NTNU – Trondheim
Norwegian University of
Science and Technology

Pricing Contingent Convertible Capital

An Empirical Approach

Vegard Gullaksen Veiteberg
Fredrik Toft Bysveen
Bård Haugland Rosef

Industrial Economics and Technology Management
Submission date: May 2012
Supervisor: Einar Belsom, IØT

Norwegian University of Science and Technology
Department of Industrial Economics and Technology Management

NTNU
Det skapende universitet

MASTERKONTRAKT

- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Bysveen, Fredrik Toft**	Fødselsdato **08. mar 1987**
E-post **fredrby@stud.ntnu.no**	Telefon **92864449**

2. Studieopplysninger

Fakultet **Fakultet for Samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Investering, finans og økonomistyring**

3. Masteroppgave

Oppstartsdato **16. jan 2012**	Innleveringsfrist **11. jun 2012**
Oppgavens (foreløpige) tittel **Pricing Contingent Convertible Capital**	
Oppgavetekst/Problembeskrivelse Purpose: Develop pricing model for contingent convertible capital. 1. Review and discussion of theoretical and empirical literature related to contingent convertible capital. 2. Development of pricing model for contingent convertible capital with a common equity ratio trigger. 3. Evaluation of model using theoretical reference and/or empirical analysis. Overall assessment of the strengths and weaknesses of the proposed model.	
Hovedveileder ved institutt **Førsteamanuensis Einar Belsom**	Medveileder(e) ved institutt
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

....
Sted og dato

....
Student

....
Hovedveileder

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

NTNU
Det skapende universitet

MASTERKONTRAKT
- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Rosef, Bård Haugland**	Fødselsdato **06. mar 1987**
E-post **rosef@stud.ntnu.no**	Telefon **93637279**

2. Studieopplysninger

Fakultet **Fakultet for Samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Investering, finans og økonomistyring**

3. Masteroppgave

Oppstartsdato **16. jan 2012**	Innleveringsfrist **11. jun 2012**
Oppgavens (foreløpige) tittel **Pricing Contingent Convertible Bonds**	
Oppgavetekst/Problembeskrivelse Purpose: Develop pricing model for contingent convertible bonds. 1. Short discussion of the advantages/disadvantages of contingent convertible capital 2. Make an attempt at pricing contingent convertible capital with a common equity ratio trigger, using a Black-Scholes framework with pricing from Monte Carlo. 3. Evaluation of model using theoretical reference and/or empirical analysis. Overall assessment of the strengths and weaknesses of the proposed model and compare them with the results with different approaches such as pricing by derivatives. Further implications.	
Hovedveileder ved institutt **Førsteamanuensis Einar Belsom**	Medveileder(e) ved institutt
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

....
Sted og dato

....
Student **Hovedveileder**

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

NTNU
Det skapende universitet

MASTERKONTRAKT

- uttak av masteroppgave

1. Studentens personalia

Etternavn, fornavn **Veiteberg, Vegard Gullaksen**	Fødselsdato **25. okt 1986**
E-post **veiteber@stud.ntnu.no**	Telefon **41905041**

2. Studieopplysninger

Fakultet **Fakultet for Samfunnsvitenskap og teknologiledelse**	
Institutt **Institutt for industriell økonomi og teknologiledelse**	
Studieprogram **Industriell økonomi og teknologiledelse**	Hovedprofil **Investering, finans og økonomistyring**

3. Masteroppgave

Oppstartsdato **16. jan 2012**	Innleveringsfrist **11. jun 2012**
Oppgavens (foreløpige) tittel **Pricing Contingent Convertible Capital**	
Oppgavetekst/Problembeskrivelse Purpose: Develop pricing model for contingent convertible capital. 1. Review and discussion of theoretical and empirical literature related to contingent convertible capital. 2. Development of pricing model for contingent convertible capital with a common equity ratio trigger. 3. Evaluation of model using theoretical reference and/or empirical analysis. Overall assessment of the strengths and weaknesses of the proposed model.	
Hovedveileder ved institutt **Førsteamanuensis Einar Belsom**	Medveileder(e) ved institutt
Merknader **1 uke ekstra p.g.a påske.**	

4. Underskrift

Student: Jeg erklærer herved at jeg har satt meg inn i gjeldende bestemmelser for mastergradsstudiet og at jeg oppfyller kravene for adgang til å påbegynne oppgaven, herunder eventuelle praksiskrav.

Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

....
Sted og dato

....
Student

....
Hovedveileder

Originalen lagres i NTNUs elektroniske arkiv. Kopi av avtalen sendes til instituttet og studenten.

Pricing Contingent Convertible Capital
– an empirical approach

Fredrik Bysveen, Bård Rosef, and Vegard Veiteberg

May 30, 2012

Preface

This thesis concludes our Master of Science in Industrial Economics and Technology Management at the Norwegian University of Science and Technology. Our objective is to shed light on the new Contingent Convertible (CoCo) asset class with a different point of view than prevailing academic literature. It has been an exciting learning experience where we have gained insight to various topics in the financial literature, and we look forward to future development of the asset class.

The text has been typeset in LaTeX, with illustrations prepared in Microsoft Excel and Microsoft PowerPoint. Simple data analyses are done in Minitab and Excel, while the main estimations and simulations are preformed in Matlab. Matlab code is available upon request. The data foundation is primarily obtained from the Reuters EcoWin database, as well as SEC and company filings.

We would like to thank our supervisor, Associate Professor Einar Belsom at the Department of Industrial Economics and Technology Management, for his valuable advice and committed guidance. We would also like to thank all other parties contributing to this thesis.

Abstract

This thesis develops a novel empirical approach to price contingent convertible bonds (CoCos) with a Core Tier 1 (CT1) ratio trigger. Existing models on CoCo pricing all develop a process linking a proxy of the trigger with the stock price, but we find that the proxies used are not representative for the CT1 ratio. In particular, they all imply high correlation with the stock price and fail to incorporate the bank's control of the ratio through their risk management. As we find the correlation between the trigger and the stock price to be historically insignificant, we model them as independent processes. Their evolution is estimated based on historical data, while allowing the bank to have a target for their capital adequacy ratio. To test our model and check its sensitivity to the input data, we study the Credit Suisse CoCo issue of March 20th, 2012. According to our best estimate, including information likely incorporated by investors, the CoCo is underpriced by the market.

Sammendrag

Denne oppgaven presenterer en ny empirisk tilnærming til å prise betinget konvertible obligasjoner (CoCos) med en Core Tier 1 (CT1) ratio trigger. Eksisterende modeller er basert på en prosess som linker en tilnærming av triggeren med aksjekursen. Vi finner at disse tilnærmingene ikke er representative for den observerte CT1 ratio, da de impliserer høy korrelasjon med aksjekursen og ikke tar hensyn til bankens kontroll over ratioen. Siden vi finner at korrelasjonen mellom triggeren og aksjekursen historisk har vært insignifikant, modellerer vi dem som selvstendige prosesser. Prosessene er kalibrert ved bruk av historiske data, samtidig som vi lar bankens mål for kapitaldekning styre det langsiktige gjennomsnittet i våre simuleringer av utviklingen til ratioen. For å teste vår modell og sjekke følsomheten for valg av variabler som benyttes i modellen, studerer vi Credit Suisses CoCo utstedelse av 20. mars 2012. Vårt beste estimat indikerer at den siste Credit Suisse utstedelsen er underpriset.

Contents

1 Introduction

The financial crisis of 2007-2008 revealed the vulnerability of today's highly interconnected financial markets and in particular the global, systematically important banks (G-SIBs). In addition to the collapse of Lehman Brothers, bulge-bracket banks on both sides of the Atlantic had to be bailed out by their respective governments due to a possible chain-reaction of banks falling, destroying the financial system. Furthermore, several quantitative eases have been deemed necessary in the aftermath of the crisis to fuel financial activity and minimise the probability of a recession similar to the Great Depression. As such measures are financed by taxpayer money, questions have been raised of the viability of the current system.

One of the many issues brought into light by the subprime crisis was the inability of prevailing hybrids and subordinated debt to sufficiently absorb losses. The structure of these products is such that they are second (after equity) to absorb losses upon bankruptcy, thereby protecting the value of more senior capital, such as deposits. The big caveat is that these hybrids are so-called *gone-concern* loss absorbing. That is, except for possibly deferred payments, they face losses only in the event of bankruptcy. Tax payers protecting the depositors are therefore also bailing out investors in these securities, negating their loss absorbing role at failure.

As a result, academics such as Flannery (2005, 2010) and Duffie (2009), publications such as the Squam Lake Report (2010) and regulators such as the Basel Committee of International Settlements (BIS) have called for *going-concern* loss absorbing hybrids, and proposed contingent convertibles as a possible solution.

