UiT
THE ARCTIC
UNIVERSITY
OF NORWAY

School of Business and Economics

Aspects and Dynamics of Contingent Convertible Bonds

Pricing Norwegian CoCo Issuances With Equity Derivative Approach

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Master's Thesis in Business Administration - June 2018

Acknowledgements

This master thesis is written as part of the Master of Business Administration at UiT, The Arctic University of Norway, and constitutes 30 ECTS of the program.

My main motivation for writing this dissertation is to shed light on the important asset class contingent convertible bond (CoCos) issued by the financial sector. The process of writing this thesis has proved challenging and demanding, but at the same time exciting. I feel fortunate to study a topic that is of personal interest to me, and I am glad to have gained insight into various subjects in the financial literature. Moreover, I look forward to following the future development of CoCos and hopefully further expand my own insights as well.

I would like to thank my supervisor, associate professor Espen Sirnes for his helpful guidance and for providing new ideas regarding the topic. I also wish to thank associate professor Torun Fretheim for valuable feedback. Moreover, I thank my partner, Iselin Emmy Pedersen, for being truly understanding and supportive all the way.

Abstract

Contingent convertible bonds have emerged as a *going-concern* loss-absorbing instrument in response to the last financial crisis. These hybrids, commenced by the new Basel III regulation, might be able to substitute the prevailing subordinated debt instruments that failed to effectively absorb losses during the last crisis. Issuing CoCos present an effective way to provide automatic recapitalizing for banks in times with financial distress, by forcing conversion to shares or automatic write-down when certain triggers are breached. Consequently, the instrument enhances robustness of the banking sector if constructed properly.

This thesis presents the structure and promising pricing methods of CoCos with Core Equity Tier 1 trigger, in which equity derivatives pricing method is found to be the most suitable. As the dynamics and structure of the instrument are complex, finding the appropriate trigger is not straightforward. Most of the existing models, including equity derivatives, imply high co-movement between Core Equity Tier 1 and stock prices in order to find the trigger level. However, as the historical correlation prove to be insignificant, there is need for new research in this field.

This thesis develop an modest attempt at finding the stock price trigger level based on an analytical approach using scenario CAPM β values. To test the analytical method in an equity derivatives approach, CoCo issuances by DNB in 2015 and 2016 are examined. The data is retrieved from TITLON financial database and company filings, whereas simple data handling is performed in Microsoft Excel. All computations are done in the statistical programming software R. The codes are available upon request. According to the best estimate, the price of both DNB CoCos are undervalued. As underpricing is apparent, the thesis points to several factors that may explain the discrepancy between theoretical and observed prices. These consists mainly of (1) mispricing caused by the model, and (2) mispricing due to market participants' perception of CoCos dynamics.

Keywords: Contingent convertible bonds, Basel III, capital structure, regulatory capital, equity derivatives

Contents

Introduction

1.1 Background

In the aftermath of the financial crisis of 2007-2008 banks became the subject of increased regulatory capital requirements. The years prior to the financial crisis was a period with overwhelming belief in increased housing prices. As Bailey et al. (2008) point out, the crisis was mainly caused by derivatives with higher risk embedded than initially assumed. Especially important were collateralized debt obligations, a security with collateral in other financial instruments. This derivative was filled with subprime loans and sold as securities-based mortgage loans, well known as mortgage-backed securities. Due to misleading credit ratings and high default risk, these derivatives were devastating for an already overheated economy.

The crisis led to severe international financial distress commenced by chain-reactions of large interconnected banks, which in turn caused the Lehman Brothers bankruptcy and the need for several rescue packages for banks around the world. These bailouts were, of course, financed by the taxpayers' money. Thus, the failure of existing debt instruments to absorb losses effectively was revealed. Seniority of prevailing hybrids and subordinated debt was structured so that these instruments suffer losses second after equity when default occurs. Therefore protecting the more senior capital sources, such as deposits. However, since these prevailing hybrids are *gone-concern* loss absorbing, as they face losses only when default occurs, regulators also bailed out investors in such debt securities using tax-payers' money. This obviously attracted strong criticism.

Subsequently, the Bank for International Settlements (BIS) proposed Basel III as a response to future crises, with a goal to increase the amount and quality of regulatory capital (BCBS, 2010). In light of new financial regulation, the issuance of a new instrument called a contingent convertible bond (CoCos) was facilitated, hereby providing a hybrid instrument with *going-concern* loss-absorbing properties. CoCos first entered the market one year after the financial crisis, with initial issuance made by Lloyds in late 2009.

CoCos are by definition hybrid instruments issued by financial institutions, where automatic conversion to shares or a write-down occur based on predefined contractual conditions (Corcuera et al., 2013). These conditions include one or several triggers related to the instrument, and are supposed to reflect a situation in which the issuing company needs restored capital. When a trigger is breached, automatic contingent conversion or write-down instigates recapitalization of the bank.

Because CoCos are intended to be a true loss-absorbing instrument, they might reduce default risk and vulnerability for banks in times of financial distress. Furthermore, by allowing CoCo issuance, the Bank for International Settlements are able to mitigate crises and stop taxpayers from becoming the loss-absorbing part in the future. This means that default risk is transferred from taxpayers to CoCo investors, reducing the need for future regulatory initiated bailouts. CoCos might also function as countercyclical capital if constructed properly. Liebenberg et al. (2017) state that this might reduce the procyclical nature of the economy. However, this requires that investors in CoCos are not mainly other banks, so that the too-big-to-fail issue observed in the last crisis is reduced.

Although CoCos are bonds with conversion and fixed income properties, they must not be confused with regular convertible bonds, as they differ widely in structure. Regular convertible bonds give bondholders the option of exchanging bonds into shares in the company (Bodie et al., 2014), while contingent convertible bonds have automatic conversion based on certain trigger levels. As regular convertible bonds have equity upside, conversion of CoCos imposes a direct loss onto the investor. Hence, the structure of the two is quite different.

The performance of CoCos as a loss-absorbing instrument is however rather untested. To date, few events involving conversion or write-down have occurred, leaving questions about CoCos long-term suitability unanswered. However, two recent events involving CoCos add to the discussion of its assessment as regulatory capital. These are presented later in the regulatory debate provided throughout the discussion of this thesis.

1.2 Motivation and Purpose

There exist a variety of CoCo structures, which are mainly differentiated by trigger and conversion properties. As these features are designed to ensure the loss absorbing ability, Corcuera et al. (2013) emphasize the importance of constantly searching for new methods to price and explore their dynamics. To qualify as regulatory capital under Basel III, CoCos should function as a direct loss-absorbing instrument restoring the core capital when a bank faces trouble. However, the discussion of evaluating the suitability as hybrid regulatory capital is an ongoing debate and Admati et al. (2013), among others, criticizes the instrument for being too complex and likely having insufficient loss-absorbing capacity.

Most issuances have a Core Equity Tier 1 trigger level, which implies that conversion to shares or write-down occur when this trigger level is breached. As CoCos are complex instruments with automatic conversion based on these lagging accounting trigger ratios, pricing them becomes challenging. Much of existing literature assumes that stock price can replace the CET1 trigger, thus assuming a one-on-one relationship, making pricing more straightforward since stock prices are observable. However, the correlation between stock price and CET1 trigger is found to be insignificant, as outlined in Section 6, highlighting the need to obtain a more realistic trigger relation.

Without the ability to price CoCos correctly, the bank as the issuer, and the investor as the buyer, are faced with decisions of high uncertainty. This uncertainty highlights the importance of constantly searching for optimal structure and pricing methods regarding the instrument. From these reflections, the following research questions are formulated:

RQ1*: How suitable are CoCos as an instrument for meeting increased regulatory capital requirements?*

RQ2*: What is the fair price of DNBs CoCo issuances? Moreover, how do one model the trigger contingency without assuming fixed historic correlation?*

This thesis seeks to address the regulatory debate by exploring *RQ1* with a foothold in prevailing academia and regulatory statements. CoCos are however empirically untested as loss-absorbing instruments, making the approach ex ante. Thus, implementation of Basel III and the defining aspects of CoCo are especially emphasized in the beginning of the thesis. As Basel III serves as a backdrop for CoCo issuance, it is important to gain knowledge of the relationship between the two. Both Section 2 and 3 seek to present the relevant structure and features which are necessary to further address the ex-ante question of suitability. Since CoCos are issued by banks, this thesis includes theory and models applicable to financial institutions. Theory which is relevant to understand the effects of banks' lending practices in the real economy is thus also briefly reviewed.

This thesis contributes to the literature of pricing CoCos, as stated in *RQ2*, by employing the equity derivatives method proposed by Spiegeleer et al. (2017) on Norwegian CoCos. The most prominent existing methods are presented in Section 4 and evaluated based on applicability and their underlying assumptions. Later, the equity derivatives method is applied to actual issuances by DNB, seeking to obtain the fair price of these CoCo bonds and comparing them to observed market values. Finally, this thesis contributes to the literature by exploring a new β approach to find the stock price trigger level, rather than assuming fixed historic correlation. To evaluate the robustness of the pricing model, a sensitivity analysis and discussion of the results are presented.

Section 2 discusses financial regulation with focus on new implementation of capital requirement under Basel III. An understanding of this regulation is essential to evaluate the usefulness and loss absorbing properties of CoCos. In Section 3, literature regarding the structure, features, issuing and risk profile of CoCos are presented, with emphasis on academic work that addresses the loss-absorbing properties of the instrument. Various pricing methods are also presented and discussed in Section 4, before our own contributions for empirical pricing is presented in Section 5. Section 6 implement the chosen pricing methodology, while Section 7 provides discussion on and sensitivity analysis of the results. Finally, Section 8 concludes and suggests future research.

Financial Regulation

2.1 Basel III

As a direct result of the missing ability to provide necessary loss-absorbing banks under the Basel II regime, a new and enhanced version was proposed by the Basel Committee on Banking Supervision (BCBS, 2010). The new Basel III framework aims at creating more robust banks for times of financial distress, through increased quantity and quality of regulatory capital. The embedded capital requirements are perceived as the building blocks of a stable financial system with greater ability to withstand future financial crises, and seek to lower the probability of defaults. Basel III also introduces new regulations with regard to liquidity, risk management, supervision and surveillance, in addition to market discipline through 3 different pillars (BCBS, 2013a). The capital requirements are considered mainly in pillar 1, which is the basis for this thesis.

BCBS (2010) wanted to reduce the procyclicality in markets at the same time as capital buffers were introduced. From their view, a crucial factor is that banks act as shock-absorbing, rather than transferring shocks to the financial system and real economy. Also, banks are perceived as the actual foundation for sustainable economic growth, since they channel savings into productive investments. Based on this reasoning, the buffer for capital conservation (CCB) and the countercyclical buffer capital was introduced. These requirements are under gradual phase-in for the membership countries of Basel III and are planned to be fully implemented by January 2019 (BCBS, 2013).

The countercyclical buffer was introduced to mitigate the effect of decreasing economic conditions, with the purpose of protecting the financial industry at times with exaggerated credit growth (BCBS, 2010). By proposing such a buffer, the bank can gain capital reserves in times when systematic risk is increasing. Here the systematic risk is the probability that a single bankruptcy trigger disturbance and financial distress, often referred to as too-big-to-fail risk (Sundaresan & Wang, 2010).

To prevent too-big-to-fail risk, the Basel Committee on Banking Supervision introduced specific requirements for banks with influential positions in the world economy. These are assumed to be systematically important financial institutions, often denoted SIFIs (BCBS, 2013a). SIFIs are required to maintain an extra high level of Core Equity Tier 1 capital. The transitional period from Basel II to Basel III is attained through withholding profits and obtaining new capital. While at the same time, banks' function in term of lending across the economy to sustain growth (BCBS, 2010).

The Basel Committee distinguishes between Tier 1 and Tier 2 by defining Tier 1 as capital with on-going concern, while Tier 2 is gone-concern capital (BCBS, 2010). Moreover, the instruments that previously were allowed under Basel II but no longer fit the description of Tier 1 or Tier 2, are phased out over a 10-year period starting from January 2013 (BCBS, 2013). Prior to the financial crisis, innovative Tier 1 instruments were used by banks to generate Tier 1 capital. Subsequently, BCBS imposed stricter requirements on these.

2.2 Capital Requirements

Total regulatory capital is the sum of Tier 1 and Tier 2, where Tier 1 is divided into CET1 and Additional Tier 1 (AT1). For each of these categories there exists a unique set of specified criteria, where all criteria must be fulfilled in order to qualify as regulatory capital. The full list of criteria are found in BCBS (2010).

According to BCBS (2010), Core Equity Tier 1 is capital with the highest level of quality in the bank capital structure. Thus, consisting of withheld own capital and ordinary shares, this form of capital is supposed to absorb losses first. As introduced by BCBS (2010), the CET1 capital level must at all times be minimum 4.5 percent of risk-weighted assets (RWA). Here the RWA capture individual banks' exposure to risk, through weighting assets of the bank in accordance with risk embedded. The calculation for CET1 capital ratio is clarified from Basel III framework and computed as in Equation (1).

$$CET1\ capital\ ratio = \frac{CET1\ capital}{RWA} \tag{1}$$

Intuitively, Equation (1) shows that the bank is able to restore its CET1 capital ratio by increasing the level of capital qualified as CET1, reduce RWA or a combination of both measures. Figure 1 easily illustrates the different requirements and associated levels in the percentage of RWA. Where the sum of CET1 capital and AT1 must be a minimum 6 percent of RWA and total regulatory minimum capital is 8 percent. The requirement regarding conservation buffer is 2.5 percent, while countercyclical buffer capital is 0-2.5 percent, depending on the level of systematic risk embedded in the economy. For systematically important financial institutions, the additional 1-3.5 percent SIFI surcharge is required in accordance with their CET1 capital (BCBS, 2013a). As outlined in depth through Sections 3.4 and 3.5, CoCos might be eligible for Tier 1 or Tier 2, depending on its structure.

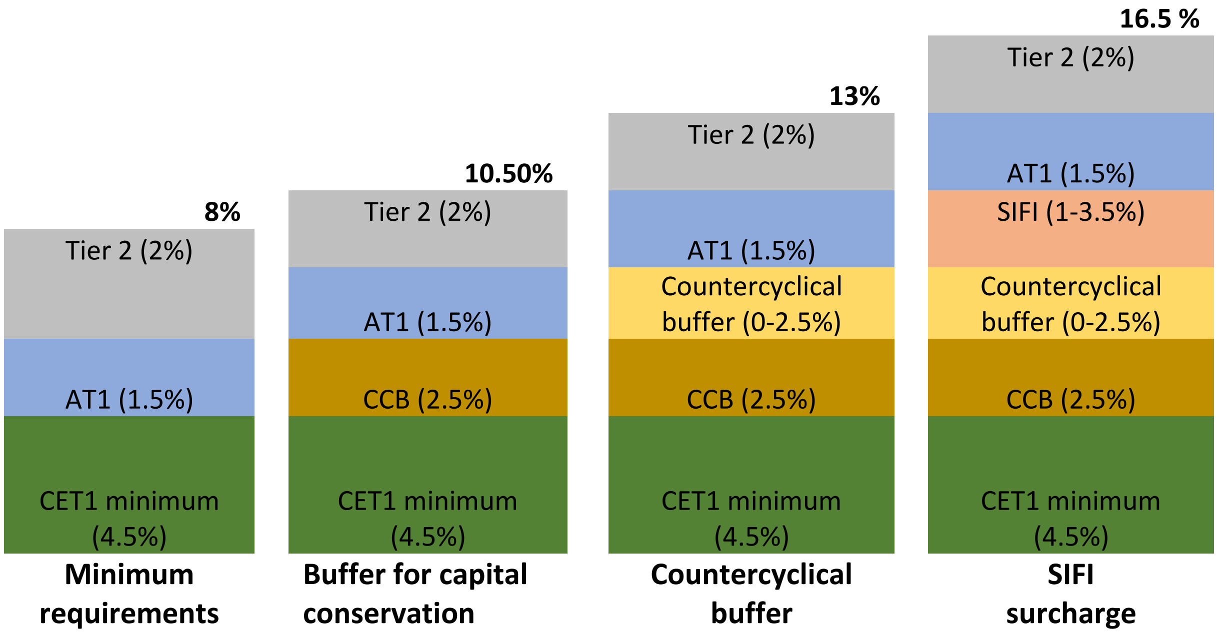

Figure 1: Capital requirements under Basel III regulation.

