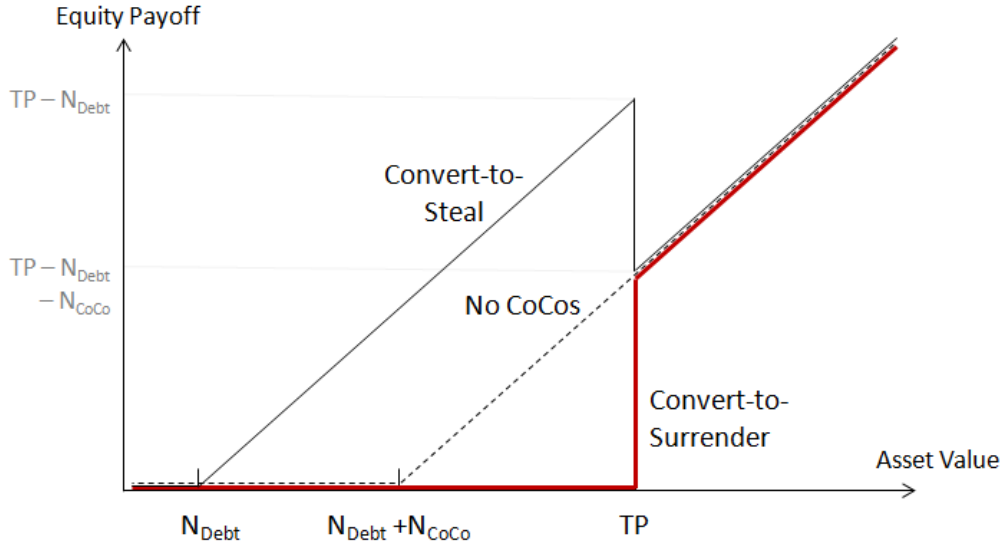


Figure 3: Payoff to equity holders at the maturity T for the cases Convert-to-Steal, Convert-to-Surrender and the case without CoCo-Bonds.

In a Merton-framework these payoffs can be described in terms of a classical European call option combined with a binary call option. A binary call option with strike price  $K$  and maturity  $T$  on an underlying process  $V$  pays out one unit if  $V_T > K$  and nothing otherwise. In the Convert-to-Steal-case, the payoff to equity holders is equal to one call option with strike price  $K$  minus  $N_{CoCo}$  times a binary call with strike  $TP$ . In the Convert-to-Surrender-case the payoff to equity holders is equal to one call with strike  $TP$  plus  $(TP - N_{Debt} - N_{CoCo})$  binary calls with strike  $TP$ :

$$S_{C-t-Steal} = C(\text{Strike} = N_{Debt}) - N_{CoCo} \cdot \text{DigC}(\text{Strike} = TP) \quad (1)$$

$$S_{C-t-Surr} = C(\text{Strike} = TP) + (TP - N_{Debt} - N_{CoCo}) \cdot \text{DigC}(\text{Strike} = TP) \quad (2)$$

Here,  $C$  denotes the value of a European call option and  $\text{DigC}$  denotes the value of a Digital call option. The equity value and the respective greeks can be derived straightforwardly based on the well-known valuation formulas and greeks for call options and binary call options (cf. appendix), i.e.

*Valuation:*

$$S_{C-t-Steal} = V_0 e^{-rT} N[d_1(N_{Debt})] - N_{Debt} e^{-rt} N[d_2(N_{Debt})] - N_{CoCo} \cdot e^{-rT} N[d_2(TP)] \quad (3)$$

$$S_{C-t-Surr} = V_0 e^{-rT} N[d_1(TP)] - TP e^{-rt} N[d_2(TP)] - (TP - N_{Debt} - N_{CoCo}) \cdot e^{-rT} N[d_2(TP)] \quad (4)$$

Greeks (Delta and Vega):

$$\frac{\partial S_{C-t-Steal}}{\partial V_0} = N[d_1(N_{Debt})] - N_{CoCo} \frac{e^{-rT} N'[d_2(TP)]}{\sigma V_0 \sqrt{T}} \quad (5)$$

$$\frac{\partial S_{C-t-Steal}}{\partial \sigma} = V_0 \sqrt{T} N'[d_1(N_{Debt})] + N_{CoCo} \frac{e^{-rT} d_1(TP) N'[d_2(TP)]}{\sigma} \quad (6)$$

$$\frac{\partial S_{C-t-Surr}}{\partial V_0} = N[d_1(TP)] + (TP - N_{Debt} - N_{CoCo}) \frac{e^{-rT} N'[d_2(TP)]}{\sigma V_0 \sqrt{T}} \quad (7)$$

$$\frac{\partial S_{C-t-Surr}}{\partial \sigma} = V_0 \sqrt{T} N'[d_1(TP)] - (TP - N_{Debt} - N_{CoCo}) \frac{e^{-rT} d_1(TP) N'[d_2(TP)]}{\sigma} \quad (8)$$