A contingent convertible bond (CoCo) is a bond issued by a financial institution, which upon the appearance of a trigger event converts into shares or experiences a partial write down of its face value (Corcuera et al., 2011). Conceptually, these instruments are truly loss absorbing since they impose a loss on their holder if the issuing bank nears a state of non-viability (Spiegeleer and Schoutens, 2011a). In the case of equity conversion there is also an automatic "infusion" of equity capital, with the CoCo investors bailing out the bank.

Moreover, since this is a state where the bank is struggling to finance itself in the market, the overall systemic risk is reduced through the automatic reinforcement. However, the effectiveness of CoCos in reducing systematic risk depends on how broad the investor base is. If it is primarily banks that buy other banks' issues, the too-big-to-fail (TBTF) problem remains unchanged. A CoCo triggered in one bank will hit the asset pool of the bank that invested in these bonds, and the interconnectedness in the financial industry will only get worse.

The CoCo made its entry into the financial landscape in 2009 with Lloyds Banking Group's USD 13.7bn offer to swap existing hybrid debt to contingent convertible notes named "Enhanced Capital Notes"[1]. After an issue by the non-public Rabobank in 2010, the market was put to test when Credit Suisse surprisingly issued USD 2bn Buffer Capital Notes in the first public offering in February 2011. The issue was a huge success and more than eleven times oversubscribed. The fact that yield-hungry investors showed great appetite for these investments, dismissed several experts' early concerns over the marketability of such an unfamiliar asset (Risk.net, 2011).

The sky seemed the limit for CoCos with an estimated market size in the region of USD 1 trillion (S&P, 2010). These speculations were founded on rumours that the Basel Committee would allow contingent capital to be used by the G-SIBs to meet the extra TBTF capital surcharge in the new Basel III accord (Spiegeleer and Schoutens, 2011a). However, in June 2011 the committee eventually ruled against this based on the fact that CoCo is a largely untested asset class (BCBS, 2011).

The Basel Committee is nonetheless very positive to contingent capital as a *future* measure in banking regulation. Given this development and recent issuances by some large banks, contingent convertible bonds might develop into one of the main financing instruments for banks in the future. Moreover, in its stress tests of October 2011, the European Banking Authority (EBA) revealed a need for approximately EUR 100bn to reinforce the balance sheets of European banks, and clearly left the possibility for banks to use CoCos in this exercise (EBA News & Communications, 2011).

For CoCos to reach its potential and emerge into a liquid market of this size, as well as attracting a diverse set of investors, development of pricing models for these instruments is essential. According to market sources: *"CoCos [are] currently done by investors seeking the higher yields the bonds offer, or to bet prices would keep rising, rather than being based on fundamental valuations. Some just think that the trigger is so out of the money that it's not a consideration for trading right now."*[2] (Hughes, 2011).

Much of the current academic literature on CoCo pricing assumes a stock price trigger, which makes pricing straightforward as the value of the CoCo is solely

[1] Lloyds' Enhanced Capital Notes were not a capital raising exercise and the investors did not really have a choice. Lloyds had received government aid and the acceptance of the taxpayers' money disallowed the holders of this hybrid capital from receiving coupons, making the only way to continue receiving a steady income to swap these poor performing hybrid bonds for new securities.

[2] According to Angela Lemos, a credit trader at Nomura, in an interview with the Financial Times.

dependent on the stock price. The problem is that these valuation techniques lack root in reality. As shown over the next sections, all issued CoCos have *accounting triggers* and the relationship between stock price and Core Tier 1 (CT1) ratio trigger is by no means one-to-one.

To accommodate these problems structural approaches have been developed. Here, the evolution of asset values is estimated according to a Merton (1974) model and both the trigger condition and share price is a function of the stochastic asset prices. Although attractive at first sight, such models assume a very high degree of correlation between the trigger contingency and share price. This is empirically problematic and will be explored in Section 3.

Whereas the trigger contingency is approximated through various assumptions in the existing models, we propose an empirical approach for pricing CoCos where the evolution of the accounting trigger is determined from its historical values. Specifically we will focus on CoCos with a CT1 ratio trigger and conversion into shares as this represents to date the biggest fraction of outstanding CoCos. We will use the new Credit Suisse issue of March 20th, 2012 to test the viability of our approach.

Based on our finding of insignificant correlation between the trigger condition and the stock price, we model them as *independent processes*. Additionally, to incorporate the control the issuing bank can exert on its capital adequacy ratio, a *mean-reverting process* is used for the CT1 ratio development, with the level set according to company stated targets.

Corcuera et al. (2011) underline the importance of employing a variety of models to price and investigate the dynamics of CoCos. Thus, we add to the existing literature by testing the sensitivity of the CoCo price, maturity and trigger probability to the various inputs and assumptions.

The remaining part of the thesis begins with a description of the anatomy and structure of CoCos in general and the new Credit Suisse CoCo in particular. Second, we provide a presentation and evaluation of existing pricing models, focusing on the assumptions these models are based upon. Third, we present our model, the dataset used to calibrate our model, and the calibration results. Finally, we evaluate our model in light of relevant theory and empirical observations, addressing possible shortcomings of our model/dataset and propose improvements to our base case to enhance pricing accuracy.

2 The Autonomy and Structure of CoCos

In its broadest sense contingent convertibles are bonds that automatically convert to equity or suffer a write down as soon as the solvency of a bank drops below a predetermined standard. It is important to underline that CoCos are not to be confused with convertible bonds, as they have very few similarities except that they have both equity and fixed income components. A traditional convertible bond has equity-upside and limited downside, whereas contingent convertibles can be said to have the flip of this (Spiegeleer and Schoutens, 2011a).

Although not the main focus of this thesis, we will briefly discuss the different components and controversies surrounding this widely debated asset class. The general rule is that there are few to no established guidelines and no "standardised" CoCo contracts as of yet. In fact, most issues to date are distinctive and contingent convertible structures are still lively debated amongst regulators, issuing banks, rating agencies, investors and trading desks around the world.

Most questions regarding the anatomy of CoCo notes are related to behaviour of the issuer when the note approaches conversion, in addition to the trigger contingency itself. Will the management of the bank do everything possible to avoid the triggering event, or will they strive to ensure conversion? After all, the CoCo and/or equity investors might be worse off, but the bank directors will keep their job by extending the life of the bank. This is moral hazard at its worst, making an appropriate structure of the CoCo essential.

The core structural elements of the CoCo are the specification of the trigger event and the conversion properties. Table 1 lists some of the current CoCo issues and their main characteristics.

2.1 Trigger Event

The trigger contingency is a heavily debated topic amongst academics and practitioners. In general, the trigger can be defined as a market measure, such as the stock price, an accounting measure, such as the Core Tier 1 ratio (CT1 ratio)[3], or as a regulatory intervention where the supervising authority decides when to convert based on its assessment of a given bank's solvency. Multi-variate triggers where both systemic macro measures and micro measures are taken into account have been proposed as an improvement (French et al., 2010; MacDonald, 2010).

Spiegeleer and Schoutens (2011a) list six desired conditions of an optimal trigger event: clarity, objective, transparent, fixed, public and frequently updated. The

[3] The Basel Accords' measure of solvency.

Value	Lloyds $13.7bn	Rabobank €1.25bn	Credit Suisse $2bn	ANZ A$1.25bn	Credit Suisse CHF750m
Name	Enhanced Captial Notes	Senior Contingent Notes	Tier 2 Buffer Capital Notes	Convertible CPS3 Preference Shares	Tier 2 Buffer Capital Notes
Host Instr.	Fixed Coupon Bond	Fixed Coupon Bond	Callable Bond	Preferred Shares	Fixed Coupon Bond
Maturity	10 - 22 years	10 years	30 years, callable after 5.5 years	Perpetual, callable after 6 years	10 years, callable after 5.5 years
Trigger	Accounting CT1 ratio < 5 %	Accounting Common equity/ RWA < 7 %	Accounting CT1 ratio < 7 % or execution by regulator	Accounting CT1 ratio < 5.125 %	Accounting CT1 ratio < 7 % or execution by regulator
Conversion	Conversion into a fixed number of common shares	Write down with 25 % cash recovery	Conversion into a fixed number of common shares	Conversion into a fixed number of common shares	Conversion into a fixed number of common shares
Conv. Price	Fixed, 59 pence	N/A	Floored max(USD20,CHF20, 30-day avg.)	Floored max(A$19.38, 20-day avg.)	Floored max(CHF20, 30-day avg.)

Table 1: Overview of characteristics of some current CoCo bonds

first two make sure that the meaning is the same no matter the jurisdiction of the issuer and that it is known at issue exactly under what conditions conversion will be executed. That the trigger is fixed, transparent, public and frequently updated ensures that it is easy for investors to continuously assess the risk and price of the CoCo.