Contingent Convertible Bonds

After the initial CoCo issuance of £7 billion by Lloyds in 2009, the market for contingent convertible bonds has grown significantly. Avdjiev et al. (2017) show that in late 2015 CoCos totaling $521 billion is issued through 730 instruments. The distribution of issuance by nationality and currency is provided in figure A.1 from appendices, showing that China and UK are the biggest contributors. Supported by the fact that CHY, EUR and USD are the dominating currencies.

Goncharenko & Rauf (2016) highlight that about 65 percent of the world's issuances is made within the European Economic Region (EEA), caused by the fact that CoCos is addressed different regulatory tax treatment between regions. Thus, Tier 1 CoCos are treated as own capital by regulators, and as debt from a taxation point of view in the EEA. Hence this asset class is favorable due to tax deductions. In other regions CoCos are not tax deductible, which explains the lack of interest in this asset class in other places, such as the USA.

Goncharenko & Rauf (2016) underscore that Tier 2 capital is treated as debt from both regulatory and tax points of view, which explains why about 70 percent of all CoCos are issued as Tier 1. However, as shown from Figure B.1 in appendices, there has been a recent shift toward more equal issuances between Tier 1 and Tier 2. Sundaresan & Wang (2010) highlight the important point that a banks' saved tax deductions is a cost for the taxpayers of the society. Thus, making room for discussion between policymakers and regulators of the features and structure of CoCos.

Flannery (2002) was the first to introduce a specific instrument with automatic reversal of capital ratio for times with financial distress. The instrument was named reverse convertible debentures, but is essentially the same as CoCos. Flannery (2002) highlights several aspects that make the instrument capable of restoring capital ratios efficiently. Among these are loss-absorbing effects through automatic recapitalizing, reduced default risk for shareholders, introduction of a more cost-effective way to convert debt to own capital, and reduction in costly bankruptcies.

Based on a Flannery (2002) framework, several contributors aim to further develop the structure for CoCos. Among the contributors are Spiegeleer & Schoutens (2011), Sundaresan & Wang (2010), French et al. (2010) and Corcuera et al. (2013). These contributions are furthermore presented as the next subsections thoroughly review CoCos important structure and features.

3.1 Loss-Absorbing Properties

The most important purpose of a CoCo bond is to function as a loss-absorbing instrument. In times of financial decrease and increased distress, the propensity to lend money to banks is assumed to be low. Liebenberg et al. (2017) highlight that this effect was largely observed during the last financial crisis. Thus, the credit models incorporated increased volatility in the financial sector as a sign of high credit risk, causing problems for banks. The credit models are often referred to as procyclical, due to their self-reinforcing effect. This resulted in banks having problems financing its lending services, which in turn had a negative effect on the entire global economy.

Haas & Horen (2012) conclude that the procyclical effect during the last financial crisis was decisive on the real economy. This occurred since globally systematic important banks (G-SIBs) considerably decreased their lending across nations. These banks had to decrease lending due to impairment of subprime assets, need for refinancing large amount of long-term debt in illiquid markets, and due to large fall in market-to-book ratios. Clearly, this caused direct manifestations in lending across nations, where the economic downturn was reinforced.

Flannery (2002) argues that if a SIFI is in danger of going bankrupt, the government have all the incentives to save the institution by providing bailouts, rather than taking the social costs embedded with bankruptcy. Zombirt (2015) expresses that if CoCos loss-absorbing mechanism work as intended, the risk is transferred from taxpayers to debt-owners in economically stressed situations. This coincides with the intention of the Basel Committee of Banking on Banking Supervision when Basel III was designed. CoCos are thus reducing capital drought since the default risk is decreased. Consequently, companies issuing CoCos might be able to automatically restore its capital ratio in accordance to their chosen trigger and conversion method.

3.2 Conversion

Conversion of CoCos occurs when a given trigger level is breached, and since conversion is contingent it cannot be stopped by any parts when first initiated. The conversion type is predefined and might be structured in one of two following ways:

1. Conversion to equity
2. Principal write-down

The loss-absorbing mechanism through conversion or write-down is of great structural importance. Zombirt (2015) underscores conversion method as crucial in terms of the deciding incentives of the investors. Where in general, being faced with conversion to equity risk is preferable from the investor's point of view. Hence, investing in CoCos with conversion to equity requires a lower risk premium. However, problems arise since institutional investors often do not have the mandates to invest directly in stocks, these investors must therefore focus on CoCos with write-down mechanisms that commands higher risk premiums.

The time for conversion is aimed at reflecting a situation where the bank is in distress, and where the banks' debt owners, depositors and regulatory authorities start to doubt the future of the company (Corcuera et al., 2013). As a result of automatic conversion, the capital ratio might be restored before it is too late. This prevents the need to summon extraordinary general meetings and gather new capital under difficult market conditions, which contributes to reduce the aggregated cost of default.

3.2.1 Fraction and Price

In addition to conversion type, i.e. conversion to equity or write-down, the conversion fraction and conversion price are essential (Spiegeleer & Schoutens, 2011). The conversion fraction dictates the degree of face value that is converted or written down. The value converted or written down is specified as αN, where α is the predefined fraction. If $\alpha = 1$, the entire face value is converted.

The conversion price C_p, has a big impact on the payoff for CoCo investors when faced with conversion. Spiegeleer & Schoutens (2011) argue that CoCo investors profits from low conversion price, since it yields a higher amount of shares when conversion is a fact. In general, the conversion price is given by Equation (2) where C_r denotes the conversion ratio, i.e. the number of shares per converted bond:

$$C_p = \frac{\alpha N}{C_r} \tag{2}$$

The conversion price can be structured in three different ways. Firstly, conversion price might be set as equal to S^*, i.e. the observed price at the trigger point. Alternatively, conversion price can be expressed as equal to stock price at the time of issuance. Finally, a conversion price with a floor can be defined. The latter is basically conversion price equal to stock price at the trigger point, but with a floor that prevents the conversion price to fall under a threshold even when trigger price is at a lower point (Spiegeleer & Schoutens, 2011). In practice, all three conversion price mechanisms are observed in the market.

Spiegeleer & Schoutens (2011) express that the main difference between the abovementioned structures is that the first induce high dilution for existing shareholders. The second structure, setting conversion price equal to the price on issuance, is going somewhat in the opposite direction, generally yielding a lower degree of dilution. The price with the floor is defined as a compromise between the first two options.

3.2.2 Death-Spiral-Effect

Flannery (2002) argues that CoCos are a more suitable regulatory financial instrument than conventional bonds, e.g. plain convertible bonds. However, the structure and dynamics of the two securities are widely different. The only commonalities are that both have a built-in mechanisms for conversion and a coupon rate. Previously, a well-known death-spiral-effect has been observed for investments in regular convertible bonds (French et al., 2010). This effect is driven by market manipulation, e.g. when a big market participant short-selling a stock while simultaneously owning convertible bonds on the company (Flannery, 2002). The bond is converted when the price is falling, so that large profits potentially can be gained over time. CoCos eliminate the death-spiral-effect due to automatic conversion and predefined contingent trigger levels. Both Flannery (2002) and Sundaresan & Wang (2010) argues that this makes CoCos more attractive with regard to mitigating financial distress, since the incentive for market manipulation is removed.

3.3 Trigger Mechanisms

Sundaresan & Wang (2010) and Corcuera et al. (2013) highlight the importance of structuring the trigger mechanism properly. Indeed, this is the most important aspect regarding the CoCo structure, as it shall ensure conversion for necessary situations.

Spiegeleer & Schoutens (2011) propose several critical factors in the design of trigger features, all of which ideally should be present.

1. **Clarity:** The trigger must be designed in such a way that it sends the same signal independent of jurisdiction. Also, different standards cannot be used to measure the same concept, e.g. CET1 ratio.
2. **Objectivity:** The process for conversion into shares must be known at issue date. Therefore, the prospectus need to be carefully designed. Since the conversion process must be known, it is suboptimal to have external intervention from regulatory forces.
3. **Transparent:** The level of the trigger must be easily observable, so that everyone has perfect information. Optimally, the trigger level should be observed with daily

changes, similarly to stocks. Using CET1 capital ratio is thus not optimal since it is based on quarterly accounting measures, with lack of detail.

4. **Fixed:** The trigger must be constant and not be changed during the lifetime of the instrument.
5. **Public:** All the information regarding structure and drivers behind a potential conversion must be public information.
6. **Update frequency:** The trigger should be updated sufficiently often, so that investors continuously are able to assess price and risk embedded with the instrument.

In total there are four different trigger mechanisms, namely: Accounting triggers, market-based triggers, multivariable triggers and regulatory triggers. These trigger types will be discussed in the next subsections.

3.3.1 Accounting

Liebenberg et al. (2017) show that the majority of CoCo issuances have accounting CET1 triggers. The purpose of the accounting trigger is that the issuing bank restores its capital ratio when the relation between Core Equity Tier 1 capital and RWA falls below a prespecified level. When a CoCo converts to shares, an increase in CET1 capital occurs, which further increases the bank's CET1 ratio given a constant level of RWA. However, a very important feature is that conversion must happen *before* the bank is facing financing trouble (Liebenberg et al., 2017).

Spiegeleer & Schoutens (2011) problematize that the accounting trigger might be triggered long after it is needed since it is a lagged indicator. Hence, the accounting indicator looks backward in time, rather than forward. Causing investors to operate blindfolded for large parts of the year. The main argument for this statement is found by looking at large financial institutions that went bankrupt or needed bail-outs in 2008. Among these were Bear Sterns, Lehman Brothers, Wachovia, and Merrill Lynch. Common for all was that they reported regulatory capital well above the minimum level of 8 percent before bankruptcy and rescue packages occurred due to financial distress.

When Banco Popular needed to be rescued in 2017, it can be argued that the situation was similar to when Lehman Brothers went bankrupt in 2008 (Euromoney, 2017). The Banco Popular incident is presented in Section 7.3 and it highlights the problem of the accounting trigger regards to update frequency. In addition, the accounting trigger might be subject to manipulation in form of creative accounting or increased focus toward low-risk assets (French et al., 2010).

3.3.2 Market Based

CoCos with market based trigger place the conversion contingency equal to stock price. Sundaresan & Wang (2010) explored this trigger form thoroughly and conclude that it generally do not lead to a unique equilibrium. CoCos with market triggers might induce instability due to an asymmetric payoff structure. Thus, conversion is punitive for existing shareholders since they face dilution. The existence of multiple equilibriums causes different incentives for shareholders and CoCo investors as shareholders want to increase stock price while CoCo owners want to decrease it.

Spiegeleer & Schoutens (2011) also argue that market triggers make conversion based on manipulation more likely. For instance, a trigger level might be breached by a large short-selling on a day with low volume. Although there are problems embedded in market triggers, Spiegeleer & Schoutens (2011) highlight that they are preferred in the academic world. This is because market based triggers are to a larger extent forward looking, since they are not based on lagged indicators.

3.3.3 Regulatory

The suggestion from the Basel Committee on Banking Supervision to use debt instruments with loss-absorbing features in form of write down or conversion, is highly related to regulatory triggers (Spiegeleer & Schoutens, 2011). The action of a regulatory authority providing rescue packages to mitigate default can be replaced by such a trigger. Conversion is thus necessary when the bank loses trust from owners, depositors and government authorities. However, CoCos with a regulatory trigger might be less attractive to investors.

Spiegeleer & Schoutens (2011) underscore that investors do not like the idea of conversion purely based on regulatory perspectives since this gives the authorities too much power. This can cause difficulties related to pricing, since quantifying the expected behavior of regulatory authorities might be impossible. Sundaresan & Wang (2010) also address lack of sufficient information, ineffective surveillance and political pressure as aspects that further increase problems with regulatory triggers.

3.3.4 Multivariable

By increasing the dimension in conversion contingency, The Squam Lake Working group on Financial Regulation proposes the use of both macro and micro triggers combined (French et al., 2010). Their suggestion embraces both the use of regulatory status and specific company measure. The idea behind The Squam Lake Working group's proposition is two-folded: first the regulatory authorities must declare economic distress, then the predefined threshold is breached, before CoCos face conversion. The former is the associated macro trigger and the latter is the micro trigger.

French et al. (2010) emphasize that this two-folded approach removes the problem of a single systematic trigger. If the single systematic trigger is used, the bank might change incentives about healthy operation since they know authorities will provide bailouts if necessary. French et al. (2010) argue that multivariable triggers have a disciplinary effect of management, as well as removing the political pressure towards declaring economic distress. The following solution is that banks with capital issues become re-capitalized in times when the whole economy is vulnerable. The proposition of multivariable triggers is close to reality. Thus, a combination of CET1 and PONV trigger is commonly used to date.

3.4 Basel III Criteria

BCBS (2010) allows for issuance of CoCos through the criteria for AT1 and Tier 2. Features embedded by the instrument are crucial for deciding its category. The following selected criteria are especially important:

1. Lifetime of the instrument
2. Loss-absorbing properties
3. Option to call the instrument
4. Trigger level
5. Distribution of coupon payments

For CoCos to accrue the category of AT1 they have to be perpetual, meaning that they cannot have a specified maturity date. Also, the necessary loss absorbing-properties must be fulfilled through predefined mechanisms of triggers and conversion. Furthermore, for AT1 CoCos there is the possibility to call the instrument after 5 years from the issuing date, and its trigger level must be minimum 5.125 per-cent of RWA. Thus, the call option gives the issuer the opportunity to buy back the bonds after 5 years (BCBS, 2010).

For Tier 2 CoCos, the instrument must have at least 5 years' maturity and the possibility for call after this minimum lifetime (BCBS, 2010). Another factor differencing AT1 and Tier 2, is that coupons of AT1 bonds are at the sole discretion of the issuer. This means that AT1 bonds might face coupon cancellation without forcing conversion. For Tier 2, coupon cancellation occurs only when conversion is a fact. Due to this non-cumulative distribution of coupon payments for AT1 bonds, a coupon cancellation risk is introduced, as extensively covered by Spiegeleer et al. (2017).