For an illustration of the resulting effects we chose the following parameters: We set  $T$  equal to 0.25. Of course, CoCo-Bonds would definitely have a longer maturity. However, banks are well-known for having short term liabilities. Hence, if the trigger is observed on a say quarterly basis, conversion of CoCo-bonds will be considered each quarter. Extensions of this simple modeling will be discussed in the next subsection. The risk-free rate is assumed to be 5%. We set  $V_0$  to 100,  $N_{Debt}$  to 85 and  $N_{CoCo}$  to 5. This can be interpreted as a capital ratio of 10% and an additional buffer of CoCo-bonds equal to 5% of the (risk-weighted) assets.

This parameter choice together with an assumed asset volatility of 5% results in a risk-neutral probability that the trigger is hit of 0.56% per quarter or 2.27% per annum. A credit default swap paying one in case of conversion would therefore have a spread of (roughly) 227 bp. Given that bank CDS are currently trading at appr. 50-150 bp and the trigger event should be more likely than an outright default this seems to be a reasonable calibration. The asset volatility range from 0-10% is chosen based on values from Gropp and Heider (2010). Gropp and Heider (2010) report a mean asset volatility for a sample of banks from the U.S. and EU from 1991-2004 of 3.6% with a standard deviation of 3.4%. In times of crisis - where asset substitution problems are more prevalent - asset volatility is likely to be higher than the unconditional mean.

The resulting equity value is depicted in figure 4 for all three cases (Convert-to-Steal-type, Convert-to-Surrender-type and without CoCo-Bonds). We make two key observations for the sensitivity of the equity value with respect to the asset volatility: First, the sensitivity in the case without CoCo-Bonds is dwarfed by both other cases in absolute terms. Second, the Convert-to-Steal-type significantly increases bank managers' incentives to increase risk whereas the Convert-to-Surrender-type (CoSu-bonds) significantly decreases risk-taking incentives.<sup>7</sup>

Both observations together have an alarming implication: Banks incentives to increase risk will be a magnitude higher if Convert-to-Steal-type CoCo-Bonds are mandatorily introduced. This can be illustrated by a simple example: By doubling asset volatility from 5% to 10%, bank managers can increase the value of equity by only 0.13% without CoCo-Bonds; but by 4.43% with Convert-to-Steal-type CoCo-bonds. If we assume an asset value of only 96, i.e. a distressed situation, the respective values are 1.72% vs. 9.28%. With CoSu-Bonds the effect is exactly the opposite. Banks now have an incentive to decrease risk. Increasing asset volatility from 5% to 10% decreases equity

<sup>7</sup>Given these asset substitution effects, CoCo-Bond holders will require compensation in terms of higher interest rates. These agency costs of Convert-to-Steal-CoCo-Bonds may be suboptimal from a macroeconomic perspective.