Academia has a tendency to prefer market-based triggers which are consistent with all of the six properties and additionally has a forward-looking nature, ensuring a timely conversion (Spiegeleer and Schoutens, 2011c). A stock price is perceived as more objective and up to date than accounting measures and much less susceptible to manipulation and political pressure (MacDonald, 2010).

Regulators and decision-makers however, like the independent and prominent Squam Lake Working group (French et al., 2010)[4] and the government mandated Swiss Commission of Experts (Swiss Commission of Experts, 2010), have called for regulatory or accounting based rules. And, as seen in Table 1, all prevailing CoCos are based on such triggers[5]. Regulatory triggers breach all six of the aforementioned properties, while accounting triggers are neither transparent, public nor frequently updated. An investor would have to rely on audited balance sheets

[4]The Squam Lake Group is a non-partisan, non-affiliated group of 15 academics who offer guidance on the reform of financial regulation.

[5]Also holds for issues not in Table 1, for example the recent USD 1bn UBS issue.

which are only released quarterly (not frequently updated), do not provide much detail (not very transparent) and are not made public until weeks or months after the trigger contingency is breached (not very public).

The fact that an accounting ratio is not updated daily leaves the investors in the dark for long periods of the year, and several authors argue that this leaves room for speculation on whether the CoCo has triggered or not (Flannery, 2010; Spiegeleer and Schoutens, 2011a). It is also argued that a trigger system based on a single accounting number is easy to game (Bloomberg, 2009), and leaves the banks with too much discretion regarding whether the CoCo will trigger or not.

However, using a market-based trigger also comes at a risk. An investor holding contingent convertible debt exposes his portfolio to the risk that the bond gets converted because of market manipulation. If a big player goes short a large amount of shares when the share price is trading very close to the barrier on a day with little volume, the CoCo might trigger[6] (Spiegeleer and Schoutens, 2011a). Flannery (2009, 2010) have extensive discussions on the possibilities of profitable stock price manipulation. Moreover, Sundaresan and Wang (2011) show that setting the conversion trigger at a level of the stock price may result in multiple solutions or no solution for the market price of the stock and the CoCo.

In short, it is thought that the chances of a false positive (conversion when not needed) is larger with a market based trigger and that the likelihood of a false negative (no conversion when needed) is higher with an accounting based trigger. The latter is conceived the most dangerous with regards to financial stability.

The main reason why accounting triggers are still used by practitioners is that they can be very closely linked to solvency. A stock price, on the other hand, is a result of the expected future earnings of the bank and incorporates much more information than just bankruptcy risk. Additionally, the CT1 ratio trigger is in close accordance with the Basel III Accord in their recommendations for the national regulators, where it has received a warm welcome and is expected to sustain as the key solvency measure (BCBS, 2011).

As we will examine CoCos with Basel accounting triggers, in particular the new Credit Suisse issue, we take a closer look at how these solvency measures are defined and calculated.

[6] The flash crash, also known as ‘The Crash of 2:45’, that took place in the afternoon of May 6, 2010 in the United States illustrates this. Almost all of the 8000 securities traded in the U.S. suffered an aggressive price correction only to recover those losses within minutes, because of a bulk sale by a large mutual fund in E-mini S&P contracts, being followed by algorithmic high-frequency traders. Over 20,000 trades across more than 300 securities were executed at a price which was more than 60 % away from their values minutes earlier (SEC, 2010).

2.2 The Core Tier 1 Ratio

The rationale behind the capital adequacy requirements proposed by BIS is to ensure that banks have sufficient loss-absorbing capital to avoid defaults when forced to write down the assets value. To measure this loss absorbing capacity, BIS put forward several ratios to use as solvency indicators for financial institutions[7]. The strictest ratio in the Basel II & III accords is the Core Tier 1 (CT1) ratio defined in Equation 1, which is used as the trigger contingency in all CoCos[8].

$$\text{CT1 ratio} = \frac{\text{Core Tier 1 Capital}}{\text{Risk-Weighted Assets (RWA)}} \tag{1}$$

Bank default risk is dependent on both what sort of assets the bank has invested in and how those assets are funded. Core Tier 1 Capital is a measure of the highest quality, loss-absorbing capital, mainly consisting of common equity and retained earnings, while RWA is a standardised measure of assets or off-balance exposure weighted according to risk. Using RWA instead of total assets makes banks under different accounting regimes comparable, allows off-balance sheet positions to be included, and does not deter banks from carrying low risk liquid assets, such as government bonds, in their books (Basel Capital Accord, Revised 1998).

The Basel accords use three categories of risk to calculate a bank's RWA: (1) credit risk, (2) market risk and (3) operational risk (Spiegeleer and Schoutens, 2011a). The credit risk is a measure of the bank's counterparty risk, found by weighting the balance sheet investments in accordance with a perception of their respective default risk[9]. Market risk, on the other hand, is defined as *"the risk of losses in on and off-balance-sheet positions arising from movements in market prices"* and is related to interest rate, FX and commodity risk. The last risk category, operational risk, is defined *"as the risk of loss due to inadequate or failed internal processes"*. BIS has championed that the risk categories should be seen as independent, making the total required capital equal to the sum of the required capital due to credit-, operational and market risk separately (Breuer et al., 2008).

[7]Liquidity and leverage ratio measures are beyond our scope. We refer interested readers to BCBS (2011).

[8]With the Rabobank issue as an exeption

[9]As many of the loans may be illiquid and non-tradable investments, the banks are to decide whether to implement the Standardized Approach, supported by external credit assessments, or the Internal Ratings-based Approach which needed approval from the bank's supervisor (BCBS, 2006).

The concept of the CT1 ratio as a solvency measure has maintained since the first BIS Accord in 1988. However, the definition of the different components, as well as the requirements, has had to evolve over the last decades due to increased complexity of the financial industry.

In particular, the Basel II accord was criticised in the aftermath of the financial crisis. One revealed flaw in the regulatory framework was that it awarded banks who securitised their credit holdings with a too low amount of risk weighted assets[10] (e.g. Cannata and Quagliariello, 2009) and in response BIS introduced a more conservative approach for the risk weights (Spiegeleer and Schoutens, 2011a). Amongst other, there has been an increased focus on over-the-counter (OTC) derivatives risk. The definition of Core Tier 1 capital has also tightened[11] and the required amount has been increased from 2 to 7 per cent. In addition, the required total capital has increased from 8 to 10.5 per cent (Spiegeleer and Schoutens, 2011a). For a more thorough discussion on the new requirements in Basel III, look to the Basel III Accord.

2.3 Conversion Properties

There are basically two forms of conversion; (1) a face value write-down, as in the Rabobank issue, or (2) conversion into shares, like in the other examples in Table 1. We focus on the latter, which is the most common structure to date, and is likely to remain so in the future. The reason why Rabobank opted use the face value haircut is largely because the bank is not publicly traded, making a share issuance unattractive to investors (Corcuera et al., 2011)[12].

The most important feature of equity conversion is the conversion ratio[13], or equivalently the conversion price. The CoCos could be converted at a *fixed share* or a *fixed dollar* level. Fixed share means that each bond at par value will convert to a fixed amount of shares – implying that the conversion price is set at issue. A fixed dollar conversion means that each bond will convert to a fixed dollar value of shares regardless of the market price – implying that the conversion price will be equal the price when it triggers.

The choice of conversion ratio has a big impact on the CoCo dynamics. If the

[10] By selling of loans to SPVs, and buying it back as structured products, banks received higher ratings on their credit holdings.

[11] One example is the deduction of goodwill and intangibles.

[12] Such a write down with cash recovery might be suboptimal because it gives the bank's management an incentive to increase the risk of the firm at the expense of CoCo investors as common equity is likely to accrue from the big write-down. The cash recovery may additionally decrease the liquidity of the bank.

[13] The number of shares received at conversion.

conversion price is equal to the price upon conversion, the CoCo investor will essentially not lose any value, getting shares worth the face value of the bond. Assuming the conversion will happen at a depressed share price the existing shareholders are diluted. If the conversion price is equal to the price on issue, on the other hand, a conversion to shares may give a substantial loss for the CoCo investors.

A third alternative, which as seen in Table 1 is the most common structure to date, is a fixed dollar conversion with a floor. This offers a compromise between the two extremes above, where the CoCo investor suffers a loss if the share price falls below the floor price. More importantly, it partly solves the death spiral problematics[14] voiced by academia (Flannery, 2010; Spiegeleer and Schoutens, 2011b).