3.5 CoCo Implementation

Capital Requirements Directive no. 4 (CRD IV) and Capital Requirements Regulation (CRR) form the framework for implementation of CoCos in coordination with Basel III. These are regulations and directives ongoing from January 2013. CRD IV compromises legislation that is brought to light through national law, while CRR are regulations that are ongoing for companies across the EU (Cahn & Kenadjian, 2014). Basel III also specifies that every member-nation can introduce additional provisions and faster implementation than the original framework presented (BCBS, 2010).

The combination of CRD IV, CRR and Basel III provides the framework that decides a bank's opportunity to issue CoCos. Figure 2 shows that the maximum issuance allowed is limited to 3.5 percent, divided into AT1 and Tier 2. Avdjiev et al. (2013) show that typically AT1 CoCos have CET1 trigger ratios of 5.125 percent of RWA, while Tier 2 typically is around 7-8 percent. Intuitively it is easy to understand that for high-trigger CoCos, probability of breaching the CET1 ratio is higher, which cause higher coupon rates to investors. The opposite is true for low triggers. Consequently, both Zombirt (2015) and Avdjiev et al. (2015) points to the fact that low trigger has little regulatory value since conversion occurs later.

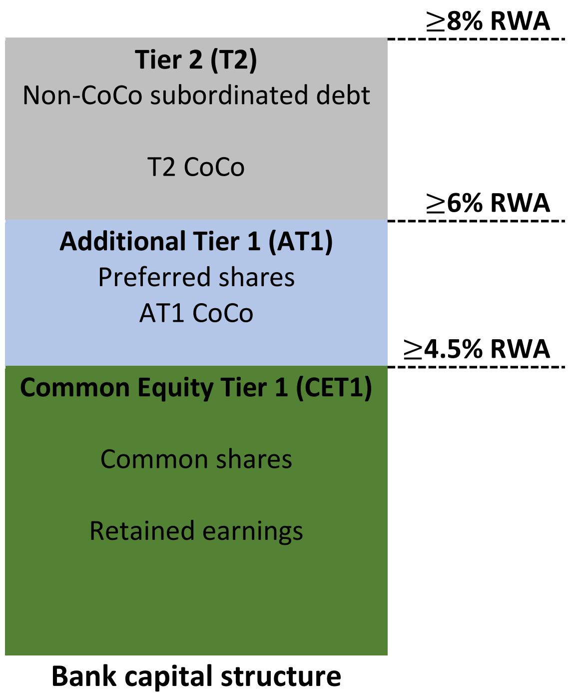

Figure 2: Bank capital structure and CoCo implementation.

Avdjiev et al. (2013) emphasize that CoCo ownership must be distributed in such way that total systematic risk is reduced, not just moving concentration of risk between different companies. This is one explanation for why SIFIs are prohibited from issuing CoCos as a source of additional capital (Zombirt, 2015). The interconnectedness of these large financial institutions simply imposes too much risk. However, this has caused debate since it is important for the real economy to have robust systematic important financial institutions.

Admati et al. (2013) are among the sceptics who emphasize that CoCos are too complex and are likely to have insufficient loss-absorbing capacity. From their view, issuing common equity would be least as good. Consequently, Admati et al. (2013) state that tax deductions achieved by issuing CoCos are a cost to society, and therefore common equity is more advantageous. Also they underscore that *debt-overhang-effect* causes negative impact, since high levels of debt might lead to underinvestment. This may in turn lead to disrupted lending and investment decisions for otherwise profitable projects.

Goncharenko & Rauf (2016) show that CoCo issuance is used by banks to maximize return on equity (ROE). This is especially true for banks that must adopt increased regulatory requirements and for those who are faced with low risk. Moreover, issuing CoCos is less costly than collecting new money at the market, since the banks are imposed with reserve capital provisions (Goncharenko & Rauf, 2016). Hence, issuing CoCos appear as attractive for many banks, as well as a cheap alternative for banks with low risk.

3.6 Risk Profile

CoCos are so-called over-the-counter (OTC) instruments. Spiegeleer & Schoutens (2011) compares the risk profile of CoCos with insurance contracts. Investors in such hybrid instruments expose themselves to limited profits and unlimited downside, thus investing in CoCos provides low probability of loss and high probability of moderate returns.

Delivorias (2016) highlights the complexity and uncertainty of coupon payments as the main factors that credit bureaus have difficulties with regarding CoCos. Typically the instrument achieve credit ratings three points below the issuing company, mainly since CoCo coupons can be cancelled. Avdjiev et al. (2013) show that the biggest credit bureaus do not allow credit rating to surpass BBB+, and that many will not make any assessment of the instrument. This creates difficulties with regard to building a solid investor depth, since institutional investors often have no mandates to invest in objects below the specified credit ratings (Avdjiev et al., 2013). In addition, such investors often cannot be faced with the risk of conversion to shares.

There are also worries that investors in CoCos are driven by need for higher interest returns in a world dominated by low interest rates. Several contributors to literature also embrace uncertainty regarding investors' ability to assess risk within CoCos. Hence, Delivorias (2016), Spiegeleer & Schoutens (2011) and Zombirt (2015) problematize that investors underestimate the possibility of conversion since it is a low-probability outcome, similar to tail-events. On the other side, Avdjiev et al. (2015) conclude that investors are aware of the risk embedded with conversion, and that they are willing to take the additional risk. This was found by measuring the credit spreads for credit default swaps (CDS) connected to other debt instruments from the same issuer, in the time before and after issuing CoCos. The study proved a significant decrease in the banks' CDS spread when the CoCos were issued, implying that credit risk was reduced.

Avdjiev et al. (2015) also show that the effect on credit risk was different depending on the mechanism of conversion, where the effect of principal write-down was the strongest. The effect on stock price had two implications: for CoCos with write-down the effect on stock price was negative for low triggers, but became significantly positive for high triggers. For CoCos with conversion to shares, the effect was significantly negative independent of the trigger level. Recent research by the same contributors gave same results as these mentioned effects (Avdjiev et al., 2017).

The abovementioned results are intuitive since existing shareholders welcome CoCos with write-down mechanism and high trigger, as they share downside risk with debt investors. At the same time, issuances with conversion to shares face dilution risk, which might negatively influence stock price. The results indicate that investors anticipate a high probability of loss with conversion, and that CoCos are perceived as a risky investment (Avdjiev et al., 2015).

Modelling Contingent Convertible Bonds

The remainder of this thesis is focused on CoCo issuances with Core Equity Tier 1 trigger and conversion to equity or principal write-down. Thus, issuances with market based and pure PONV triggers are not considered. Pricing CoCos have proved to be a complicated task as there is no unique way to handle these instruments. However, several contributors have, as outlined throughout the next sections, proposed models aimed at modelling CoCos with the abovementioned characteristics. Central contributors are Spiegeleer & Schoutens (2011), Corcuera et al. (2013), Spiegeleer et al. (2017) and Pennachi (2010).

The pricing methods are highly dependent on structuring factors such as loss-absorbing and conversion properties. In addition, parameters of the specific CoCo issue related to coupon payment, maturity and volatility are important. The hybrid nature of CoCos increases the pricing complexity since they are possible to price from both equity- and credit point of view. The most prominent models consist of structural and derivative methods, where the derivative methods are divided into equity and credit models. In the following sections, these approaches are explored and evaluated based on applicability and underlying assumptions, aimed at addressing *RQ2*.

4.1 Derivative Methods

4.1.1 Credit Derivatives

Spiegeleer & Schoutens (2011) introduced credit derivatives as a CoCo pricing method with regard to fixed-income derivations. Serjantov (2011) has a similar proposition, but this is not covered in detail in this thesis. Cheridito & Xu (2015) further developed credit derivatives by introducing pricing based on CDS spreads. Next, the initial model from Spiegeleer & Schoutens (2011) is considered.

The main intuition of credit derivatives pricing method is closely related to CoCos conversion features aimed at reflecting financial distress. Thus, the pricing problem seeks to reveal the extra yield needed to accept the risk of a loss. It is based on a reduced form methodology known as intensity-based credit modeling, whereas the default intensity and recovery rate are calculated. Duffie & Singleton (2003) cover this methodology in further detail. In the case of CoCos, the default intensity is denoted the trigger intensity λ_{Trigger}. The recovery rate is R upon conversion, and the price of the CoCo bond is thus assumed to be strongly related to a bank's financial health and default probability. When default occurs, the investor face a loss equal to $(1 - R) \times N$, with N being the face value of the bond. At the point of the default, the investor expects to recover a proportion of face value. By using this relationship Spiegeleer & Schoutens (2011) state that the following formula determines the credit spread on CoCos, using a rule of thumb:

$$CS_{\text{CoCo}} = (1 - R) \times \lambda_{\text{Trigger}} \tag{3}$$

Equation (3) expresses an easy way to calculate the value of a CoCo bond by adding the continuous interest rate to the credit spread obtained. The approximation found using this rule-of-thumb method therefore expresses the total yield demanded. To obtain values for λ_{Trigger} and R, one must use the following relations:

$$R = \frac{S^*}{C_p} \tag{4}$$

Equation (4) illustrates the impact that conversion price C_p, and S^* the moment that the bond is converted into shares has, on the value of CoCos. It is easy to see that for increased conversion price a higher yield is required. Also, the effect of trigger intensity yields room for interpretation as presented in Equation (5).

$$\lambda_{\text{Trigger}} = -\frac{\log(1-p^*)}{T} \tag{5}$$

The trigger intensity is determined by p^*, the probability of hitting the trigger and time to maturity T. Equation (6) is a formula used in barrier option pricing from the Black and Scholes framework, presented by Spiegeleer & Schoutens (2011). It models the probability for a stock price breaching stock price trigger level S^* sometime during the CoCo lifetime. In general $N(x)$ is the probability for a random variable X, taking a value less than x, as shown in (7), under assumption that the random variable is normally distributed. Hence, we got the following relations:

$$p^* = N\left(\frac{\log\left(\frac{S^*}{S}\right) - \mu T}{\sigma\sqrt{T}}\right) + \left(\frac{S^*}{S}\right)^{\frac{2\mu}{\sigma^2}} N\left(\frac{\log\left(\frac{S^*}{S}\right) + \mu T}{\sigma\sqrt{T}}\right) \tag{6}$$

$$N(x) = Probability\ (X \leq x) \tag{7}$$

Where,

$\mu = r - q - \dfrac{\sigma^2}{2}$

$q = Continuous\ dividend\ yield$

$r = Continuous\ interest\ rate$

$\sigma = Volatility$

$T = Maturity\ of\ the\ CoCo$

$S = Current\ share\ price$

The trigger itself is defined as the accounting Core Equity Tier 1 measure. Instead of modeling CET1 directly, Spiegeleer & Schoutens (2011) link this accounting trigger to stock prices. When Core Equity Tier 1 falls below a predefined level a corresponding stock price barrier S^* could replace it, capturing the equivalent effect, as illustrated in Figure 3.

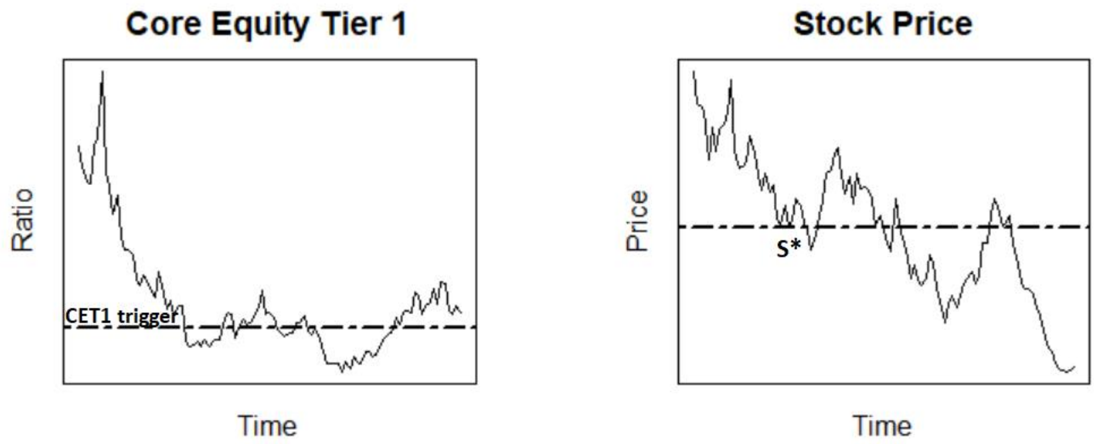

Figure 3: Linking accounting CET1 trigger to stock price trigger level.

Under derivative methods stock prices are assumed to follow a geometric Brownian motion (GMB), which has the quality of constant volatility and a continuous path. In reality, Taylor (2005) among others, highlight that stock prices follow a Leptokurtic distribution with fatter tails and a higher peak. In addition, the link between the stock price barrier S^* and CET1 ratio might be a theoretical flaw since the co-movement between stock price and Core Equity Tier 1 lack empirical significance. The credit derivatives method is easy to use, but may not be rooted in reality. In order to enhance the model Spiegeleer & Schoutens (2011) suggest using a more complex process such as Lévy or Variance Gamma to explain stock price movement.

4.1.2 Equity Derivatives

Equity derivatives derive from the risk-neutral valuation associated with options pricing (Black & Scholes, 1973), stating that in general, value of financial assets is the expected future payoff discounted at the risk-free interest rate. Based on a generalized version of the formula proposed by McDonald (2011), the price of CoCo can be found in Equation (8), under the assumption that a bank cannot default before conversion. Here, τ denotes the breach of a trigger. The first part of the equation shows the value of coupons with a spread, λ, and face value, F. The second part denotes the payoff at a time, $\tau = (0, T)$, where the payoff either equals stock price (S_τ) times the conversion ratio (C_r), if conversion happen, and F if not. Moreover, τ is determined by the trigger, and the associated stock price, S, is crucial to the value upon conversion.

$$V_{\text{CoCo}} = E^{Q}\left[\int_0^{\tau} e^{-rt}(r-\lambda)Fdt + e^{-rt}(S_{\tau}C_r \; if \; r \neq T, \;\; F \; if \; r = T)\right] \tag{8}$$

Spiegeleer & Schoutens (2011) proposed the equity derivatives approach with the additional underlying assumption that the accounting trigger is linked to a stock price level. This method is aimed toward CoCo issues with conversion into stocks. However, a similar method can be used to price issuances with write-down mechanism. Such an approach is covered in Spiegeleer et al. (2017). Equity derivatives price CoCos in light of barrier options, using knock-in forwards and binary down-in options.