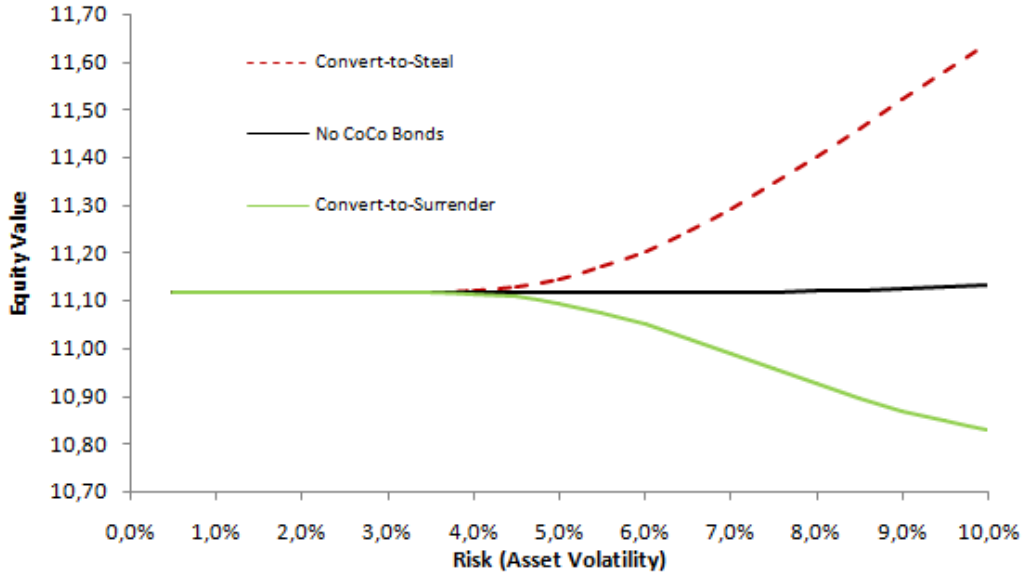


Figure 4: Equity value as a function of the asset volatility for all three cases (Convert-to-Steal CoCos, Convert-to-Surrender CoCos (CoSu-Bonds) and situation without CoCo-Bonds)

value by 2.39%.

It should be noted that CoCo-Bonds with a pre-specified conversion price, for instance depending on the equity price, lie somewhere in between our two extreme examples. To generate the desired incentive effect of equity holders being short volatility, as a necessary condition a wealth transfer from equity holders to CoCo-Bond holders has to take place at conversion.

Figure 5 presents both the delta and the vega of the equity value as a function of the asset value for all three cases. It shows the banks' incentives for different economic situations (normal asset value, high asset value after gains, low asset value after a crisis). The Convert-to-Steal type does not only have the effect of increasing the asset substitution problem (cf. right panel of figure 5), it also decreases the incentives for bank managers to invest in positive NPV projects (left hand picture of figure 5). The reason is that with Convert-to-Steal, a higher asset value means a lower probability of conversion and subsequent wealth transfer from CoCo-Bond holders to equity holders. The opposite effect is at work for CoSu-Bonds.<sup>8</sup>

## 4.2 Extensions of the model

Some of our assumptions in the previous section have been strict in order to yield simple results. First, CoCo-Bonds will usually have a longer maturity compared to standard debt or demand deposits. Second, CoCo-Bonds will usually have a first-passage time mechanism where the conversion

<sup>8</sup>There are actually two effects at work: First, with Convert-to-Steal, there is a larger likelihood for equity holders that they can reap the benefits of the additional dollar of NPV. Second, with Convert-to-Steal there is a lower likelihood of wealth transfer from CoCo-Bond to equity holders for each dollar increase in NPV. The second effect dominates the first when the wealth transfer is sufficiently large.

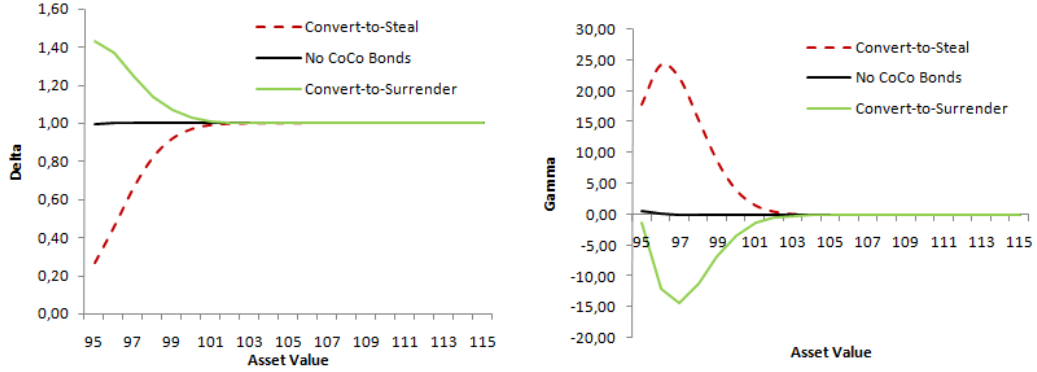


Figure 5: Delta (left-hand picture) and Vega (right-hand picture) of equity value as a function of the asset value.

is triggered once the value falls below the trigger point. We briefly discuss the impacts of changes in these assumptions.<sup>9</sup>

*Duration of CoCo-Bonds:* With longer durations of CoCo-Bonds, the asset substitution problem becomes even more pronounced because the cumulative standard deviation of asset returns will increase. This is somehow offset in a Merton-style framework where conversion and default can only happen at the end of the maturity. The asset drift will in this case decrease the probability of conversion which offsets the asset value effect.