All conversion prices have been used in practice: Lloyds opted for a fixed share conversion while Credit Suisse has used a fixed dollar conversion price with a floor. Consensus in the CoCo-debate regarding the best mechanism is yet to be reached and regulators have not given any indication so far (Spiegeleer and Schoutens, 2011a). Intuitively, we believe fixed dollar conversion is better, as it gives the issuing bank incentives to maintain the more conservative capital structure stricter regulations tries to accomplish.

2.4 The Credit Suisse Issue

The key details of the Credit Suisse CoCo of March 20th, 2012 are listed in Table 1: It has a fixed coupon of 7.125 per cent and converts if the CT1 ratio drops below 7 per cent at any calendar quarter, or if the financial regulator intervenes. The conversion price is defined as *"the higher of 30 days volume weighted average in the period preceding conversion or a floor price of CHF 20 per share"*[15] (Credit Suisse, 2012). It furthermore has the second lowest seniority, and a BBB- rating[16].

The new CHF 750 million 'Tier 2 Buffer Capital Notes' issue is designed to comply with the new Swiss TBTF regime, and adds to the one year old high-trigger issues; namely the agreement to put in place CHF 6 billion of "Tier 1 Buffer Capital Notes" with Qatar Holding LLC and The Olayan Group and the public USD 2 billion issue also in Table 1. In the three issues, Credit Suisse has

[14]Speculation that might lead to a downward spiral in both the CoCo and stock price.

[15]A 30-day average, together with a floor price, mitigates the death spiral risk (Spiegeleer and Schoutens, 2011b).

[16]The bond was rated by Fitch Ratings. S&P and Moody's have not rated any CoCo issues as of yet.

covered almost 90 per cent[17] of the high trigger contingent capital requirements in this new regime.

The Swiss TBTF proposal, approved by the Swiss Parliament September 2011, require large banks in Switzerland to hold loss absorbing capital up to 19 per cent of their RWA (Swiss Commission of Experts, 2010), consisting of at least 10 per cent common equity and up to 9 per cent contingent capital. The proposal of stricter capital requirements stems from the significant role the banking industry has in Switzerland, with the total assets of Credit Suisse and UBS adding up to a multiple of Swiss GDP (Zähres, 2011). Figure 1 compares the Basel II & III capital adequacy requirements with that of the new Swiss regime.

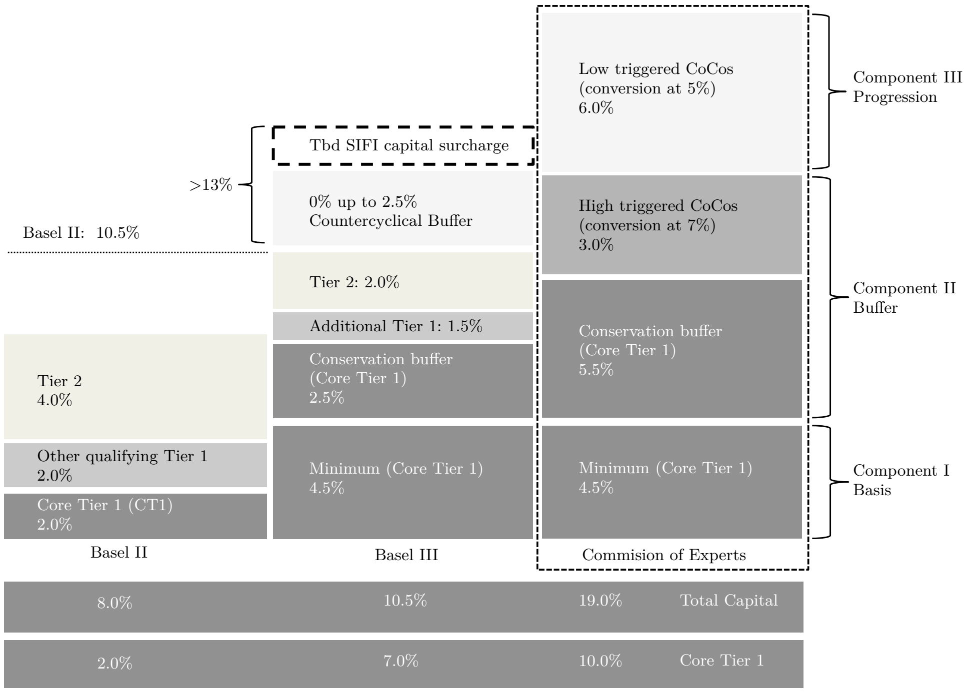


Figure 1: Capital requirements in Basel III and Swiss TBTF legislations

That the Swiss regulators require banks to have at least 10 per cent common equity, while the trigger level for *"high-triggered CoCos"* is set at 7 per cent, creates further regulatory uncertainty. The regulatory trigger is vaguely defined, demanding conversion when the authorities regard *"customary measures to im-*

[17]Estimated assuming USD/CHF=1.1, and using the estimated RWAs as of Basel III.

prove Credit Suisse's capital adequacy inadequate or unfeasible" (Credit Suisse, 2011). Adding this clause reduces the likelihood of default between each quarterly report by allowing the authorities to intervene. But it also adds much uncertainty to an already complex security, as its not clearly addressed how they will respond if the CT1 ratio is between the required 10 per cent and the conversion level of 7 per cent.

3 Proposed Models and Empirical Difficulties

The value of CoCos is largely dependent of two factors: (1) The Core Tier 1 ratio, the accounting metric determining if and when the conversion into shares will take place, and (2) the stock price, determining how many shares the CoCo investor receives upon conversion. This section will review some of the proposed models of pricing CoCos with accounting triggers and conversion to shares, focusing on the underlying assumptions of the movement of the CT1 ratio and the stock price. We will then make comparisons with empirical observations and assess their validity.

3.1 The Credit and Equity Derivative Approaches

Spiegeleer and Schoutens (2011a) present two "standard" approaches of pricing contingent convertibles: the credit derivative pricing model and the equity derivatives approach. The difference between the two is their respective roots in fixed income and equity derivatives mathematics.

The credit derivatives approach is based on the so-called reduced form method or *intensity based credit modelling*[18], where the default intensity and the recovery rate is calculated. In the case of CoCos this is the trigger intensity, λ_{Trigger}, and the recovery rate, R, upon conversion. The CoCo recovery rate is found by dividing the share price upon conversion, S^*, by the conversion price, C_p. The credit spread, cs, is then given by the rule of thumb in Equation 2 (Spiegeleer and Schoutens, 2011a).

$$cs = (1 - R)\lambda = \left(1 - \frac{S^*}{C_p}\right)\lambda_{\text{Trigger}} \tag{2}$$

When using this formula, R and λ_{Trigger} have to be estimated. The credit derivatives approach assumes that one can replace the accounting trigger with an equivalent stock price level, making this a straightforward exercise. S^* is then equal to the barrier level, and λ_{Trigger} is found by assuming a stochastic stock price and finding the probability of conversion, from which it is easily calculated[19]. By assuming that the stock price follows a geometric Brownian motion (GBM) and using the Black-Scholes framework, Spiegeleer and Schoutens (2011a) derive a closed form solution for the credit spread.

[18] The reduced form approach revolutionised credit derivatives pricing and is extensively covered in for example Duffie and Singleton (2003).

[19] $\lambda_{\text{Trigger}} = -\frac{\ln(1-p^*)}{\text{T}}$, where p^* is the probability of conversion in the life of the CoCo, T.

The equity derivatives approach derives from the risk-neutral valuation (martingale pricing) method often associated with options pricing. Under risk-neutral measure, assuming the bank cannot default before conversion, the price of a CoCo is given by Equation 3 where τ denotes the first time the trigger conditions are satisfied[20]. The first part of the equation is the value of the coupons with a spread λ and face value F. The second part is the final payoff at time $\tau = (0, \mathrm{T}]$, which will be the stock price, S_τ, multiplied by the conversion ratio, C_r, if conversion happens and F if not. The trigger will then determine τ, and the stock price S will determine the value upon conversion.

$$\begin{aligned} V_{CoCo} &= E^Q\left[\int_0^T e^{-rt} v(t)\right] \\ &= E^Q\left[\int_0^\tau e^{-rt}(r+\lambda)F dt + e^{-rt}(S_\tau C_r \text{ if } \tau \neq T, F \text{ if } \tau = T)\right] \end{aligned} \tag{3}$$

Under the equity derivatives approach, Spiegeleer and Schoutens (2011a) make the same simplifying assumption that the accounting trigger corresponds to a stock price level. They are then able to use the mathematics of regular equity derivatives with stock price barriers. The resulting formula for the CoCo price is given in Equation 4:

$$\text{CoCo} = \text{Corp. Bond} + \text{Knock-in Forward(s)} - \sum \text{Binary Down-in Options} \tag{4}$$

The logic is as follows: Start with the bond, add the value of the possible conversion, simplified as C_r *knock-in forwards* with the value $(S^* - C_p)$ at conversion[21], and subtract the lost coupons if the bond convert, which each has the value of a *binary down-in option*. A complete derivation and explanation of the approach is found in Spiegeleer and Schoutens (2011a), and an explanation and valuation of the different derivatives is found in e.g. Bouzoubaa and Osseiran (2010).