A barrier option value is dependent on whether the underlying asset breaches a specific level during a certain time period (Hull, 2015). Here, the knock-in forward is a kind of barrier option that comes into existence when the asset price reaches the stated barrier. Further, the binary-down-in is an option where the payoff is path-independent and occurs based on whether the asset is above or below the trigger level (Hull, 2015). Hence the binary feature, i.e. 1 or 0, ensure payoff if the option is in the money or out-the-money. A CoCo position is thus regarded as a long position in C_r shares that are knocked-in when the trigger occur. The main intuition of this method is to replicate the cash flow of CoCo investments using a portfolio of equity derivatives. The pricing formula proposed by Spiegeleer & Schoutens (2011) is:

$$CoCo = Corporate\ Bond + Knock\_in\ Forward(s) - \sum Binary\ Down\_In\ Options \tag{9}$$

Equation (9) can be broken down into three parts: corporate bond, knock-in forwards and binary-down-in options. First, the value of a regular corporate bond is easily found by calculating the present value of its cash flows. Next, the effect of the trigger event is replicated using knock-in forwards. If a trigger event occurs, the bond is converted into forwards, which is a simplification of the real conversion event into shares. Finally, a binary down-in option position is used to cancel the effect of lost coupons. Coupons are only received when the trigger event is not a fact, thus BDI options are completely offsetting coupon payments if the trigger is breached. The different parts of the pricing formula are expressed as follows:

$$CoCo = A + B + C \tag{10}$$

$$A = N\exp(-rT) + \sum_{i=1}^{K} c_i \exp(-rt_i) \tag{11}$$

$$B = C_r \times \left[S\exp(-qT)(S^*/S)^{2\lambda}N(y_1) - K\exp(-rT)(S^*/S)^{2\lambda-2}N(y_1 - \sigma\sqrt{T}) - K\exp(-rT)\,N\left(-x_1 + \sigma\sqrt{T}\,\right) + S\exp(-qT)\,N(-x_1)\right] \tag{12}$$

$$C = -\alpha\sum_{i=1}^{k} c_i \exp(-rt_i)\,[N(-x_{1i} + \sigma\sqrt{t_i}) + (S^*/S)^{2\lambda-2}\,N(y_{1i} - \sigma\sqrt{t_i})] \tag{13}$$

Several parameters must be obtained before calculating CoCo value in the equity derivatives pricing Equation (10). Here K is equal to, C_p, the conversion price and C_r is the conversion ratio. The parameters K, C_r, x_1, y_1, x_{1i}, y_{1i} and λ are given by almost identical variables as for credit derivatives, and consists of:

$$K = C_p$$

$$C_r = \frac{\alpha N}{C_p}$$

$$x_1 = \frac{\log(\frac{S}{S^*})}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}$$

$$y_1 = \frac{\log(\frac{S^*}{S})}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}$$

$$x_{1i} = \frac{\log(\frac{S^*}{S})}{\sigma\sqrt{t_i}} + \lambda\sigma\sqrt{t_i}$$

$$y_{1i} = \frac{\log(\frac{S^*}{S})}{\sigma\sqrt{t_i}} + \lambda\sigma\sqrt{t_i}$$

$$\lambda = \frac{r - q + \sigma^2/2}{\sigma^2}$$

Where,

$q = Continuous\ dividend\ yield$

$r = Continuous\ interest\ rate$

$\sigma = Volatility$

$T = Maturity\ of\ the\ CoCo$

$S = Current\ share\ price$

All equations and parameters derived from the pricing Equation (10) is also found in Rubenstein & Reiner (1991). Moreover, the price of the CoCo is equal to the corporate bond (A) calculated using a risk free interest rate, plus the value of the knock-in forwards (B). The sum of the binary-down-in options is subtracted, capturing the effect of lost coupons C_i upon the trigger event. Indeed, for every C_i in Equation (13) there is a matching BDI option with exactly corresponding maturity to the maturity date t_i for every coupon payment. Hence, the sum of the BDI options lowers the CoCo price.

The equity derivative pricing model proposed by Spiegeleer & Schoutens (2011) yields a closed form solution, which provides applicability and computational straightforwardness. An obvious flaw of the pricing model is the fact that CoCo investors receive shares and not forwards. This flaw might be substantial when the trigger event happens long before the final expiration date. Consequently, a difference would occur if the converted shares pay dividends. However, Spiegeleer & Schoutens (2011) argue that under the reasonable assumption that dividend payout after a trigger event is going to be low or nonexistent, the barrier option technique is a generally well-accepted model. However, like credit derivatives, this model exhibits difficulties in term of realistic assumptions regarding the link between stock price and the accounting trigger.

4.1.3 Introducing Smile Conform Dynamics

Corcuera et al. (2013) extend the equity derivatives approach by proposing a model that embodies more realistic dynamics of stock price movements. In their proposition, risky asset dynamics are introduced through a smile conform model, which is the exponential Lévy process incorporating jumps and fat-tail distributions. The specific Lévy process used is a $\beta - Variance\ Gamma$. While outside the scope of this thesis, a decomposition of this process is found in Kuznetsov et al. (2012). The risk-neutral stock price process expressed as exponential $\beta - VG$ process can be formulated as:

$$S_t = S_0 e^{(r-q)t} \frac{\exp(X_t)}{E[\exp(X_t)]}, \ where \ S_0 > 0 \tag{14}$$

In Equation (14), r is the risk-free rate and q is the dividend yield. In general, Lévy processes have naturally built-in fatter tails than geometric Brownian motion, thus they also capture volatility smiles better. CoCo is an instrument with substantial tail-risk, therefore Corcuera et al. (2013) argue that Lévy processes are better suited for describing its price dynamics. Pricing CoCo bonds with Lévy processes follow somewhat the same logic application as in Spiegeleer & Schoutens (2011). Indeed, the first step of the pricing process (A) is identical to Equation (11) under the equity derivatives method. The rest proceed as follows:

$$CoCo_{\beta-VG} = A + B + C \tag{15}$$

$$B = C_r \times \exp(-rT) \times E[(S_T - K)\mathbf{1}_{\{inf_{0 \le t \le T} S_t < S^*\}}] \tag{16}$$

$$C = -\sum_{i=1}^{k} c_i \exp(-rt_i)\, E[\mathbf{1}_{\{inf_{0 \le t \le t_i} S_t < S^*\}}] \tag{17}$$

Expression (16) is a simplification since it does not regard the aspect of time to conversion within CoCos. Spiegeleer & Schoutens (2011) argue, however, that the impact of this simplification is negligible since the company is in distress when conversion is taking place, making it natural to stop paying dividends. It is possible to obtain numerical solution to this pricing problem using a Monte Carlo simulation technique based on the randomized law of infimum called Wiener-Hopf factorization (Kuznetsov et al., 2011). This specific method provides an efficient simulation of the abovementioned process, making it very well-suited for the task. The basic algorithm for the Wiener-Hopf Monte Carlo simulation is the following, stating that for all $t > 0$:

$$\sum_{i=1}^{n} \frac{t}{n} e_i(1) \rightarrow t \quad as \ n \uparrow \infty \tag{18}$$

The relation in (18) follows from the strong law of large numbers. Corcuera et al. (2013) outline the Wiener-Hopf Monte Carlo simulation as an alternative to straightforward Monte Carlo random walk approximation. They also highlight the well-documented fact that straightforward Monte Carlo simulation might induce numerical errors into the distribution. The Wiener-Hopf method solves this problem by sampling from the law of $\left(X_g, \bar{X}_g\right)$, where g is random time with distribution concentrated arbitrarily around t, depending on the chosen algorithm. Also, we have that X is the chosen Lévy process and $\bar{X}$ the arithmetic mean. For a sufficiently large n in Equation (18), Kuznetsov et al. (2011) proved the suitable approximation to be:

$$P[X_{g\left(n,\frac{n}{t}\right)} \in \ dx, \bar{X}_{g\left(n,\frac{n}{t}\right)} \in \ dy] \tag{19}$$

Introducing CoCo pricing under the $\beta - VG$ process comes at the cost of reduced form solution, making Monte Carlo simulation a necessity. Corcuera et al. (2013) conclude that it better captures the nature of CoCo compared to the model employed by Spiegeleer & Schoutens (2011), albeit with increased complexity in modelling and computational features. However, CoCo pricing with smile conform dynamics is calibrated using CDS data, something that might not be optimal, as Wilkens & Bethke (2014) found other drivers to be of higher significance in explaining the price.

4.1.4 Implicit CET1 volatility

Spiegeleer et al. (2017) developed new insight that resides on the early-stage credit and equity derivative methods, focused on issuances with full write-down features. Their findings highlight that CoCos can be perceived as a derivative of the Core Equity Tier 1 level. Also, they proved that CoCo spreads are identical at a significant level for issuances made by the same financial institution with corresponding triggers. Thus, indicating that the market attaches different probabilities for loss to occur for different banks'. The credit spread is found by using Equations (3) and (5). Since CoCos with full write-down have no recovery rate, the credit spread is equal to the trigger intensity, as stated in Equation (20). Furthermore, distance to the trigger was introduced as a measure of the relationship between CET1 ratio and trigger condition expressed as in (21).

$$CS_{CoCo} = -\frac{\log(1-p^*)}{T} \tag{20}$$

$$D_T = \frac{CET1\,ratio}{Trigger} \tag{21}$$

Spiegeleer et al. (2017) proved the distance to trigger D_T, to be the intrinsic value of a CoCo bond, similar to deep-in-the-money options. The market value of an option deep-in the money is higher the more the option is in the money. However, notice that unlike for equity derivatives with conversion to shares, a binary-down-and-out is used rather than down-in options. Thus, the payoff is maintained or written down when the asset price breaches the barrier level (Hull, 2015). Clearly, the binary-down-and-out option is more appropriate for pricing full write-down CoCos since it captures the true conversion mechanism. By modelling the CET1 ratio as a continuous geometric Brownian motion without drift and using a similar pricing formula as in equity derivatives Equation (10), pricing formulae for such CoCos are denoted as following:

$$CoCo_{write-down} = Zero\ coupon\ bond\ (ZC) + \sum Binary\_Down\_And\_Out\_Options\ (Cpn) \quad (22)$$

Where,

$$ZC = N \exp(-rT) \times (1 - p^*) \quad (23)$$

$$Cpn = \sum_{i=1}^{k} c_i \exp(-rT_i) \times \left[\phi\ (x_i - \sigma_{CET}\sqrt{T_i}) - D_T\phi(y_i - \sigma_{CET}\sqrt{T_i})\right] \quad (24)$$

The parameters of this pricing method are essentially the same as in Equation (10). In addition, p^* and DT is introduced, where p^* captures the probability that the trigger occurs, similar to credit derivatives. From Equation (22) it is possible to derive implied CET1 volatility, and from implied CET1 volatility the adjusted distance to the trigger can be found. Spiegeleer et al. (2017) were able to show that the implied CET1 volatility and the adjusted trigger to distance are more significant for attributing risk than CoCo spreads. Hence, the risk embedded can be decomposed into cancellation risk, i.e. the risk of facing cancelled coupon payments, and the risk of facing loss due to a PONV trigger. Indeed, implied CET1 volatility also yields new interpretations in CoCos with different contract features, e.g. Tier 1 and Tier 2, coinciding with expected dynamics from option theory. The implementation of implied CET1 volatility might enhance CoCo pricing for market practitioners, as well as providing new interpretations of risk.

4.2 Structural Models

The structural approach is modeled where assets and liabilities are expressed as stochastic processes. Most issued CoCos have conversion with accounting trigger, therefore the use of a balance sheet as the main price driver contributes to a fundamental economic view. When modelling the value of assets and liabilities, assets less liabilities is representing the capital of the financial institution. Under the general Merton (1974) structural approach, default is considered to happen when the value of assets falls below liabilities, which is a realistic assumption. Based on Merton (1974), several contributors have proposed pricing methods with a structural approach. Among the contributors are Pennachi (2010), Albul et al. (2010), Madan & Schoutens (2011) and Glasserman & Behzad (2010). All have similar features, but are aimed toward solving different aspects of CoCos.

Albul et al. (2010) search for the optimal capital structure and are investigating risk incentives. Madan & Schoutens (2011) introduced CoCo pricing using conic finance, while Glasserman & Behzad (2010) modelled contingent capital with a feature of partial and on-going conversion in order to maintain a minimum capital level. However, Wilkens & Bethke (2014) indicate that Pennachi has the most prominent structural model regarding pricing, making it worthy of a closer look.

4.2.1 Pennachi

Pennachi (2010) proposed a structural model with the goal of finding the yield that CoCo investors require, under a Merton (1974) credit risk framework. The most important qualities introduced by Pennachi are allowing for jumps in the bank's asset returns, dynamics of short-term deposits, stochastic interest rates and mean-reverting capital ratio.

In this model, the individual bank issuing the CoCo has a given capital structure consisting of short-term deposits, bonds and common equity. Assets are invested into loan portfolios, financial securities and off-balance sheet positions. The return on these assets are determined by a mixed jump-diffusion process, allowing jumps to occur. This is supposed to capture the dynamics of times with financial distress. Furthermore, Pennachi (2010) uses market values to determine the rate of return on assets, which deviates from the Merton (1974) method where observed balance sheet values is used.

Deposits are assumed to have short maturity with continuous interest payment, thus they are senior claim liabilities and function as short-term funding of the bank. Since interest rates are paid continuously, Pennachi (2010) allows the bank's total capital to increase only when net growth in new deposits occurs. This makes sense since empirical studies, e.g. Adrian & Shin (2010), show that banks have target capital ratios and deposit growth in times of excess capital. In other words, there is no stochastic movement for deposits. Furthermore, this makes deposit growth positively correlated to the bank's asset-to-deposit ratio (capital ratio). The relation of this mean-reverting process is expressed as:

$$\frac{dD_t}{D_t} = g\left[\left(\frac{A}{D}\right)_t - \left(\frac{A}{D}\right)_{target}\right] \tag{25}$$

In Equation (25), g is a positive constant, and the second part inside the brackets represents the target asset-to-deposit ratio. When the actual ratio is larger than the targeted ratio, the bank issues a positive amount of new deposit. If, however, the targeted ratio exceeds the actual ratio, the bank will make gradual adjustments by shrinking its balance sheet. To accommodate the trigger condition, Pennachi (2010) proposed a fixed assets-to-deposit ratio, expressed as $(\bar{x} = \frac{A}{D})$. The stochastic process of this trigger ratio is then found by combining the processes of assets and deposits using the Monte Carlo simulation introduced by Boyle (1977). Moreover, it is possible to derive the CoCo price from associated martingale pricing, with formulas identical to those of derivative methods.

The Pennachi model introduces some improvements to the literature on CoCo pricing, since it considers both the numerator and denominator of the trigger condition. The model also allows for continuous conversion, not just quarterly conversion, which is more realistic. However, since Pennachi (2010) uses market values in the trigger relation, it means that trigger ratio and stock price will be fully correlated. This occurs since there is no stochastic movement of deposits, thus both the trigger and stock price are only dependent on the asset process. Since the co-movement of capital ratios and stock prices is not fully correlated in reality, it introduces a flaw. In addition, Wilkens & Bethke (2014) highlight that the performance of Pennachi's model is very dependent on accurate estimations of asset values, since they are not observable.

4.3 Assessment of Models

When evaluating the existing CoCo pricing models, it is clear that they all have both strengths and weaknesses. All have proved to provide somewhat accurate pricing of CoCos, but differ widely in terms of applicability. Wilkens & Bethke (2014) examine the suitability of structural, credit- and equity derivatives, and highlight three important criteria. First, the pricing model should capture the nature of CoCos, e.g. capital ratios and trigger mechanisms. Second, the model must incorporate the most significant price drivers of the CoCo bond. Finally, the model should be based upon observable market parameters such as share prices, bond prices, equity options and CDS prices.

In light of the abovementioned criteria, Wilkens & Bethke (2014) indicate that equity derivatives are the most promising as a model for pricing CoCos. Several arguments point in this direction, as equity derivatives have parameters that are observable and are based on stock price as the main CoCo price driver. Indeed, both Spiegeleer et al. (2017) and Wilkens & Bethke (2014) found stock price to be of higher significance as CoCo price drivers than CDS spreads. Although not the main scope of this thesis, Wilkens & Bethke (2014) also conclude that equity derivatives are the most suited for market practitioners when it comes to hedging and risk management performance.