*First passage mechanism:* Most CoCo-Bonds will be equipped with a first-passage-style conversion trigger, i.e. conversion is triggered as soon as e.g. the Core Tier 1 ratio falls below a specified level. A first-passage time conversion trigger increases the likelihood of conversion.<sup>10</sup> Therefore, under a first-passage time framework, banks' incentives will be even larger than what we demonstrated in the last subsection.

### 4.3 Unique equilibrium, price manipulation and the option to issue new equity

Sundaresan and Wang (2010) point out that CoCo-Bonds have multiple equilibria if a wealth transfer takes place at time of conversion. With our proposal of CoSu-Bonds, a wealth transfer takes place from equity holders to CoSu-Bond holders at time of conversion. Therefore, these CoSu-Bonds have multiple equilibria and may therefore be more prone to price manipulations.

However, there is a simple trick to avoid such multiple equilibria: Equity holders can be equipped with a right to issue new equity if the trigger is hit. If sufficient new equity is issued to bring the equity ratio above the trigger point, then no conversion will take place. With CoSu-Bonds, equity holders have a delta of larger than one close to the trigger point. Therefore, they do not suffer from a debt overhang problem and it would be rational to provide this new equity. A unique equilibrium in the sense of Sundaresan and Wang (2010) therefore exists. Intuitively, CoSu-Bond holders can

<sup>9</sup>This section is currently under development but would be completed for the conference.

<sup>10</sup>Mathematically, this can be shown with the reflection principle.

therefore not profit from short-selling equity anymore because the equity holders' option to issue new equity prevents CoSu-Bond holders from pocketing the possible gain from conversion. The unique equilibrium in a first-passage time set-up with continuous prices is therefore a situation where conversion will never take place because equity holders will always have an incentive to raise new equity in such a setup.<sup>11</sup>

If such an option to issue new equity is included, equity holders still cannot benefit from increasing risk and there is an incentive to raise new equity in case of distress. Therefore, there is no asset substitution problem and no debt overhang problem in this setup.<sup>12</sup> Equity holders are now neutral to increasing risk and would still inject new funds in times of distress. In fact, such an option to issue new equity always exists in the real world. No regulator would prohibit banks which are close to the trigger point from issuing new equity. Without contingent capital or with Convert-to-Steal-type contingent capital equity holders suffer from a debt overhang problem and would not inject new funds. With Convert-to-Surrender-type contingent capital, equity holders always benefit from injecting new funds once they are close to the trigger point.

## 5 The Llyods ECN Notes

In November 2009, Lloyds converted GBP 8.3 bn of subordinated debt into Enhanced Capital Notes (ECNs).<sup>13</sup> These ECNs are in effect contingent convertible capital. If Lloyds Core-Tier-1-ratio (CT1-ratio) drops below 5%, the ECNs will convert to equity and thereby immediately raise the CT1-ratio by 1.8 PP. The main features of these ECNs are summarized in table 2. ECN holders will receive a total of 13.6 bn shares on conversion which is equal to roughly 17% of the after-conversion total shares outstanding. Roughly speaking, the ECNs are at 17.02% between the Convert-to-Steal and the Convert-to-Surrender case above.

The current market capitalization (as of June, 30th, 2010) of Lloyds is GBP 36.6 bn and the Core-Tier-1-ratio is 9%. A rough estimate of the combined market value of current equity capital and ECNs at the trigger point is  $5\%/9\% \cdot 36.6bn + 8.3bn \approx 30bn$ . Hence, the 17% share of the ECN-holders will be worth approximately GBP5bn - which is a 40% discount on the nominal value (cf. table 6). This back-of-the-envelope calculation is likely to be optimistic. First, market values usually decline faster and sooner than Tier-1-ratios due to the stickiness of accounting ratios. Second, accounting ratios are not observed in continuous time; therefore the Core-Tier-1 ratio at conversion is likely to be lower than 5%. Taken these points into account, ECNs will probably lose more than 50% of their nominal value when converted to equity.

For the following calculations, we make the following simplifying assumptions:

- Assumptions as in section 3

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<sup>11</sup>In a Merton-type setup or a set-up with asset value jumps the asset value might be too low at the end of maturity to justify new equity issuances. However, a price manipulation incentive by CoSu-Bond holders is also ruled out in these situations. If information asymmetries persist – in particular if CoSu-Bond holders have an informational advantage over equity holders – a unique equilibrium may not exist anymore.

<sup>12</sup>The asset substitution problem would now not be reverted anymore but simply neutralized.