The closed form solutions of Spiegeleer and Schoutens' models have some theoretical flaws. The credit derivatives approach assumes that the stock price follows a GBM, which has been shown to poorly describe reality (e.g. Taylor, 2005), and the equity derivatives approach assumes an investor receives forwards and not shares on the trigger event. However, these assumptions can be removed by using more complex stock price processes and the Monte Carlo approach. The

[20] The formula is a generalised version of the one found in MacDonald (2010).

[21] Negative or zero as one will not get shares cheaper than the share price upon conversion.

crucial and simplifying assumption of these approaches is that the trigger contingency corresponds to a stock price barrier, making the price solely dependent on the stock price process.

3.2 Structural Approaches

The structural approaches analyse contingent capital in the context of structural credit risk models of individual banks using the Merton (1974, 1977) approach; determining the stock price and capital adequacy ratio from the resulting asset process. Intuitively, these structural models offer an improvement compared to the credit and equity derivative approaches, as they offer a more realistic trigger contingency. The pricing formulae itself is the same, with both the reduced form rule of thumb and risk-neutral valuation applicable. The difference lies in the trigger condition and assumptions.

The most prominent structural models are those of Pennacchi (2010) and Madan (2011) that are analysed in this sub-section. There are also other papers on CoCo pricing, such as Glasserman and Nouri (2010), Madan and Schoutens (2011) and Metzler and Reesor (2011), but the models used in these papers are essentially the same as those of Pennacchi and Madan.

3.2.1 The Pennacchi Model

Pennacchi (2010) studies a generic bank with assets funded by short-term deposits, contingent convertibles and common equity. The bank's assets are invested in loans, securities and off-balance sheet positions, and the rate of return of these assets is assumed to follow a mixed jump-diffusion process. The total change in the *market value* of the assets then equals their rate of return plus cash inflows less cash outflows. Pennacchi furthermore assumes no dividends or cash inflows, an assumption that can be easily removed[22], which makes the risk-neutral process followed by the bank's assets equal the risk-free rate less the payout to depositors and, as long as the CoCos are not converted, coupons to the CoCo investors.

The most senior claim, deposits, are assumed to have a short (instantaneous) maturity with interest paid continuously, meaning that the total quantity of deposits change *only* due to growth in new deposits (deposit inflows and outflows). This

[22] To include dividends and capital inflows one simply has to add these to the drift. For example in Lucas and MacDonald's credit risk model (2006) they assume continuous externally financed asset growth and dividends and add g_t, representing externally financed firm asset growth, and subtract $\delta\frac{E}{A}$, where δ is the dividend yield, to the drift term.

also simplifies the valuation of the contingent capital, as changes in bank capital or other liabilities will not shift value to or from depositors. Because empirical evidence shows that banks have target capital ratios with deposit growth during times of excess capital (Adrian and Shin, 2010), the model furthermore assumes that deposit growth is positively related to the banks current asset-to-deposit ratio. Equation 5 shows the resulting mean-reverting process followed by the deposits, with g being a positive constant representing the gradual adjustment of the asset-to-deposit ratio towards the target.

$$\frac{dD_t}{D_t} = g\left[\left(\frac{A}{D}\right)_t - \left(\frac{A}{D}\right)_{\text{Target}}\right] \tag{5}$$

As for the trigger condition, Pennacchi assumes the trigger threshold to be in terms of a fixed ratio of assets to deposits ($\bar{x} = \frac{A}{D}$), which can be converted to capital-to-asset ratios. The stochastic process for this trigger ratio is then found by combining the asset and deposit processes. This ratio and the equity value, which is the market value of the assets less the market value of the liabilities (deposits and contingent convertibles), can then be simulated using the Monte Carlo approach, and the value of the CoCo found by martingale pricing.

Although this ratio is more closely linked to the capital adequacy ratio trigger of current CoCos than the stock price, it has three distinct differences: First, and most importantly, it is defined in terms of *market values* and not accounting values. Second, it is defined in terms of *total assets* and not risk-weighted assets. Third, the model assumes that *conversion can happen at any time* and not just quarterly[23]. The fact that Pennacchi's model uses market values in the asset-to-deposit ratio, and additionally assumes no stochastic behaviour of the deposits, implies that the trigger ratio and the stock price will be *fully correlated* as they are both direct functions of the asset process.

In general, Pennacchi (2010) is most interested in studying how the contract terms affect valuation and the bank's risk taking incentives rather than the actual price, and computes model values for "benchmark" parameters of the asset and deposit processes. To find the real parameters of such a process one would have to use the Merton (1974) approach where equity is treated as an option on the spread of risky assets over liabilities with a strike determined by the face value of the debt less cash on hand.

[23]This assumption can be removed by introducing time steps.

3.2.2 The Madan Model

The model developed by Madan (2011) generalise the Merton approach by treating equity as an option on the *jointly modelled* spread of random assets over *random liabilities*. *Equity options* are then compound spread options and Madan employs the surface of all traded equity options to find the joint law of risky assets and risky liabilities. This is done by transforming the path space of assets and liabilities into a path space of equity from which equity option prices can be calculated and fitted to the observed option prices for strike K and maturity t.

To describe the stochastic evolution of the assets and liabilities, Madan uses a mixture of four independent Lévy processes[24]; two idiosyncratic, one compensating and one compounding – allowing idiosyncratic shocks to assets and liabilities as well as shocks that raise or reduce assets and raise liabilities simultaneously. Compared to the relatively simple Pennacchi model, this model is far more complex but probably more realistic. Instead of developing a process only for the assets and assuming the value of the deposits are changed only due to cash inflows and outflows (and is the only liability besides CoCos and equity), Madan models processes for the total value of the assets *and* the total value of all liabilities.

To find the risk-weighted assets, Madan simulate the assets and liabilities one year forward and define RWA as the losses on an unfavourable unwind of assets and liabilities. Using methods of conic finance that delivers bid and ask prices in two-price economies (Cherny and Madan, 2010), RWA is estimated as the level of the assets less the bid price of the assets plus the ask price of the liabilities less the liability value (Madan and Schoutens, 2011). The capital ratio is then determined endogenously as the ratio of equity values to these risk-weighted assets, and Madan thus have a joint stochastic process for the capital adequacy ratio and the stock price, similarly to Pennacchi.

This capital adequacy ratio also has some differences from the Basel ratios. First of all, the numerator is taken as the *market value* of the equity instead of the book value[25] like in the Pennacchi model, while as displayed in Figure 2 the relationship between the market value and the book value of equity for Credit Suisse is by no means one-to-one[26].

Moreover, the definition of RWA is not the same. Although it has similarities with the value-at-risk (VAR) approach that may be used to calculate the credit

[24] Lévy processes assume the price has lognormal distribution with a stochastic time interval between the observations, making the final distribution a mixture of lognormal distributions. We refer interested readers to for example Wu (2005).

[25] Or more precisely the (Core) Tier 1 Capital.

[26] This holds for all public companies, Credit Suisse is just used as an example.

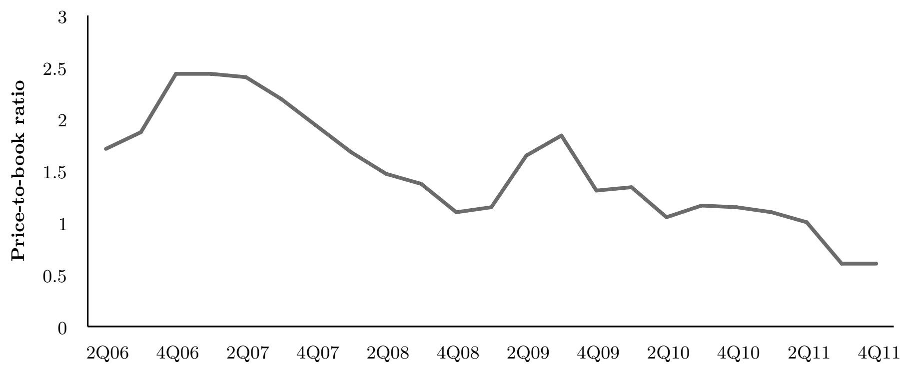


Figure 2: The development of the Price-to-book ratio for Credit Suisse over the last five years

risk of balance sheet assets, it is not very similar to the Basel definition and calculation procedures discussed in Section 2. We also question the validity of the conic finance theory, also developed by Madan, because it lacks widespread acceptance and is connected to the risk behaviour of the financial markets that has proved hard to quantify (Schleifer, 2000).