Table 1, provided by Wilkens & Bethke (2014), gives a useful overview of the different parameters required for each of the distinctive models, and shows the usage and the source of the data obtained. Equity derivatives stand out as less complex and more applicable than the structural model introduced by Pennachi, whereas credit derivatives lack ground in reality since they use a rule-of-thumb estimation. Hence there are strong indications that equity derivative methods, including smile conform dynamics or implicit CET1 volatility, might be the way to proceed regarding pricing and exploring the dynamics of these hybrids. However, the main challenge with equity derivatives is to accommodate a significant relation between stock price and Core Equity Tier 1, in order to model the stock price trigger correctly. As a response to this problem, a new approach including β assumptions is presented.

Table 1: Overview of parameters, data usage and data source for all models reviewed.

Symbol	Description	Usage	Source
All models			
T	CoCo maturity	Static	Term sheet
N	CoCo nominal	Static	Term sheet
c	CoCo coupon rate	Static	Term sheet
f	CoCo coupon frequency	Static	Term sheet
r	Risk-free interest rate	Dynamic	Market data
Structural model			
A	Asset value of issuer	Dynamic	Market data
D	Deposit value of issuer	Dynamic	Balance sheet
p	CoCo bond conversion factor	Static	Term sheet
x_c	Critical asset-to-deposit ratio	Static	Term sheet
$\bar{x}$	Target asset-to-deposits ratio	Static	Balance sheet
g	Mean-reversion speed in asset return	Static	Expert judgement
σ	Volatility of asset return process	Fitting	Expert judgement
λ	Jump intensity in asset return	Fitting	Expert judgement
μ_y	Mean jump size in asset return	Fitting	Expert judgement
σ_y	Jump volatility in asset return	Fitting	Expert judgement
Equity derivative			
S	Stock price of issuer	Dynamic	Market data
S^*	Stock price trigger level	Fitting	Market data
C_p	Conversion price	Static	Term sheet
q	Dividend yield	Dynamic	Market data
v	Implied volatility	Dynamic	Market data
Credit derivative			
s_d	Spread for default	Dynamic	Market data
s_c	Spread for trigger	Fitting	Market data
R_d	Recovery at default	Static	Expert judgement
R_c	Recovery at conversion	Static	Expert judgement
ρ	Copula correlation for trigger	Static	Expert judgement

Empirical Methodology

When addressing the issue of pricing CoCos this thesis builds on the methods presented in the previous section. Mainly equity derivatives are used for empirical consideration, as that is the most prominent method and it reflects the true characteristics of the bonds considered. Additionally, equity derivatives present an opportunity to improve the stock price trigger relation in a Black-Scholes approach by using forward looking β values to obtain stock price trigger levels. Hence, the pricing model proposed does not rely on the simplifying assumption of fixed historic correlation between Core Equity Tier 1 and stock prices.

5.1 Analytical Approach

As there is a lack of evidence for historical significant correlation, a modest attempt at enhancing the link between CET1 ratio and stock price is proposed. This is done by introducing scenario-based β values to find the stock price trigger level. Intuitively, β displays the movement of the CET1 ratio compared to the stock price. Since β is a lagged indicator, using historical correlations in calculations is misleading, especially when financial distress has been absent during the period in question. Thus, scenario β values are used as a proxy to capture the possible effect of times with financial distress, in an ex-ante manner.

The new idea resides on the fact that correlations in good times usually are different from times with financial distress. Rossi & Malavasi (2016) found the average β between Core Equity Tier 1 and return on assets ranging from 0.90 to 1.47 in the time period of 2007-2013. They also found that β was higher in the subsequent years of the subprime mortgage crisis, somewhat contrary to what is expected. A possible explanation for the rise in β might be that Core Equity Tier 1 is affected by both CET1 capital and RWA, creating a self-reinforcing effect since both the nominator and denominator are affected in Equation (1).

The proposed analytical derivation is based on Equation (26) with α, β and S_T as unknown parameters. Here α is a constant capturing the outperformance factor of the Core Equity Tier 1, including the risk-free interest rate. Furthermore, β is the CAPM β embedding the systematic risk of the asset compared to the benchmark. Although, CAPM β lacks empirical significance in predicting asset returns (Fama & French, 2004), it is employed as a new assumption of the CoCo pricing model to find the trigger relation. As CAPM β is calculated from the covariance between return of asset and benchmark, and divided by the variance of the benchmark, it does imply that some correlation implicitly is assumed. However, this correlation is not obtained from lagged historical measures.

S_T is the associated stock price level when the CET1 level is lower than the predefined threshold. $CET1_0$ is the observed CET1 level at time 0, $CET1_T$ is the accounting CET1 trigger level, and S_0 is the observed stock price at time 0. Equation (26) relies on a Black and Scholes risk-neutral valuation framework (Black & Scholes, 1973), where constant volatility, constant interest rate and no dividends are important assumptions.

$$\ln(CET1_0) - \ln(CET1_T) = \alpha + \beta \times (\ln(S_0) - \ln(S_T)) \qquad (26)$$

After rearranging:

$$\ln(S_T) = \ln(S_0) - (\ln(CET1_0) - \ln(CET1_T) - \alpha)\,/\beta \qquad (27)$$

Solving for S_T:

$$S_T = S_0 \times \left(\exp(\alpha) \times \frac{CET1_T}{CET1_0}\right)^{\frac{1}{\beta}} \qquad (28)$$

Equation (28) yields the analytical solution to obtain S_T, the stock price trigger level. In order to estimate S_T, values for α and β must be inserted based on economic intuition since they cannot be observed from historical data. Using scenarios with different β values therefore presents a new approach of finding S_T. The stock price trigger level is thus dependent of the chosen β and α levels, as well as the observed CET1 ratio, the CET1 trigger ratio and stock price. In addition, throughout the pricing model, α is assumed to be zero. Consequently, the outperformance factor is identical to the risk-free rate, which in reality is close to zero.

5.2 Scenarios and Assumptions

The main assumptions of the pricing model are that a bank cannot default before conversion, and that conversion only happens when the predefined trigger level is breached. However, one could argue that when CoCos are designed with a low trigger, typically that of 5.125 percent, regulators would enforce conversion by the PONV trigger prior to breach of the CET1 trigger level (Spiegeleer et al., 2017). Even though this PONV trigger level is difficult to price with accuracy, it can provide useful interpretation regarding risk assessment when comparing theoretical price to observed CoCo price.

Furthermore, in this thesis CoCo bonds are priced under the assumption of three different β values. In accordance with existing research that states that a higher correlation and β for times with financial distress, the values are expected to lie between 0.5 and 1.5 (Rossi & Malavasi, 2016). Testing for such a big interval provide extremal cases, and should provide a useful proxy to capture the future β values between CET1 and stock prices. The different scenarios are defined as follows:

- **Scenario 1:** $\beta = 0.5$
- **Scenario 2:** $\beta = 1$
- **Scenario 3:** $\beta = 1.5$

5.3 Calibrating the Pricing Model

Using the above β values and assuming that α is equal to zero, three different stock price trigger levels are found. Table 2 shows the parameters used and the S_T estimates for all three scenarios, using Equation (28).

Table 2: Parameters and trigger level estimations.

$\boldsymbol{CET1_0}$	16.3%
$\boldsymbol{CET1_T}$	5.125%
$\boldsymbol{S_0}$	160.56
$\boldsymbol{\alpha}$	0
Scenario 1: $\boldsymbol{\beta = 0.5}$	$S_T = 15.86$
Scenario 2: $\boldsymbol{\beta = 1}$	$S_T = 50.46$
Scenario 3: $\boldsymbol{\beta = 1.5}$	$S_T = 74.21$

In order to calculate CoCo prices by the equity derivatives approach the statistical software R is employed for computational applicability. The package *fExoticOptions* can be used to calculate the price of a binary down-and-out asset-or-nothing option based on the relevant parameters (Wuertz & Setz, 2017). These parameters and formulas are the same as provided by Rubenstein & Reiner (1991), which essentially form the basis for the equity derivatives approach proposed by Spiegeleer et al. (2017).

After S_T several other parameters must be obtained. These consist of stock price S_0, exercise price X, time to maturity, annualized interest rate r, cost of carry b, cash or nothing K and volatility of the underlying asset $sigma$. However, the parameters cash or nothing K, exercise price X and cost of carry b are set equal to zero due to the characteristics of the instrument.

The stock price S_0 is obtained from the last observed DNB price on the day of estimation. The volatility of the underlying asset is found by calculating the standard deviation using daily historical DNB adjusted stock price data from 1992:Q3 to 2017:Q3. Here the observed value for S_0 is 160.56 while the estimated $sigma$ for the period was 38 per cent. Using constant volatility based on historical standard deviations is obviously a simplification, as volatility is stochastic and unobservable. Although, outside the scope of this thesis, one could use a generalized autoregressive conditional heteroscedasticity (GARCH) model, in order to capture the clustering and mean-reverting tendencies of long-term volatility (Hull, 2015). Alternatively, the model could be calibrated with implied volatility, i.e. market's forward looking opinion of volatility obtained from option prices (Taylor, 2005). Instead of using implied volatility, the sensitivity in different volatility levels is tested through the sensitivity analysis, to address discussion of the volatility used.

Time to maturity is found by assuming redemption at the first call date of the instrument. Although the instrument is perpetual by definition, Spiegeleer et al. (2017), Murphy (2008) and Spiegeleer & Schoutens (2014) argue that it is common practice for issuers of Tier 1 and Tier 2 instruments to call at the first possible call date. Hence the case of CoCo issuance could be subject to similar incentives and priced thereafter.

Damodaran (2008) emphasizes the importance of using a risk-free rate nominated in same currency as the future cash flows of the company. The Norwegian 10-year government bond at 1.64 per-cent is therefore used as a parameter for annualized risk-free rate r and for discounting the zero coupon bond (NBIM, 2018). Furthermore, p^*, the probability that a trigger will occur, is needed to calculate the value of zero coupon bond. The probability of a trigger occurring is found from the parameters DT, distance from trigger, annualized standard deviation of CET1 ratio, time to maturity T and μ, the expected value, as presented in Equation (29):

$$p^* = 1 - \varphi\left(\frac{\log(D_T) + \mu T}{\sigma_{CET1}\sqrt{T}}\right) + D_T \varphi\left(-\frac{\log(D_T) - \mu T}{\sigma_{CET1}\sqrt{T}}\right) \tag{29}$$

Equation (29) is almost identical to Equation (6) in credit derivatives, with the same assumption of a normal distributed random variable. A further explanation of the former is provided in appendices C. The probability that a trigger will occur estimates the likelihood of CET1 ratio breaching the trigger point during the CoCo lifetime. Consequently, when discounting par value with 100 years to capture the perpetual effect and subtracting the probability of trigger p^*, the value of a zero-coupon bond is calculated using Equation (22).

Empirical Implementation

The issuing bank to be considered for empirical pricing is DNB, the largest Norwegian bank. DNB issued two CoCo bonds at the Oslo stock exchange in 2015 and 2016, respectively. Both issuances are Additional Tier 1 bonds with embedded full write-down structure. As shown by Avdjiev et al. (2017) in figure B.1 from appendices B, there has been a structural shift toward issuing CoCos with write-down mechanism the latest years, supporting the need to further explore such bonds.

As previously mentioned, the aftermath of the subprime mortgage crisis led to capital build up in response to increased regulatory capital requirements. The target CET1 ratio implemented by Basel III is gradually being phased-in, thus a positive drift in the CET1 ratio is expected to be observed during the last decade. This must be carefully regarded when linking Core Equity Tier 1 and stock price.

6.1 Data

The dataset contains daily observations of the DNB adjusted stock price from 1992:Q3 to 2017:Q3. DNB's quarterly reported Core Equity Tier 1 from 2009:Q1 to 2017:Q3 are provided from company filings. Focusing on the last decade yields the most up-to-date perspective, with the correct standards for measuring Core Equity Tier 1 ratios applied. The adjusted stock price data is subsequently transformed into quarterly data from 2009:Q1 to 2017:Q3, in order to match the corresponding CET1 observations. The daily DNB adjusted stock price data from 1992 is used to calibrate the volatility. In addition, all historic data regarding DNB CoCo issuance at the Oslo stock exchange is collected. Within the dataset for CoCo issuance coupon rate, open price, high price, low price, last traded price, official volume and unofficial volume are included. All data except Core Equity Tier 1 is collected from the TITLON database.

6.2 Stock Price Trigger Level

Modeling trigger contingency by linking stock price to the associated Core Equity Tier 1 barrier is based on the idea that such a relation can be a proxy for the actual trigger condition. However, stock price is a function of expected future earnings, thus including much more information than just default risk (Taylor, 2005). Consequently, the co-movement between the two variables cannot be fully correlated. Figure 4 presents the reported Core Equity Tier 1 ratio and DNB adjusted stock price level, with the CET1 ratio ranging from 6 percent in 2009:Q1 to 16.3 percent in 2017:Q3, while the adjusted stock price ranged from NOK 22 to 160 in the same time period.

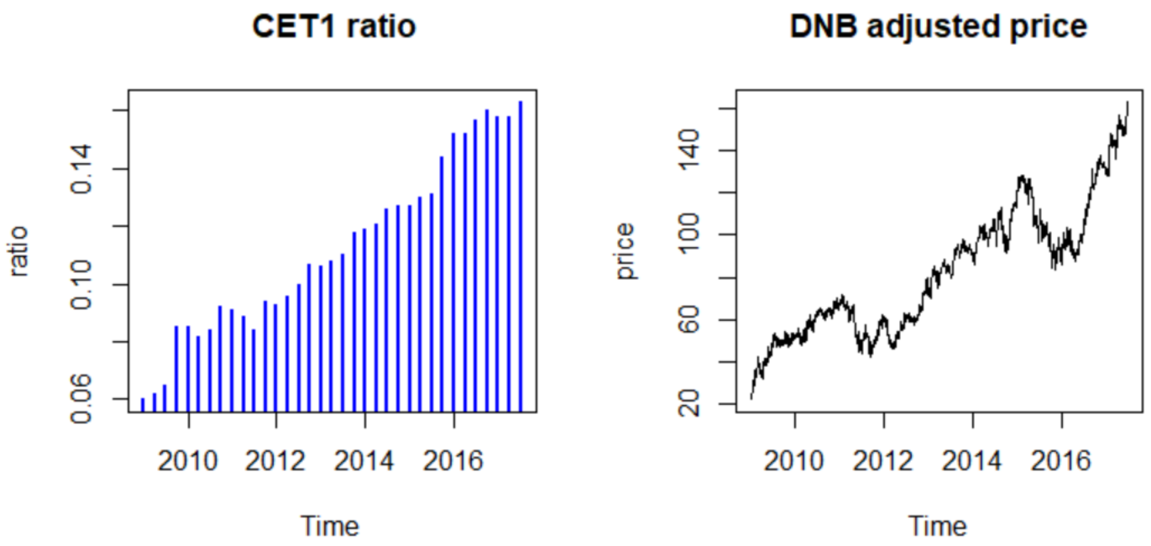

Figure 4: Core Equity Tier 1 ratio and DNB adjusted stock price level.