<sup>13</sup>The conversion was a combination of forced conversion and some incentives for the holders of subordinated debt with Lloyds stopping interest rate payments on the subordinated debt and offering more favorable terms for the ECNs compared to the subordinated debt.

Equity		ECNs (CoCo-Bonds)	
Market cap (GBP)	36.6bn	Notional (GBP)	8.3bn
Core Tier 1 capital (GBP)	41.9bn		
RWA (GBP)	493.2bn		
Core Tier 1 ratio	9.04%	Core Tier 1 trigger	5.00%
Core Tier 1 ratio after conversion (based on today's RWA): 6.8%			
Share price (pence)	53.70	Conversion price (pence)	59.21
Shares outstanding (#)	68.1bn	Shares @ conversion (#)	13.9bn
Shares outstanding after conversion (#): 82.0bn			
Pct of share capital for old equity holders after conversion	83.0%	Pct of share capital for ECN-holders after conversion	17.0%

Table 2: Overview of Lloyds capital structure, regulatory ratios and ECN (CoCo-Bond) issuance.

- The maturity is set equal to 0.25, i.e. a quarterly observation of the trigger event
- Changes in the Tier-1-ratio can only be induced by gains/losses on the assets (no change in RWA via increased/decreased business volume, no changes in average risk weight, no new equity issuance, etc.)
- The market value of equity moves one-to-one with the core-Tier-1-capital. E.g. if the CT1-ratio drops by 9PP to 8.1PP (i.e. by 10%), then the market value of equity will also drop by 10%
- We use all values as of June, 30th, 2010

The payoff profile as a function of RWA-volatility is depicted in figure 7. Due to the ECNs, the equity holders have a significant interest in increasing the riskiness of the portfolio (or, equivalently: operating with a small core Tier 1 ratio). An increase of the asset volatility from 5% to 10% increases the equity value by 8% or GBP 2.6 bn (from GBP 32.7bn to GBP 35.3 bn). If Lloyds CT1-ratio falls closer to the 5%-trigger-point, the effects will even be larger. Under the same assumptions, the equity value increases by 16% if the asset volatility is increased from 5% to 10%.

To further illustrate this point, let us look at the payoff for equity holders close to the trigger point. At  $5\% + \epsilon$  core tier 1 ratio, the value of Lloyds equity would be GBP 20.2bn ( $= 5\%/9\% \cdot 36.6bn$ ). At  $5\% - \epsilon$  Lloyds equity value would be GBP 23.7bn ( $83\% \cdot (20.2bn + 8.3bn)$ ), i.e. GBP 3.5 bn higher. This payoff-profile should be a nightmare to the British regulators. If Lloyds ever comes into a situation where its core Tier-1 ratio drops close to 5%, they have an immense incentive to increase risk and there is an immense disincentive to raise new equity.<sup>14</sup>

<sup>14</sup>This is the so-called debt-overhang problem. ECNs dramatically increase the debt-overhang problem for Lloyds in case of a crisis.

	Market Cap 06/2010	Market Cap @5%+ $\epsilon$		Market Cap @5%- $\epsilon$
Tier-1 ratio	9.0%	5.0%		5.0%+1.8%
Value to current equity holders	36.6 bn	20.2 bn	+3.5 bn	23.7 bn
Value to current ECN holders	8.3 bn	8.3 bn	-3.5 bn	4.8 bn
Total	44.9 bn	28.5 bn		28.5 bn

Figure 6: Payoffs for Lloyds equity holders and ECN holders around the conversion point.

## 6 Policy discussion and conclusion

### *Introducing Convert-to-Surrender-Bonds (CoSu-Bonds):*

In this paper we have proposed a new way how to implement an equity buffer for systemically relevant institutions and simultaneously setting a risk-reducing incentive for their owners. More specifically, we propose an instrument labeled Convert-to-Surrender-Bonds (CoSu-Bonds), a special type of a conditionally convertible bond (CoCo-Bond). CoCo-Bonds have already been introduced in the discussion about banking regulation by Flannery (2002). In the wake of the financial crisis this instrument gained some attention by academics as well as by regulators. Typically, these bonds are regarded as convertible debt with the specific characteristic that conversion into stocks does not take place at the discretion of bond holders but is mandatory once the bank's equity falls below a pre-specified trigger point. This is an appealing idea, as this mechanism makes sure that banks can increase their equity exactly in the situation when this is most important. Without such CoCo-Bonds it would be extremely difficult for a bank to raise new equity under circumstances of individual or even systemic distress.