3.3 The Capital Adequacy Ratio and the Stock Price

The distinction between the equity and credit derivatives approaches and the two structural approaches lies in their assumptions about the trigger contingency. In general, they all develop a single stochastic process determining both the trigger and the stock price. None of the models are thus able to develop an accounting trigger as defined by Basel as they have to work with market values in order to provide the stock price from the same process(es). As Figure 2 indicates though, market measures and accounting measures are not very similar. The question is therefore not whether the trigger contingencies used are the same as the Core Tier 1 ratio, which they are obviously not, but whether they can be seen as representative proxies for the true trigger condition.

The simplest assumption is that the trigger contingency can be replaced by a share price barrier as in the equity and credit derivatives approaches of Spiegeleer and Schoutens (2011a). This implies that the share price will fall below this barrier (only) every time the capital adequacy ratio breaches the trigger. Intuitively this assumption is far-fetched, since the stock price is a function of the expected future earnings which incorporates more information than just bankruptcy risk.

Figure 3 shows the share price and the capital adequacy ratio[27] for Credit Suisse over the last 10 years, and Figure 4 shows the asset-size-weighted average of the share price and the ratio for a sample of 18 global, systematically important banks over the same period[28]. Both figures reject the stock price barrier assumption. The Credit Suisse data, for example, shows that a CoCo issued in 2003 or 2004 might trigger in Q4 2007 when the share price is nearly twice as high. The same CoCo based on a stock price barrier, on the other hand, would probably trigger in Q3-Q4 2008 when the capital adequacy ratio was at a record high. Figure 4 tells the same story, and suggests that there is no "generalizable" pattern between the accounting trigger and any stock price barrier.

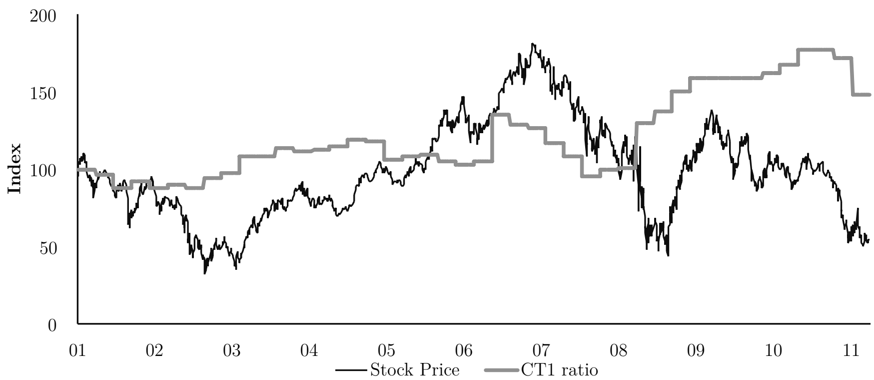


Figure 3: The Core Tier 1 ratio and the Stock Price of Credit Suisse re-based as of Q1 2001

The structural models offer an obvious improvement to the stock price barrier approaches, as their trigger condition take into account both the numerator *and* the denominator of the capital adequacy ratio. Building on the Merton (1974) model, such models assume a stochastic process for the market value of assets from which the accounting trigger proxy is defined.

The movement of this market measure and the book value of the assets should be comparable under GAAP[29] and IFRS[30] which is incorporated by most G-

[27]As the CT1 ratio is only available for the last couple of years, the Tier 1 ratio is used as a proxy for the trigger contingency. The Tier 1 ratio and the Core Tier 1 ratio are essentially equivalent, except for a stricter definition of regulatory capital. Testing with common equity to RWA, which is the closest one gets to the CT1 ratio, yields practically identical results in terms of relative changes.

[28]A full list of the banks included can be found in Appendix.

[29]Generally Accepted Accounting Principles

[30]International Financial Reporting Standards

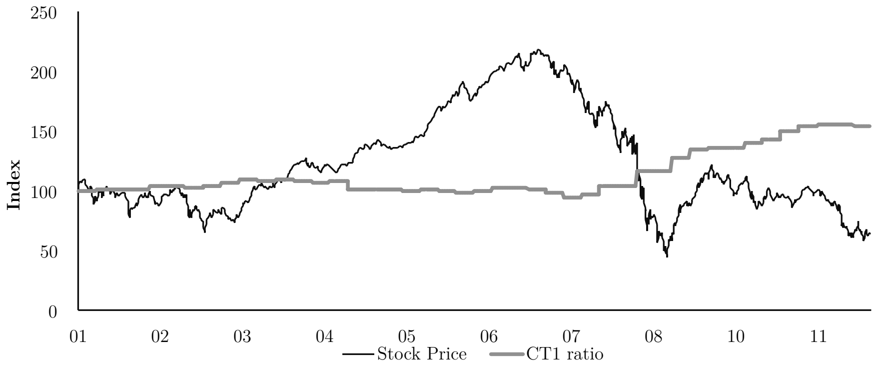
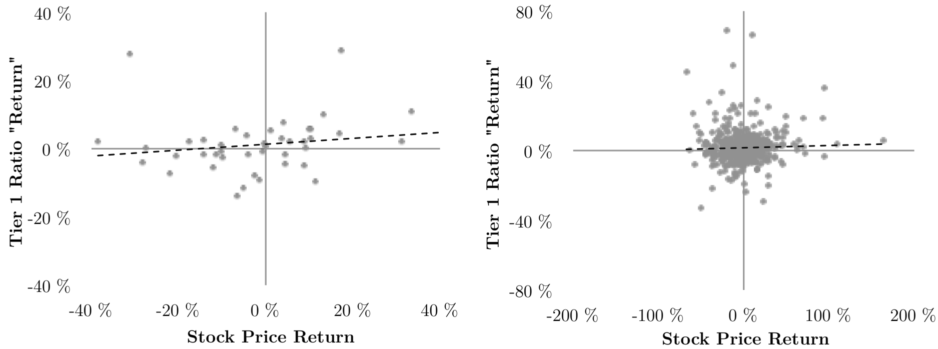


Figure 4: The asset-size weighted Core Tier 1 ratio and Stock Price of a sample of 18 G-SIBs re-based as of Q1 2001

SIBs. Here the book value is the price against which assets can be sold and debt bought back at the measurement date in an orderly way. Valuing assets in this fashion means that unrealised gains are recognised, impacting the book value of the shares in essentially the same way as in the market value (FASB, 2006). Also assuming that the movement of the “market-influenced” part of the share price and assets cancel each other in the ratio, the trigger contingencies of these models might behave similarly to accounting metrics.

In general, Merton-style structural approaches require a very high degree of correlation between the capital adequacy ratio and the stock price. In Pennachi’s model, as mentioned previously, both the stock price and the trigger contingency are direct functions of the stochastic asset process - implying that the two are fully correlated. Madan’s model, however, generalises the Merton approach such that both the assets and the liabilities are stochastic, reducing the implied correlation. In addition, the risk-weighted assets used in his trigger proxy incorporate more than the asset value.

The high degree of correlation between the capital adequacy ratio and the stock price in Pennacchi's model is not supported empirically. Figure 5 shows a scatter plot of the 'returns' of the capital adequacy ratio and the stock price for (a) Credit Suisse and (b) our G-SIB sample in the last decade. In both datasets the correlation between the 'return' of the ratio and the return of the stock is insignificant, with correlation coefficients of 0.182 (p-value = 0.244[31]) for Credit Suisse and 0.035 (p-value = 0.351) for the bank sample. Moreover, the correlation between the absolute level of the price and ratio is insignificant negative at -0.148 (p-value = 0.337) and -0.028 (p-value = 0.457), respectively. We only calculate the linear correlation, but it is evident from the scatter plots that a higher order of correlation would not yield significant results either.



(a) Credit Suisse (b) 18 G-SIBs

Figure 5: Scatter plots of the Tier 1 "return" and the quarterly stock return

The correlation between the stock price and the capital adequacy ratio has a big impact on the price of a CoCo. A higher correlation, in general, implies a lower price as the CoCo holders would receive less valuable shares upon a possible conversion. Pennacchi's model will therefore likely lead to underpricing of the CoCo.

Madan's model is more intricate and requires further scrutiny. The parameters in the model are not generic, and the correlation between the stock price and trigger contingency will differ from bank to bank. In testing his model, however, he tailors the parameters to the first public Credit Suisse issue – making us able to make interferences about how well his model describes the trigger contingency for Credit Suisse.

[31]The p-value is calculated from the Pearson statistic.