At first glance there seems to be a positive relation between the reported Core Equity Tier 1 ratio and DNB stock price movements. However, measuring correlation from levels might give misleading results due to random stochastic trends. In other words, calculating correlations from non-stationary variables, might induce spurious results (Hill et al., 2012). Hence, variables must be first-order differenced in order to be made stationary. The quarterly log CET1 changes and adjusted stock price return yields a Pearson correlation coefficient of 0.027 with p-value equal to 0.8793, i.e. not significantly different from zero. Figure 5 illustrates the insignificant correlation between the returns, showing that there is no fixed co-movement based on historic data. This finding coincides with the results provided by Veiteberg et al. (2012), showing that for a sample of 18 G-SIBs the correlation was insignificant with a Pearson coefficient equal to 0.035.

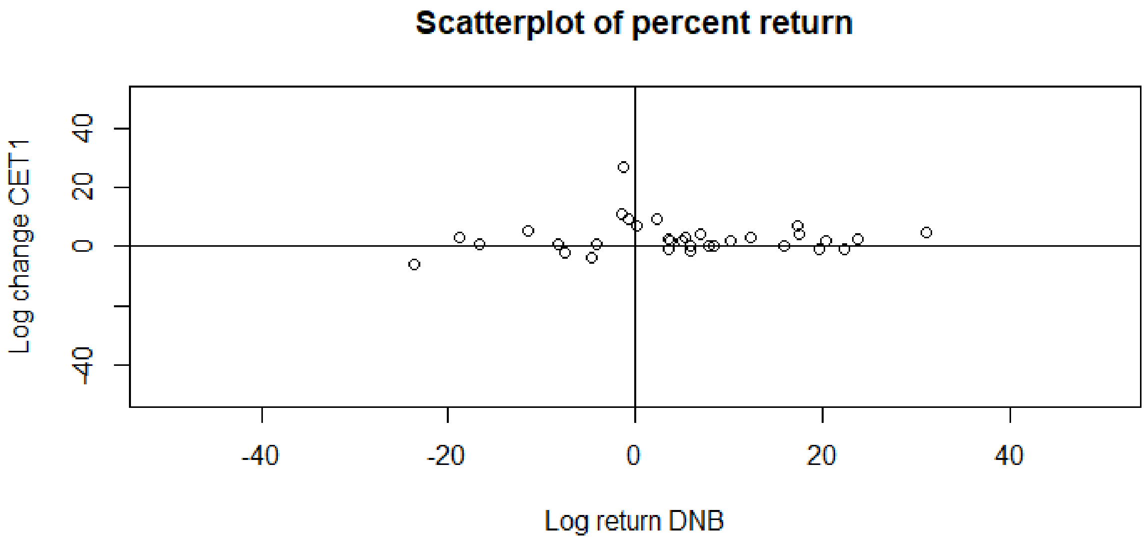

Figure 5: Scatterplot of log CET1 change and log stock price return.

To find a generalized pattern between CET1 ratio and DNB stock prices, samples of banks of similar size should be considered. Therefore, analyzing domestic-SIBs across countries to obtain more recent results for CET1 and stock returns is a possibility. This, however, could induce biased results since all membership nations can impose different implementation of Core Equity Tier 1 ratio from a regulatory perspective (BCBS, 2010). Also, finding samples of such banks under the same legislation is close to impossible, since DNB is the only listed D-SIB bank with headquarters in Norway.

Figure 6 shows the distribution of log quarterly change for CET1 ratio and daily returns for DNB adjusted stock price. The red line illustrates the normal distribution while the black line represents the observed distribution. It is apparent that both are drawn from a non-normal distribution. DNB stock price returns have both higher kurtosis and fatter-tails compared to the normal distribution (Taylor, 2005). Core Equity Tier 1 changes display severe problems with the more extreme outliers, making the empirical distribution far from normal. Spiegeleer et al. (2017) highlight that skewness often is observed with equity, something that is also observed with CET1 changes, as expected. By testing for normality using Shapiro-Wilk test, we are able to reject the null hypothesis that distributions are normal, with p-values lower than $\alpha = 0.05$ in both cases.

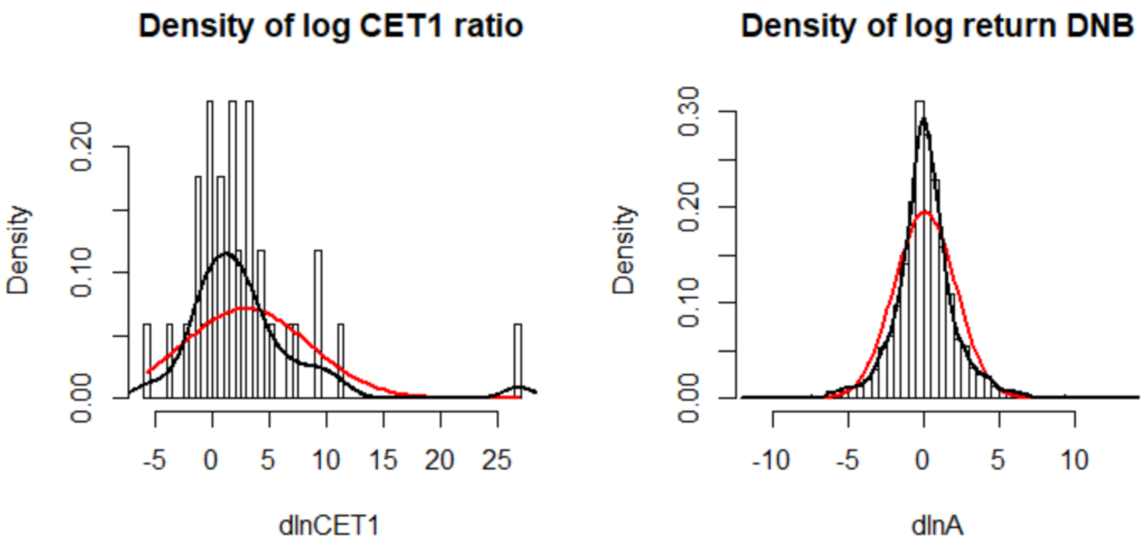

Figure 6: Distribution of log CET1 change and log adjusted daily stock price return.

Finding a generalized pattern between CET1 ratio and stock price proves difficult using historical data. Obviously, this makes it difficult to price CoCo bonds, as the majority of issuances have trigger contingency equal to accounting CET1. Moreover, obtaining the correct stock price trigger level is impossible based on such historical data. Therefore, the analytical approach to solve the link between CET1 ratio and stock price is emphasized. Next, the stock price trigger level is put into the equity derivatives pricing method to find the fair price of both CoCos on a given date.

6.3 Pricing DNB CoCos

DNB issued Additional Tier 1 CoCos in 2015 and 2016. Table 3 displays the most significant details of each instrument. Both issuances were priced at a par price of 100 on the issuance date. The 2015 issuance has coupons equal to 3-month NIBOR plus a margin of 3.25 percent (DNB, 2015), while the 2016 issuance has 3-month NIBOR plus margin of 5.25 percent (DNB, 2016). Both issuances have an accounting Core Equity Tier 1 trigger ratio of 5.125 percent, with full write-down if trigger occurs. The first call dates for the instruments are February 2020 and June 2021 respectively, which serve as the maturity dates. As empirical pricing is commenced, the pricing date is set to September 29, 2017 due the lack of Core Equity Tier 1 ratios that are reported later.

Table 3: Issuance details.

	DNB AT1 2015		DNB AT1 2016
Name	15/PERP FRN C HYBRID	**Name**	16/PERP FRN C HYBRID
ISIN	NO0010730708	**ISIN**	NO0010767957
Ticker	DNBA59	**Ticker**	DNBA60
Issue Date	2015.02.27	**Issue Date**	2016.06.30
CET1 date	2017.09.29	**CET1 date**	2017.09.29
Coupon	4.61	**Coupon**	6.29
Trigger	5.125	**Trigger**	5.125
Outstanding	2.150 mill NOK	**Outstanding**	1.400 mill NOK
CoCo Price	101.15	**CoCo Price**	107.87

6.3.1 AT1 2015

The first step in the equity derivatives pricing model for write-down CoCos is to calculate the price of a zero coupon bond using Equation (23). Second, the price of a binary-down-and-out option is calculated using Equation (24). For practical purposes both are solved in Rstudio using programming language R.

The value of a zero coupon bond:

$ZC = 13.51$

The price of binary-down-and-out options:

To ensure that the correct option type is priced, the binary-down-out asset-or-nothing from Wuertz & Setz (2017) is used. This captures the true characteristics of the CoCo bond, where either the payout of the asset is maintained or the whole value is written down if the price of the underlying stock breaches the barrier level. A further explanation of the different option types is found at Wuertz & Setz (2017) and Rubenstein & Reiner (1991). Note that in Table 4 and 5, the stock price trigger level is denoted as H.

Table 4: Input parameters and option price estimation for DNB AT1 2015.

Parameters	$\boldsymbol{S}$	$\boldsymbol{X}$	$\boldsymbol{H}$	$\boldsymbol{K}$	$\boldsymbol{Time}$	$\boldsymbol{r}$	$\boldsymbol{b}$	$\boldsymbol{Sigma}$	Price
Scenario 1	160.56	0	15.86	0	2.5	1.64%	0	38%	154.10
Scenario 2	160.56	0	50.46	0	2.5	1.64%	0	38%	149.59
Scenario 3	160.56	0	74.21	0	2.5	1.64%	0	38%	133.82

The corresponding CoCo prices are found by adding the value of the zero coupon bond (ZC) and the option price for all three trigger levels. Consequently three prices are found due to scenarios in which there are different stock price trigger levels. The value of the zero coupon bond is the same in all scenarios since the only different factor is the trigger level. Hence the AT1 2015 CoCo prices are calculated 167.61, 163.10 and 147.33, ranged from the lowest to the highest trigger level.

6.3.2 AT1 2016

By employing step-by-step method as in the previous subsection, the price of the AT1 2016 CoCo is found by changing the input value for time to maturity and calculating new probability of breaching the trigger p^*. This provides new estimates for both the zero coupon bond (ZC) and the three option prices.

The value of zero coupon bond:

$ZC = 11.65$

The price of binary-down-and-out options:

Table 5: Input parameters and option price estimation for DNB AT1 2016.

Parameters	S	X	H	K	$Time$	r	b	$Sigma$	Price
Scenario 1	160.56	0	15.86	0	3.9	1.64%	0	38%	150.52
Scenario 2	160.56	0	50.46	0	3.9	1.64%	0	38%	140.70
Scenario 3	160.56	0	74.21	0	3.9	1.64%	0	38%	120.65

The estimated CoCo prices for the AT1 2016 bond are 162.17, 152.35 and 132.3 ranged from the lowest to the highest trigger level. In the next section, a discussion and sensitivity analysis is presented to evaluate assumptions and the results from the empirical part. New link between CET1 and stock price trigger level will be interpreted. A sensitivity analysis is also provided to get a grasp of the most important price drivers of CoCo bonds. Subsequently, the regulatory debate highlights aspects that indicate CoCos quality as regulatory capital.

Discussion and Sensitivity

The market priced DNB's issuances at 101.15 and 107.87 on the nearest closing day. Table 6 displays the observed and estimated prices for different trigger levels. The pricing model points to underpricing of both CoCo issuances for all three scenarios, as the theoretical prices are higher than the observed market prices. However, the theoretical price of 132.30 for the AT1 2016 bond is not far from its true value of 107.87, leaving room for interesting interpretations.

Spiegeleer et al. (2017) highlight that underpricing is likely to occur for issuances with a large distance to trigger (DT) since it represents the intrinsic value of a deep-in-the-money option. Consequently, shorter time to maturity should yield a lower probability of hitting the trigger. The estimated probability of hitting trigger p^* confirms this, being 31.25 percent for the AT1 2015 bond and 40.71 percent for the 2016 bond. These findings coincide with the dynamics of the price from the AT1 2015 bond, which is significantly underpriced for all scenarios.

Table 6: Observed and estimated CoCo prices

Issuance	***Observed price***	$\boldsymbol{S_T = 15.86}$	$\boldsymbol{S_T = 50.46}$	$\boldsymbol{S_T = 74.21}$
AT1 2015	101.15	167.61	163.10	147.33
AT1 2016	107.87	162.17	152.35	132.30

7.1 Sensitivity Analysis

In this subsection several sensitivity tests are conducted to see the effects of varying some inputs, while keeping others constant. The purpose of these tests is to reveal the sensitivity of the primary input parameters and their importance in calculating the CoCo price. The parameters considered are the risk-free rate, time to maturity, volatility (σ) and stock price trigger level. Allowing these parameters to vary can lead to increased knowledge about the dynamics of the bond and indicate which assumptions require the most attention. Thus exploring dynamics might fill the gap between the theoretical prices found and the observed market prices. First, the interest rate sensitivity is considered, to address the discussion of which interest rate to use as a proxy for the risk-free rate.

Table 7: CoCo price when changing the risk-free rate.

rf	***0.5 %***	***1 %***	***1.64 %***	***2 %***	***3 %***	***4 %***
AT1 2015	179.43	161.39	147.33	142.10	132.92	127.51
AT1 2016	162.13	145.61	132.30	127.09	117.50	111.21

Table 7 shows that the market price of the AT1 2016 bond implies a risk-free rate just above 4 percent. However, for the AT1 2015 bond the implied risk-free rate is much higher as the calculated CoCo price is 127.51 for a 4 percent risk-free rate, when keeping everything else constant. These results further imply that the discrepancy between market and theoretical prices is not mainly due to the interest rate chosen in the pricing model. Although, the chosen interest rate might be too low, a risk-free rate above 4 percent seems unreasonably high when it is possible to invest in less safe 10-year bonds with a 2.9 percent interest rate (DNB, 2018). Surely nobody would invest in the latter if the risk-free rate was 4 percent.

Figure 7 and 8 shows the effect of varied risk-free rates on the CoCo price for all three trigger levels. An increased interest rate is shown to decrease the price of the bond since it provides a higher alternative risk-free investment. When keeping the other parameters constant the bond therefore has a lower value at higher interest rates. At a 5 percent interest rate the AT1 2015 bond is still heavily underpriced at all trigger levels. However, the AT1 2016 bond is quite close to its observed value of 107.87 at a 5 per cent risk-free rate and a stock price trigger level of 74.21.

Figure 7 and 8 also shows the differences that occurs for the respective trigger levels, where the isolated effect of increased stock price trigger level decreases the CoCo value. When time to maturity is longer, the probability of breaching the trigger is higher. This is especially true for the stock price trigger level of 74.21, since it is closer to the observed DNB stock price. This effect is similar to the intrinsic value of options, as shown in Spiegeleer et al. (2017). For the 2015 bond the difference in price at different trigger levels is almost constant, since it has less time to redemption. This means that there is a lower probability of hitting the trigger and therefore the bond has higher intrinsic value. The difference in price between triggers is increasing for the 2016 bond as its future value is more uncertain. Here a higher stock price trigger facilitates to lower *DT* and lower the intrinsic value. Furthermore, it is worth noticing that the AT1 2016 is less sensitive to increased risk-free rates than AT1 2015, likely due to the different coupon rate embedded.