It is well known that the features of these CoCo-Bonds, including the risk-setting incentives for bank owners and managers, crucially depend on how the conversion price is set. While there has been some discussion about the optimal conversion price, our approach follows a new line of thought in this regard. Actually, we suggest that the conversion price should be zero, or in other words that holders of CoSu-Bonds take over the bank once its equity ratio falls below a critical level set by the financial authorities. It might be natural to think of this trigger point as being equal or slightly above the minimum common equity capital ratio according to the Basel accord, which starting from 2015 will be set at 4.5%. Of course, as this mechanism should be relevant for systemically relevant institutions in the first place, there may also be arguments for setting the trigger point even higher. It should be noted, however, that in our proposal the trigger point is a number set by the financial authority and based on accounting numbers. The bank management together with the financial authorities would have to check the conversion trigger regularly, for instance at the end of each quarter.



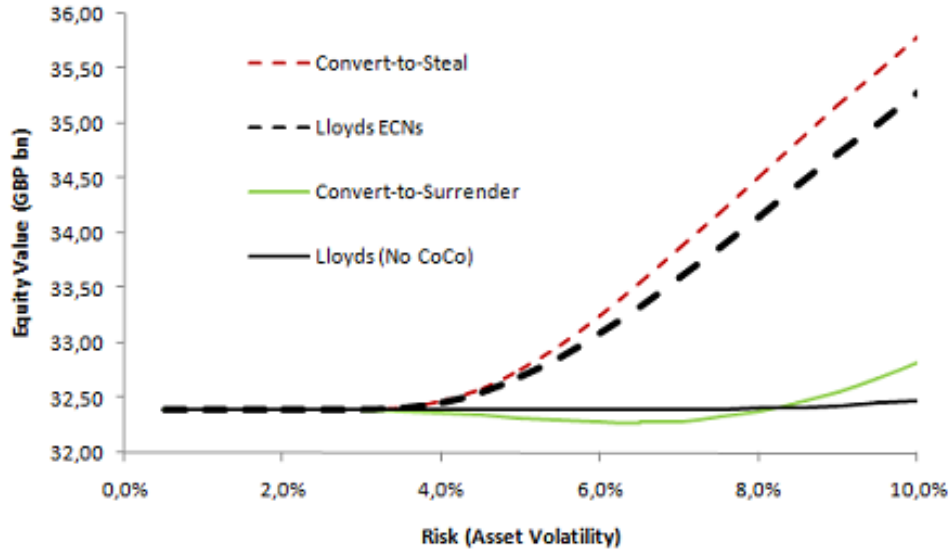


Figure 7: Payoffs for Lloyds equity holders and ECN holders around the conversion point.

*What is the impact of CoSu-Bonds on risk taking incentives?*

We have shown in this paper that CoSu-Bonds share an important feature with "normal" CoCo-Bonds: banks can increase their equity whenever they are in financial distress. This should improve the stability of the financial system. However, compared to CoCo-Bonds they have two additional appealing features: First, we have shown that under a wide range of parameters the existence of CoSu-Bonds eliminates the asset substitution incentives for bank owners. In fact, bank owners profit from reducing - and not from increasing - the bank's asset volatility, i.e. they are short in asset volatility. Second, they are still long in the bank's asset value, i.e. they profit from any increase in the present value of future cash flows. Hence, we argue that CoSu-Bonds are an appealing instrument not only for having an additional equity buffer under conditions of distress, but also for mitigating the risk-incentive problem. As we have shown with the example of Lloyds, current CoCo-Bond structured even significantly increase the risk-taking incentives for bank owners.

*What is the impact of CoSu-Bonds on the managers' incentives?*

In this paper we have analyzed the impact of CoSu-Bonds on the risk-taking incentives of bank owners. There was no formal analysis of the impact on the risk-taking incentives of bank managers. This is, of course, an important issue that is left for further research. The crucial question is how risk-taking incentives generated by stock options, or similar instruments, are changed, if CoSu-Bonds are introduced. We do not yet know how exactly these incentives would be influenced. However, it is obvious in any case that risk-taking incentives generated by options will be mitigated. Whether and under what specific conditions they can even be eliminated has to be left open at this point. But shareholders can only be expected to set the right incentives for the management, if their own incentives are compatible with the goal of a stable banking system.