Madan uses his model to simulate paths for assets, liabilities, stock prices and quarterly capital adequacy ratios for Credit Suisse. After running 100,000 simulations, he regresses the logarithm of the capital adequacy ratio (CAR) with the logarithm of the stock price. The resulting simulation-based, average relationship between them is shown in Equation 6 for a standard normal variate z (Madan, 2011).

$$\mathrm{CAR} = 0.00053572 S^{1.5615} \exp\left(0.2943z - \frac{0.2943^2}{2}\right) \tag{6}$$

To see how well this relationship coheres with the historic movement of the BIS ratio, we use Equation 6 to calculate CAR from the historical stock price movements. Because the relationship involves a random component (z), CAR will not be fixed for a given stock price, and consequently we calculate the evolution of the trigger contingency in 5 separate runs. Figure 6 shows the resulting CARs and the actual Tier 1 ratio for the period.

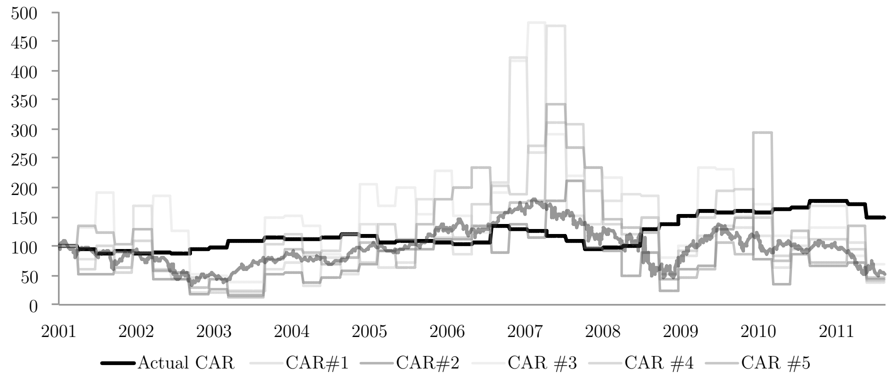


Figure 6: Madan's implicit CAR re-based as of Q1 2001

Madan's CAR proxy deviates heavily from the T1 ratio reported by Credit Suisse. First of all, it is way too volatile: Whereas the "returns" on the quarterly reported BIS ratio has a standard deviation of 8.17 per cent, the 5 sets have quarterly standard deviations ranging from around 50 to 70 per cent[32], dwarfing even the 17.1 per cent quarterly stock volatility. As expected, a Kolmogorov-Smirnov test rejects the hypothesis that any of the 5 sets come from the same distribution as the Tier 1 ratio at a <0.005 significance level.

[32] $\sigma_{\#1} = 48.15\%, \sigma_{\#2} = 73.63\%, \sigma_{\#3} = 59.07\%, \sigma_{\#4} = 59.31\%, \sigma_{\#5} = 65.75\%$

Figure 6 also includes Credit Suisse's stock price development. It is evident that, contrary to our empirical findings, the capital adequacy ratio in Madan's model tends to co-move with the stock price. This is particularly clear in the booming years leading up to the subprime mortgage crisis and during the crisis, and is a result of CAR being dependent on the stock price[33]. The correlation coefficients of the returns for all 5 sets are in the region of 0.5 and significant at a <0.005 level[34].

Summing up, the existing models imply too much co-movement between the stock price and the trigger contingency, a result of using market measures as the trigger. Historically the correlation between the two is insignificantly different from zero. The models will therefore trigger at occasions where the stock price is very low, and for floored triggers such as in the Credit Suisse CoCo, this means that the expected losses upon conversion will be too high. It further gives a wrong estimate for the probability of conversion, and in the Madan model in particular, this probability will be especially high.

[33] When regressing the ln(Tier 1 ratio) with ln(Stock price), we do not get a significant linear relationship.

[34] $\rho_{\#1,S} = 0.464$ (p-value $= 0.002$), $\rho_{\#2,S} = 0.592$ (p-value $= 0.000$), $\rho_{\#3,S} = 0.518$ (p-value $= 0.000$), $\rho_{\#4,S} = X$ (p-value $= X$), $\rho_{\#5,S} = 0.472$ (p-value $= 0.001$)

4 Pricing CoCos: An Empirical Approach

The price of a CoCo depends on the trigger contingency and the stock price[35], and all the reviewed CoCo pricing models tries to develop a more or less fundamental process linking the two. This is problematic because the trigger is an accounting measure while the stock price is not. As shown in the previous section, the existing models imply high correlation between the capital adequacy ratio and the stock price, not supported empirically. We therefore propose a different approach where the stock price and the Core Tier 1 ratio are modelled as *independent* processes.

This independence is in line with our findings of historically insignificant correlation. However, one aspect such a model does not capture is investor preference for banks with solid capital ratios during very bad times – yielding a positive relationship between ratio and stock price under extreme circumstances. CoCos are designed to trigger under these conditions, and this relationship might have an effect on its price. On the other hand, it can be argued that with high trigger CoCos, such as the Credit Suisse issue, the bond will convert into shares at ratios where the bank is still far away from being insolvent.

As seen in Section 2, the Core Tier 1 ratio is dependent on the core capital and the risk-weighted assets of the bank, where the RWAs incorporate more than balance sheet measures. To avoid basing our model on assumptions of the confounding relationships between market and book values and between assets and risk-weighted assets, we model the Core Tier 1 ratio *directly*. That is, rather than postulating to have a model with various independent variables describing the evolution of the ratio, we determine its process from the actual movement of the ratio in the past.

4.1 Data

In determining the processes for the stock price and the Core Tier 1 ratio, we will use the historic movement of the variables. A possible objection to relying on historic data for the CT1 ratio is that CoCos have been formed with the objective to conform to emerging bank regulation, and the regulatory capital requirements have increased during the sampling period. As such there has been a structural break and as a result the inference will be invalid. To accommodate this problem, we will use the historic data mainly to estimate the volatility of the process, while the drift is determined from stated targets.

[35] In addition to other fundamentals of bond pricing, such as the interest rate.

4.1.1 The Core Tier 1 Ratio

To calibrate the model for the CT1 ratio, we use data from a sample panel of global, systematically important banks (G-SIBs). This is mainly a consequence of lack of sufficient firm specific data. Capital adequacy ratios are only provided in recent years when the reporting standards have tightened, and only reported quarterly. For example, the Credit Suisse specific data is limited to just 48 data points starting in Q1 2000.

Using data from several banks generalise our model and make it compatible to most G-SIBs due their homogeneity. However, when the regulatory framework stabilises and enough data points become available, the model can be tailored to each bank. This will allow the model to pick up idiosyncrasies, making it more accurate and well suited for a wider range of banks.

The dataset has been constructed using numbers from quarterly statements and SEC filings. The panel consists of 18 of the world's largest banks[36], with similar characteristics regarding exposure and assets as Credit Suisse. Pure investment banks, such as Goldman Sachs and Morgan Stanley, have been excluded from the sample as their income comes from market-making and underwriting fees primarily, which in general have a much more cyclic and volatile nature than net interest income (Koller et al., 2010). Moreover, banks from countries such as France and China have been omitted since they report on a semi-annual basis, which would be insufficient for a quarterly trigger contingency.

We use a common equity ratio as the proxy for the Basel III CT1 ratio as banks do not provide this ratio prior to recent years. This is calculated as reported common (or shareholders) equity divided by RWA. This ratio offers the most attractive properties to calibrating our model because it is close to the CT1 ratio in definition, as well as being the subject of the capital adequacy requirements in Basel I & II[37]. The former property should provide a good measure of the expected volatility in the CT1 capital due to its junior lien, whilst the second property should pick up the banks' risk management control.

Observations where a bank has been bailed-out through an equity infusion are removed, as CoCos are designed to remedy such events. We furthermore focus our parameter calibration to data from the period 1Q01 to 4Q09. This removes the structural shift observed in 2010 after the proposed Basel III Accords that required banks to hold more of their RWAs as common equity than earlier Basel Accords, while still capturing the effect of the global financial crisis.

[36] See Appendix I for the list of banks used in our panel data.
[37] Banks were required to hold two per cent of RWA as common equity (Basel II).

4.1.2 The Stock Price

As we model the stock price process independent from the capital adequacy ratio, we are not restricted to the short time frame and low resolution associated with the Core Tier 1 ratio. This allows us to calibrate the model with firm specific data through daily quotes on the bank stock. For example, in pricing the Credit Suisse CoCo, our model is calibrated using daily data on the Credit Suisse stock (CSGN.VX) from April 1989 until the day prior to the CoCo issue.

4.2 The Model – Dynamics and Specifications

Through investigating the data, this section will propose models for the two processes. The pricing model used will also be explained. Of the two processes needed to determine the value of the CoCo, the one for the Core Tier 1 ratio is the less studied and will be studied in detail, while the stock price process is not emphasised.