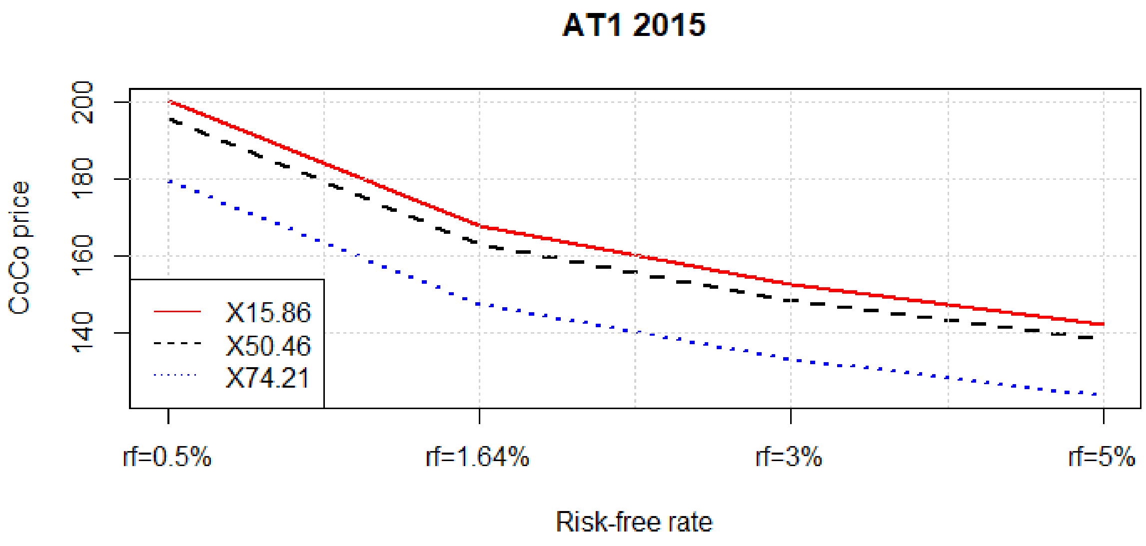

Figure 7: AT1 2015 price for different trigger levels and varied risk-free rate.

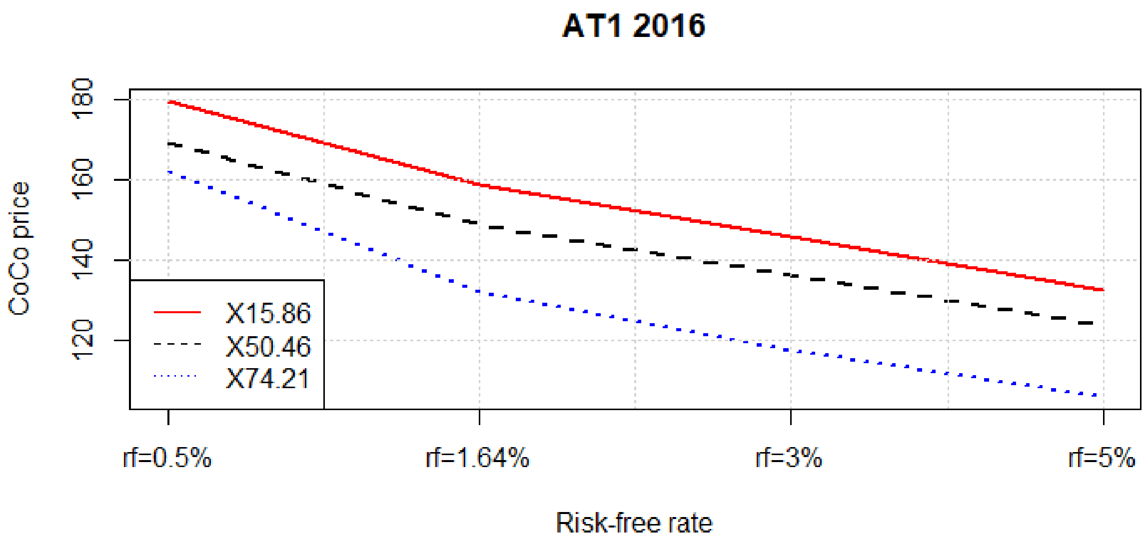

Figure 8: AT1 2016 price for different trigger levels and varied risk-free rate.

Figure 9 presents the CoCo price sensitivity for a range of stock price trigger levels in both bonds. If the correlation is equal to zero as found from historical data, the stock price trigger level would be equal to the observed stock price. As shown, then the price of the AT1 2015 and the AT1 2016 bond would be unreasonable low, equal to 14.50 and 12.51, respectively. Obviously, using historical correlation to determine the trigger level is farfetched, as the prices deviate heavily from what is realistic. Additionally, one can see that in order to obtain theoretical prices equal to the observed, the AT1 2015 trigger level is equal to 110 and the AT1 2016 is equal to 95. This imply a fall in stock price of about 31.5 and 41 percent, which also might be too low.

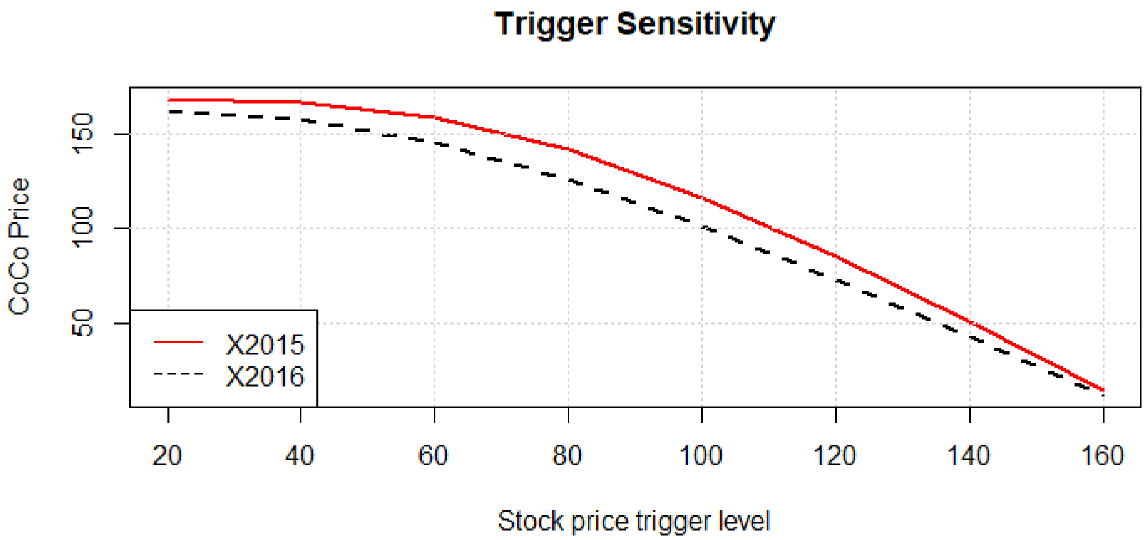

Figure 9: CoCo price sensitivity for different stock price trigger levels.

Figure 10 shows the sensitivity analysis of varied volatility levels. Here CoCo prices are plotted as a function of volatility, ranging from 10 to 80 percent. The red line represents the AT1 2015, while AT1 2016 shown in black. The prices of both bonds are decreasing with increased volatility. This occurs since higher volatility means higher probability of hitting the trigger for a given stock price trigger level. Consequently, the estimated bond prices are closer to the observed values for higher volatility.

The theoretical price is equal to the market price for a volatility of 70 percent with the AT1 2016 bond. For the AT1 2015 bond, however, a volatility above 80 percent still indicates that underpricing is present. Comparing these findings to the 38 percent volatility used in the pricing model, it show that market participants are likely to attach higher risk in both CoCos. These findings coincides with volatility smile dynamics observed with options deep-in or deep-out the money (Hull, 2015). Thus, the market might assume a higher probability of hitting the trigger, and a higher stock price trigger levels than emphasized in the pricing model. If market participants assume a higher stock price trigger level, the option becomes more out-the-money and therefore less valuable.

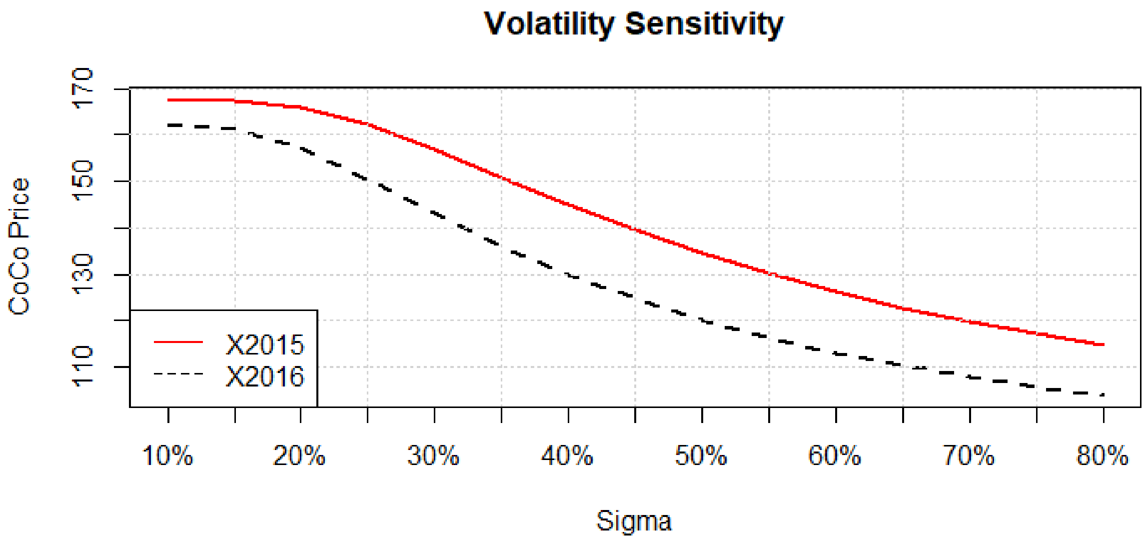

Figure 10: Sensitivity when varying volatility for AT1 2015 and AT1 2016.

Figure 11 illustrates the AT1 2015 bond prices' sensitivity toward changes in time to maturity. The maturities tested are from 0 to 10 years. As it can be seen, the bond price is decreasing with decreasing speed for increased time to maturity, all else constant. In other words, the bond price converges to par value at a larger time to maturity. Only the 2015 issue is shown here as the movement for AT1 2016 is basically identical.

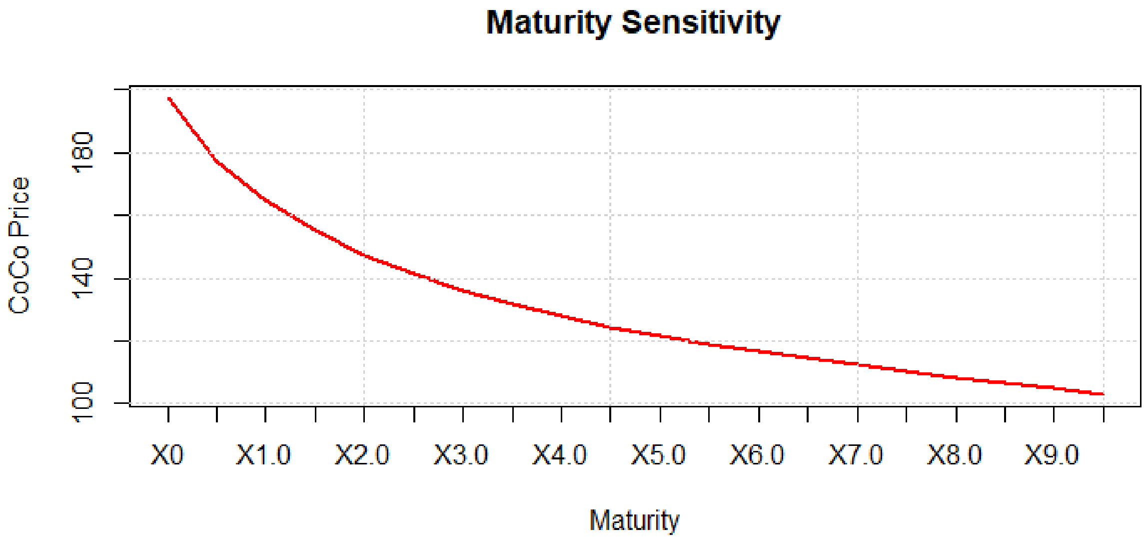

Figure 11: AT1 2015 price for different maturities.

It is reasonable to conclude that no single parameter alone can explain the discrepancy between theoretical and observed price. The results outlined through this section strongly indicate that both the volatility and maturity used in the pricing model is too simplistic. This has two important implications: first, the assumption of call on first call date might be unrealistic, and second, the market assumes higher overall risk with the instrument. Additionally, as briefly discussed, the risk-free rate might be a bit low. The combined effect of increasing these parameters contributes to a lower price for both CoCos.

7.2 How Well Does the Pricing Model Perform?

The pricing model employed in this thesis is based upon simplistic assumptions such as constant volatility, constant interest rates, no dividends and that the stock price trigger level function as a proxy for the true Core Equity Tier 1 trigger barrier. It is also assumed that a bank cannot default prior to conversion, and that conversion happens only when the trigger barrier is breached. Overall, the pricing model indicates significant underpricing for both instruments. However, it is unclear whether the underpricing occurs due to the simplistic assumptions of the pricing model, mispricing in the market or a combination of both.

Although, in Scenario 3 using $\beta = 1.5$, the estimated price is fairly close to the market value of the AT1 2016 bond.

Moreover, when pricing CoCos in an equity derivative framework there is widespread practice to assume a stock price fall of around 50 percent to reach the stock price trigger level (Spiegeleer & Schoutens, 2011). When implementing the new β-link outlined in this thesis, the stock price trigger level in Scenario 3 is 74.21, indicating a stock price fall of about 53 percent. Hence, Scenario 3 stands out as the most realistic. The other scenarios are of more extreme nature, yielding stock price fall of 68 and 90 percent, respectively. It is safe to assume that regulators would impose PONV trigger long before this stock price level to mitigate fear of default and prevent bank-runs.

By looking at the risk in both CoCo prices, one can compare the credit spreads provided in Table 8. The credit spreads are calculated using Equation (20). The estimates are 149 and 134 basis points, reflecting the low risk associated with the underlying company. The credit spreads found are, as expected, fairly identical for both issuances. However, counterintuitive as it might seem, the credit spread for the AT1 2015 issue is higher, even though it has a lower probability of breaching the trigger.

Table 8: Credit spread and probability of hitting trigger p^*

Issuance	p^*	***Credit spread***
AT1 2015	31.25 %	149 bps
AT1 2016	40.71 %	134 bps

The discrepancy between the observed and theoretical prices of both bonds may be explained by several factors. These factors include coupon cancelling risk, extension risk and PONV trigger risk. Spiegeleer et al. (2017) found coupon cancelling risk to represent around 9 percent of the CoCo bond value for Credit Suisse's full write-down AT1 bond issued in 2013. They also simulated the PONV trigger for a sample of CoCo issuances made by European banks, and estimated that the average PONV trigger was equal to 9.37 percent. This implies that regulators impose write-down far above the 5.125 per cent Core Equity Tier 1 trigger. Both the risk of coupon cancelling and PONV trigger reduce the value of the CoCo bond as they increase the volatility parameter (σ) and implied stock price trigger level. The theoretical pricing model is thus expected to deliver a price above the market since it does not allow for coupon cancelling and write-down before the CET1 trigger is breached.