*Will banks issue CoSu-Bonds voluntarily?*

Most probably not. First of all, the existence of a CoSu-Bond makes default for equityholders more likely. Hence, introducing a CoSu-Bond leads to a redistribution of wealth from incumbent shareholders to CoSu-Bondholders and holders of straight debt. However, as far as the redistribution towards CoSu-Bondholders is concerned, this might not be a problem. As long as CoSu-Bonds are issued on the basis of preemptive rights attached to stocks, no redistributions occurs. Redistribution towards holders of straight debt, however, cannot be avoided. But this objection would also apply to any regulatory intervention towards lifting tier-1-ratios. Second, for systemically relevant institutions there is also a transfer of wealth from stockholders to the taxpayer, as CoSu-Bonds make government subsidizes for systemically relevant institutions less likely. Third, to the extent that the bank managers own stock options - or other similar instruments - there would be a transfer of wealth from managers to all other claimholders. Fourth, as long as there is not a developed market for CoCo- or CoSu-Bonds, the issuance is encumbered with several imponderables. It is unlikely that the management of a bank would deliberately expose themselves to such a risky undertaking. Nevertheless, it should be noted that CoSu-Bonds would also have positive effects on shareholders. First, the probability of formal insolvency is reduced and, hence, the expected present value of bankruptcy cost will be lowered. Second, implementing a mechanism that reduces the risk-taking incentive lowers the agency cost of debt. To this extent, the bank's net interest income increases making the bank more valuable. Third, to the extent that CoSu-Bonds are a substitute to equity, a positive tax-shield effect should be realized. Therefore, under the hypothetical situation of defining a de-novo capital structure, it could well be that CoSu-Bonds would be a part of it. Under an existing capital structure this is much more difficult. In fact, for the time being there are just a very few real life examples of banks issuing conditionally convertible debt.

*How to implement CoSu-Bonds from a regulatory perspective?*

Even though CoSu-Bonds could be issued by any bank, and of course also by any other corporation, a straightforward field of application would be systemically relevant institutions. The simple reason is first that these institutions are large and sophisticated enough to tap the capital market with such an innovative instrument. It could well be that after these banks have paved the way for these instruments, several other banks will follow. Second, there is an ongoing discussion about increasing equity ratios for systemically relevant institutions. CoSu-Bonds would be an efficient mechanism to achieve the goal of a more resilient banking system. In fact, an expert group set-up by the Swiss Federal Department of Finance proposed to increase the total capital ratio of UBS and Credit Suisse up to 19%. Up to 9 PP could be raised via issuing CoCo-Bonds with a trigger set at 7% resp. 5% common equity ratio. According to this proposal, banks are free to choose the details of how to determine the conversion price. Starting from 2019 all banks subject to the Basle accord are expected to have a minimum total capital ratio of 10.5%, a minimum tier-1 capital ratio of 6% and a minimum common equity capital ratio of 4.5%. Regulators now could implement two simple additional rules: First, banks are allowed to provide tier-2 capital in form of CoSu-Bonds. Second, under the condition that the equity capital ratio by the end of any quarter falls below a given ratio, conversion becomes mandatory. This trigger point, of course, should be at least 4.5%; it could make sense to set it even higher. If regulators decide to force systemically relevant banks to have even higher capital ratios, this could easily be handled within these two rules. As all new rules regarding the minimum capital standards are finally implemented after a transition period lasting

until 2019, there should be sufficient preparation time for market participants.

*Should banks have the choice between issuing CoCo-Bonds or CoSu-Bonds?*

Basically, it could be argued that the regulator just recognizes CoCo-Bonds as a part of tier-2 capital. It is then up to the banks whether to issue such bonds and how to structure them. If they like, they could set the conversion price extremely low, making the CoCo-Bond very similar to a CoSu-Bond. They could, however, also do the opposite, making the CoCo-Bond a Convert-to-Steal bond. According to what we have discussed in this paper, the regulator should not grant this freedom to the bank. In fact, if the conversion price of the CoCo-Bond is too high, risk-taking incentives at the side of bank-owners are even enforced as compared to the situation without any CoCo-Bonds. Hence, unrestricted CoCo-Bonds could increase the instability of the financial system instead of reducing it. This is in particular worrying as the perverse risk-taking incentives with classical CoCo-Bonds are highest in case of financial distress.

*Should the issuance of CoSu-Bonds be mandatory?*

This is, of course, a crucial question. Taking most of the pertinent discussions - or also the Swiss example mentioned above - CoCo-Bonds are regarded as an instrument accepted by the financial authorities as a substitute to (tier-2) capital, but their issuance is clearly not considered to be mandatory. The basic idea behind this is that the capital structure is the outcome of a complex bargaining process, where the cost of equity (including agency cost) is traded-off against the cost of debt (including agency cost as well). Any restriction set by a regulatory authority would therefore distort this process and, hence, generate a deadweight loss. Under this perspective an appealing feature of CoCo-Bonds consists in the fact that it is left up to the owners of the bank whether they fulfill a minimum capital standard by issuing equity or by issuing (conditionally convertible) debt. This is an obvious argument not to make the issuance of CoCo- or CoSu-Bonds mandatory. This consideration, however, neglects path dependency and market failures in corporate governance systems. Even though CoSu-Bonds may be an attractive instrument for mitigating the asset substitution problem, their first implementation is, as we have already mentioned, encumbered by substantial imponderabilities. Moreover, bank managers have only weak incentives to implement these instruments. Therefore, it is a serious concern from a social perspective whether the regulator should leave the decision about issuing CoSu-Bonds to the banks and their management. For a transition period, however, it might be sufficient to recognize CoSu-Bonds as tier-2 capital. This would set an incentive to become acquainted with that instrument.

*Are CoSu-Bonds subject to price manipulations?*

According to some proposals made in the literature (cf. e.g. Flannery (2002)) the trigger point of CoCo-Bonds is determined on the basis of the market value of the bank's equity. In this case, however, it can be shown that multiple equilibria exist (cf. Sundaresan and Wang (2010)), unless the construction of CoCo-Bonds does not obey to some specific characteristics. Even though this is a technical argument, concerns have been raised that CoCo-Bonds could create strong incentives for price manipulation. To put it very simply, CoCo-Bondholders have an incentive to depress the bank's stock price, e.g. by short-selling the stock, as in that case they can take over the bank. Without going too much into detail, we would like to point out to two issues here: First, the triggers

applied so far (e.g. in the Lloyds case) are usually determined on the basis of accounting figures, so with these trigger events conversion can never be forced via any type of price manipulation on the market. However, setting a trigger based on accounting ratios comes at a cost. The assessment of whether the trigger point is reached is left to the bank management, most probably in cooperation with the financial supervision authority. This makes the mandatory conversion subject to window dressing or even criminal behavior. It cannot be ruled out that this causes serious mistrust on the side of investors making the market for these bonds potentially collapse. Even if the trigger would be set based on the market price, we think that price manipulations of this type will be rare due to two reasons: First, CoCo- or CoSu-Bonds would be required for systemically important financial institutions. Their pure size and market capitalisation will make price manipulations hard to succeed. Second, the usual price manipulation arguments only work under the assumptions that the intrinsic value of the company is unaffected by the price manipulation. For banks, this is certainly not the case since financial distress by itself causes heavy costs for banks. This reduces or even eliminates incentives for CoCo-Bond holders to profit from manipulating the price of a bank's stock. In addition, there is simple trick of how to ensure unique equilibria: By giving equity holders the option to raise sufficient new equity when the trigger is hit - and thereby circumventing conversion - CoSu-Bond holders can no longer profit from manipulating the stock price while the benefits from reduced risk-taking incentives remain.

## A Pricing and Greeks of European call options and European binary call options

The price of a European call option ( $C$ ) and a European binary call option ( $DigC$ ) can be determined via:

$$C = V_0 e^{-rT} N(d_1) - K e^{-rT} N(d_2) \quad (9)$$

$$DigC = e^{-rT} N(d_2) \quad (10)$$

with

$$d_1 = d_1(K) = \frac{\ln(V_0/K) + (r + 1/2\sigma^2)T}{\sigma\sqrt{T}}$$

$$d_2 = d_2(K) = d_1(K) - \sigma\sqrt{T}$$

The corresponding derivations with respect to the asset value  $V_0$  and the volatility  $\sigma$  are:

$$\frac{\partial C}{\partial V_0} = N(d_1) \quad (11)$$

$$\frac{\partial C}{\partial \sigma} = V_0 \sqrt{T} N'(d_1) \quad (12)$$

$$\frac{\partial DigC}{\partial V_0} = \frac{e^{-rT} N'(d_2)}{\sigma V_0 \sqrt{T}} \quad (13)$$

$$\frac{\partial DigC}{\partial \sigma} = -\frac{e^{-rT} d_1 N'(d_2)}{\sigma} \quad (14)$$

where

$$N'(x) = \frac{1}{\sqrt{2\pi}} e^{-1/2x^2}$$

Applying (9)-(14) to (1) and (2) yields (5)-(8).

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