The presence of extension risk might also influence the CoCo bond value. Spiegeleer & Schoutens (2014) highlight that in the years prior to 2008, coupon step-up was a common practice to ensure that debt instruments were called at first call date. However, from the new rules implemented in January 2013, banning coupon step-up for AT1 CoCos, an extension risk is introduced (BCBS, 2013). As for risk of coupon cancelling and PONV triggers, the presence of extension risk reduces the value of the CoCo bond since it increases the parameter of time to maturity. However, this is not considered in the pricing model, as redemption at first call date is assumed in line with traditional AT1 and Tier 2 instruments.

The pricing model employed in this thesis emphasizes applicability and simplicity for both issuers and market practitioners. It seeks to find a more accurate relation between the CET1 trigger and stock price trigger level by employing scenarios through β relations, instead of assuming a fixed correlation between the two based on historical movements. This shifts the trigger relation from lagged historical movements, to an ex-ante, forward looking approach. As the main focus is at enhancing the trigger relation, the pricing model does not aim to employ the more advanced process dynamics, e.g. mean-reverting volatility and tail-risk.

In order to enhance the model with regard to volatility and tail-risk, more advanced dynamics could be implemented by using Lévy processes as outlined in Section 4.1.3, or introducing more complex stochastic volatility, e.g. through GARCH models. However, this would shift the pricing model from a closed form solution to simulation based, making it more complicated and time consuming from a computational point of view. Moreover, the model could be calibrated with the implicit CET1 volatility as proposed by Spiegeleer et al. (2017) to reveal the true dynamics of the CET1 level. The pricing model could furthermore consider extension risk, cancellation risk and PONV trigger risk as briefly discussed in this section.

Clearly more research is required to find the appropriate β values between CET1 trigger level and stock price. However, the current results present an improvement compared to the ordinary equity derivatives model, since the pricing model does not assume a one-on-one correlation between Core Equity Tier 1 and stock price. Additionally, the scenario analysis might function as a useful guideline in searching for the optimal β relation.

7.3 The Regulatory Debate

CoCos have potential to mitigate future financial distress by functioning as a loss-absorbing instrument that restores a bank's capital, without spending taxpayers' money. This coincides with the increased regulatory capital requirements implemented by Basel III. Although, Admati et al. (2013) and Sundaresan & Wang (2010) argue that saved tax deductions for the bank is a cost to society. Furthermore, if constructed properly, CoCos can reduce the need for bailouts, reduce default risk and reduce the possibility of market manipulation. However, there are challenges that needs to be addressed by regulators in ensuring that CoCos function as intended.

The complex nature and low standardization of CoCos make it hard for investors to compare issuances. Thus, pricing is a difficult aspect. Regulators also leave investors uncertain by not providing standardized trigger and conversion mechanisms. Both are critical in deciding the incentives for investors and the loss-absorbing ability of the bond. There is particularly widespread agreement that structuring trigger mechanisms is the most important aspect in order to ensure loss-absorbing ability (Sundaresan & Wang, 2010; Corcuera et al., 2013; Spiegeleer & Schoutens, 2011).

CoCos might be constructed with accounting, regulatory, market and multivariable triggers, with conversion to shares or write-down. Where conversion might be structured with different fraction and price, e.g. fully, partly or conversion with floor. A combination of accounting trigger and regulatory PONV trigger is most often observed in the market. This launches an important discussion, since regulators do not provide any clear guidance on how to interpret the PONV trigger (Spiegeleer et al., 2017). However, as emphasized in last section, investors are likely to take into account the uncertainty regarding PONV, but with lack of precision. This might increase the overall risk assumed with CoCos.

Consequently, CoCos current trigger structure might be suboptimal with respect to the critical factors in design of trigger, as proposed by Spiegeleer & Schoutens (2011). Here the main problem is: firstly, not being sufficiently transparent and updated, as Core Equity Tier 1 ratio is not observable with daily changes. Second, since the conversion process must be known, regulatory PONV intervention is not optimal. Finally, all information regarding structure and drivers behind a potential conversion is not public information, as it should be.

CoCos are still in an early phase as a financial security, but two important events adds empirical knowledge to the discussion of the instrument's suitability. Investors in Deutsche Bank AT1 bond started a panic sale due to speculations of cancelling coupons in February 2016, which caused CoCo prices and stock prices to fall dramatically. At the same time, the credit default spreads of Deutsche Bank increased due to this fear, increasing the risk associated with the bank. Delivorias (2016) argues that this panic was caused by fear of coupon cancelling, not fear of conversion. In this case, the structure of CoCos, by allowing coupon cancelling, created financial distress as investors feared lost coupon payments.

Second, the rescue of Banco Popular in June 2017 stands as a warning to CoCo investors. This was the first time losses occurred in the AT1 market. Banco Popular's CoCos were converted to shares that had zero value, while leaving senior bondholders untouched (Euromoney, 2017). Banco Popular was declared the state of non-viability since regulators feared a bank-run due to large amounts of deposit withdrawals. None of the bank's outstanding AT1 bonds had ever missed coupon payments, which according to the structure of CoCos should occur before write-down or conversion. The incident of Banco Popular clearly was an issue of liquidity problems and not of regulatory capital. Before this event, Banco Popular reported a Core Equity Tier 1 of 10.02 percent in 2017:Q1, way above the CoCo trigger at 5.125 percent, thus supporting the conclusion of liquidity issues. Consequently, the conversion of Banco Polpulars's CoCos proves that regulators do not hesitate to impose non-viability for the sake of common wealth at the investors' expense.

The abovementioned empirical knowledge underscore the importance of an ongoing regulatory discussion, to search for optimal structure and features. Questions that presents themselves are if banks' really has become safer in light of the increased regulatory capital, and if the potential CoCo issuance is big enough to have mitigating effect on default risk. Interestingly, Spiegeleer et al. (2017) found that although banks' has increased their Core Equity Tier 1 ratios, they are perceived as more risky, as the CET1 volatility increased from 14.1 to 22.4 per cent in the recent years. Admati et al. (2013) early introduced concerns that CoCo are too complex and have insufficient loss absorbing capacity. However, the latter is still rather untested from an empirical point of view.

The unexpected dynamics observed during the events related to Deutsche Bank and Banco Popular illustrates the risk of a changed regulatory landscape. Further, there is an ongoing debate that Tier 2 CoCos might be substituted with new securities under Minimum Requirement for own funds and Eligible Liabilities (MREL) and Total Loss Absorbing Capacity (TLAC) regulations in order to enhance the liquidity of banks (Avdjiev et al., 2015). This uncertainty about changed future regulatory requirements adds to the uncertainty faced by the investors and issuers. It might also imply that market practitioners have focused too much on the impact of Core Equity Tier 1 triggers compared to the other risks associated with the instrument. Consequently, whether financial engineering or more restrictions on structure are the future response in designing CoCos, is dilemmas that financial regulators and policymakers are facing going forward.

Concluding Remarks

Contingent convertible bonds have emerged as a promising hybrid *going-concern* loss-absorbing instrument under the Basel III regulation, seeking to enhance the quality and amount of regulatory capital. Therefore, CoCos might replace subordinated debt as loss-absorbing regulatory capital, as it transfers risk from tax-payers to investors of CoCo bonds. Additionally, if CoCos are constructed properly, they contribute in creating more robust banks for times with financial distress. However, as CoCos are instruments with high complexity and varying structures, pricing becomes a challenging and important topic.

Well-established CoCo pricing models consist of structural, credit and equity derivatives methods. Equity derivatives are found to be most suitable as they are less complex and are based upon observable market parameters and incorporate the most important price drivers. As for all CoCo pricing models with accounting CET1 trigger, equity derivatives solve the trigger contingency by assuming high co-movement between Core Equity Tier 1 and stock price. However, making such an assumption induces a flaw since no significant correlation is found empirically.

This thesis makes a modest attempt at solving the trigger relation analytically by employing CAPM β values between Core Equity Tier 1 and stock price in different scenarios. The β relation provides a realistic estimate of the stock price trigger level compared to previous literature. According to the best estimate, the fair values of both DNB CoCos are higher than the market price, indicating that the pricing model fails to incorporate some value-decreasing property or that mispricing has occurred due to limited understanding of its dynamics. The results from the pricing model does however introduce an improvement to existing models as stock price trigger level is found without assuming a one-on-one correlation. The price discrepancy can be divided into two main categories, namely (1) shortcomings of the pricing model, and (2) shortcomings due to market participants perception of CoCos.

The thesis presents several shortcomings of the pricing model that add to explain the discrepancy between theoretical and observed prices. First, the simplifying assumptions regarding maturity at first call date and constant volatility, might be unrealistic. The sensitivity analysis suggests that both maturity and volatility are value-decreasing factors that could be larger in reality. Moreover, the model does not incorporate coupon cancellation risk, extension risk and PONV trigger risk. These risks are likely incorporated by sophisticated investors, and thereby reduces the CoCo value.

Investors in CoCos may not be provided with sufficient information about pricing, dynamics and structure of the bonds, as emphasized throughout this thesis. This might increase investors perception of risk, causing higher expected probability for loss to occur and higher expected stock price trigger levels. Such misinterpretations can lead to reinforced risk itself, as observed in the incident with fear of coupon cancelling in Deutsche Bank. Consequently, there is clearly need for ongoing assessment and improvement of CoCos structure. If these hybrids are not structured optimally, they might impose high uncertainty for both investors and issuers. Therefore, commencing important challenges for policymakers and regulators to ensure that the loss-absorbing mechanism work as intended, in order to enhance robustness of banks.

In order to improve the pricing model, more advanced dynamics are reasonable to incorporate. Further research should focus on extending the β relation in a more advanced settings by employing Lévy processes to capture the tail-risk included with CoCos. In addition, the pricing model should incorporate the clustering and mean-reverting tendency of volatility. The introduction of coupon cancelling risk, extension risk and PONV trigger risk are also interesting topics for future research, as they undoubtedly have impact on the CoCo price.

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Appendices

A Distribution of CoCo Issuance

Figure A.1 shows the distribution of CoCo issuances by nationality and currencies, denoted in USD billions in the time period 2009-2015. The currency distribution shows that Euro, Chinese Yuan and USD are the biggest contributors.

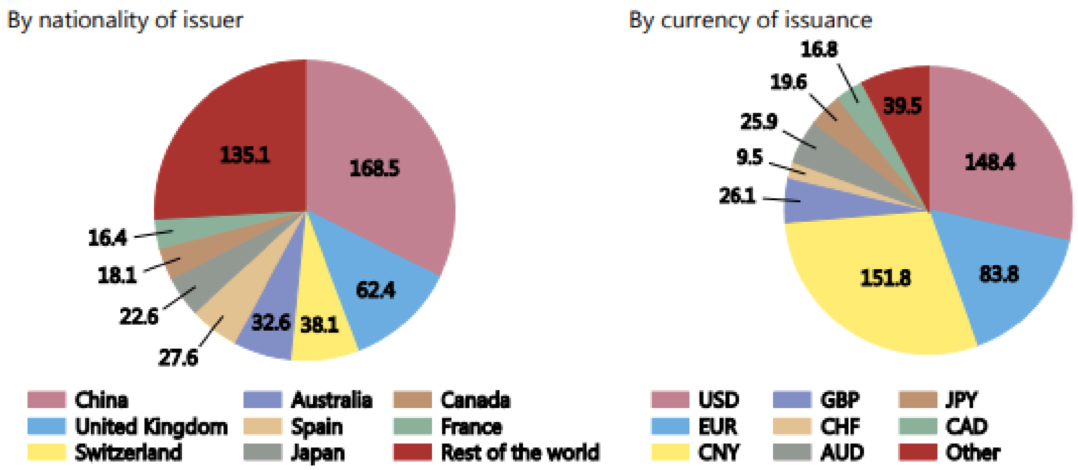

Figure A.1: Distribution of CoCo issuance between nations and by currency

Source: Avdjiev et al. (2017)

B Evolution of CoCo Issuance

Figure B.1 displays the total CoCo issuances made from 2009 to the middle of 2015. The figure especially highlights a structural shift from issuances with conversion to principal write-down mechanism. Also, the difference between Tier 1 and Tier 2 categorization is shown.

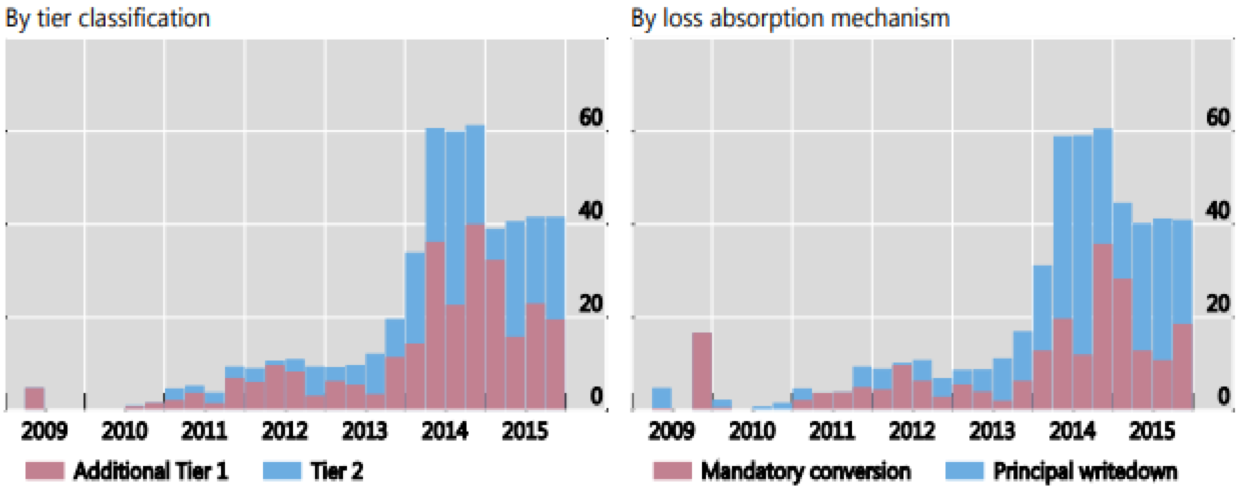

Figure B.1: Total CoCo Issuance in USD billions from 2009-2015.

Source: Avdjiev et al. (2017)

C Equity Derivatives: Probability of Breaching The Trigger

In the Spiegeleer et al. (2017) approach for full write-down CoCos, the probability of breaching the trigger is based on the same Black-Scholes formula as in credit derivatives method. The main difference is the introduction of DT. Consequently, here p^* is the likelihood of the stock price breaching the trigger during the lifetime of the CoCo bond. Thus, in general $\varphi(x)$ is the probability of a random variable X, taking a value less than x, under the assumption that the random variable has a normal distribution. Hence, we got the following relations:

$$p^* = 1 - \varphi\left(\frac{\log(D_T) + \mu T}{\sigma_{CET1}\sqrt{T}}\right) + D_T\varphi\left(-\frac{\log(D_T) - \mu T}{\sigma_{CET1}\sqrt{T}}\right)$$

$$\varphi(x) = Probability\ (X \leq x)$$

Where,

$$T = Maturity\ of\ the\ CoCo$$

$$D_T = \frac{CET1\ ratio}{Trigger}$$

$$\mu = -\frac{\sigma_{CET1}^2}{2}$$

$$\sigma_{CET1} = Volatility\ of\ CET1\ ratio$$