4.2.1 Modelling the Core Tier 1 ratio

Banks are in large part able to control their capital adequacy ratios through retaining earnings, issuing stock and altering the composition of the asset portfolio. This control is exemplified by the steep rise in the Core Tier 1 ratio throughout 2008 and 2009, when the capital markets were tight and stock prices depressed.

Furthermore, it seems natural to assume that banks strive to maintain a target ratio which provides a sufficient cushion to absorb write downs, whilst allowing a competitive return on equity. To test this hypothesis, we regressed the change in the Tier 1 ratio[38] on the preceding ratio level less the average for the period. The analysis showed significant negative relationship, implying that a mean-reverting process is appropriate. This finding is in line with related empirical research, such as Adrian and Shin (2010) which find that banks' deposit growth expands when the banks have excess capital.

Figure 7 shows the distribution of the quarterly change in the CT1 ratio (dX), where the non-normality with excess kurtosis (11.1) and fat tails[39] is apparent.

[38] Tier 1 is chosen over Core Tier 1 as it was the foremost measure of capital adequacy in this period and therefore should be the most representative for the behaviour of the CT1 ratio in terms of risk management.

[39] The maximum observation was 4.9 times the standard deviation away from the mean, while the minimum was 6.8.

Using the Jarque-Bera (Bera and Jarque, 1981)[40] test-statistic we can reject the hypothesis that the underlying distribution is normal at the <0.005 significance level.

The peak in the distribution at negative three per cent, represents the losses of three per cent and more, and clearly shows the fat-tails of the distribution not captured by the normal density function. Capturing these large negative movements should be instrumental to attain contingency events. It is worth noting that the plot also shows signs of a positive trend in the dataset, in line with stronger regulatory demands on loss absorbing capacity. This trend makes the target ratio higher than the average for the period, but does not impede our data-analysis as it will be tailored to the analysed bank.

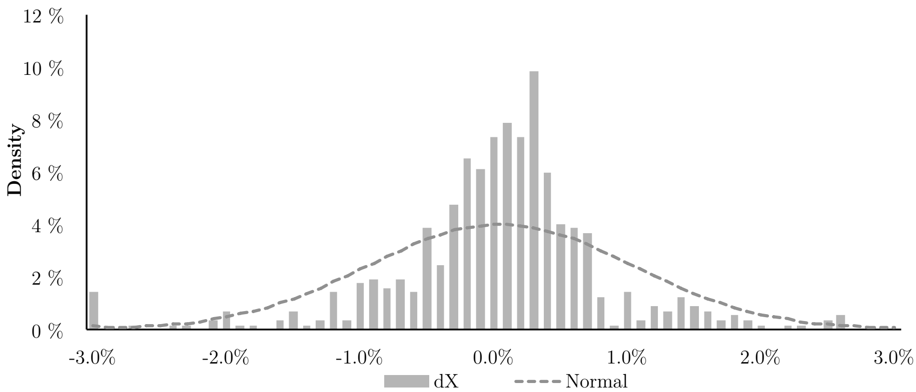


Figure 7: Distribution of changes in Tier 1 Capital Ratio

The movement of the capital adequacy ratio shows clear signs of mean-reversion and fat tails. To incorporate both these features in modelling the CT1 ratio, we use a Vasicek model with jumps (Vasicek, 1977). The change in the ratio, x, is then modelled expressed in Equation 7. We refer interested readers to Vasicek (1977), Brigo et al. (2007) or Weron and Misiorek (2008) for a further presentation of the theory behind the model.

$$\partial x(t) = \alpha[\theta - x(t)]\partial t + \sigma \partial W(t) + J(t) \tag{7}$$

Here α is the mean-reversion parameter, θ the target ratio, σ the volatility, and $W(t)$ a Wiener Process. J represents the jumps, creating the fat tailed distribution, and is defined as in Equation 8, where $N(t)$ is a Poisson process with

[40] For a further presentation of the test-statistic we refer interested readers to (Brooks, 2008).

intensity λ. Y_j are independent and identical distributed (i.i.d.) random variables.

$$
\begin{aligned}
J(t) &= \sum_{j=1}^{N(t)} Y_j \\
\partial J(j) &= Y_{N(t)} \partial N(t)
\end{aligned}
\tag{8}
$$

To simplify our calculations and to reduce computational effort we use the form proposed by amongst others Weron and Misiorek (2008) shown in Equation 9, where $\frac{\alpha}{\beta}$ is the mean-reverting level and β is the mean-reversion parameter.

$$
\partial x(t) = [\alpha - \beta x(t)]\partial t + \sigma \partial W(t) + J(t) \tag{9}
$$

In addition, by using the approach of Ball and Torous (1983) and assuming the possibility of two jumps within one period is negligible, we approximate the Poisson process with intensity λ by a binary probability $q = \lambda dt$ for a jump and $1 - q$ for no jump. The model will then be a mixture of Normal probability density functions.

To simplify, we assume the jump sizes to be normally distributed. This is naturally debatable as we do not test for other distributions, nor use existing literature to base our assumption. However, as the Normal distribution allows for both positive and negative jumps, it should provide a reasonable approximation of the underlying distribution.

4.2.2 Modelling the Stock Price

There are many theoretical processes used to describe and model the behaviour of a company's stock price. The seminal work of Merton, Black and Scholes, modelled the stock price using the Geometric Brownian motion in Equation 10, where $W(t)$ is a Wiener process.

$$
\partial S(t) = \mu S(t) \partial t + \sigma s(t) \partial W(t) \tag{10}
$$

Using Ito's lemma the stock price development can be modelled based on the PDE in Equation 11.

$$\partial(\log S(t)) = \left(\mu - \frac{1}{2}\sigma^2\right)\partial t + \sigma \partial W(t) \tag{11}$$

This model assumes that the stock price is log-normally distributed, i.e. the log returns are normally distributed. Figure 8 plots the log return distribution of the Credit Suisse stock price and the Normal distribution, indicating that this assumption is invalid.

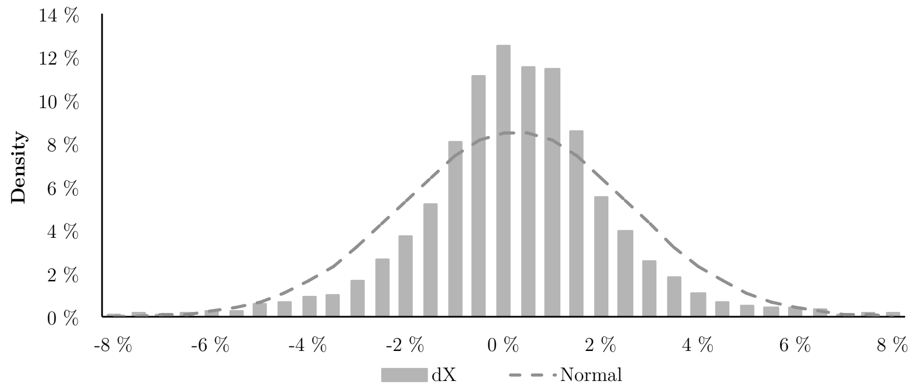


Figure 8: Log return of Credit Suisse stock price

The log returns has both excess kurtosis (8.50) and signs of fat tails[41], pointing to a leptokurtic distribution. Using the Jarque-Bera test-statistic we can reject the normality hypothesis as the test provides a p-value below 0.005. This leptokurtic distribution of stock returns is a well-known fact, and our finding is in line with recent research of stock returns (Taylor, 2005).

To capture the fat tails we incorporate jumps in our model, making the process a geometric Brownian motion with jumps (GBMJ)[42], as it allows the share price to experience large absolute daily returns (like in the fat-tailed distribution). The process for the price logarithm is then shown in Equation 12[43].

[41] The largest positive return was 10.6 times the standard deviation away from the mean, while the most negative return was 7.6.

[42] Possible alternatives to the jump diffusion are for instance ARCH models, which also produce a fat tailed distributions, but such models are designed to capture volatility clustering, and do not add any value to our analysis beyond what a jump diffusion model does. Moreover, sensitivity analysis is easier with the GBMJ-process.

[43] Such a model was championed by Merton (1976) to model the stock price.

$$\begin{aligned}\partial(\log S(t)) &= \left(\mu - \frac{1}{2}\sigma^2\right)\partial t + \sigma s(t)\partial W(t) + \log Y_{N(t)}\partial N(t) \\ &= \left(\mu + \lambda\mu_j - \frac{1}{2}\sigma^2\right)\partial t + \sigma s(t)\partial W(t) + [\log Y_{N(t)}\partial N(t) - \lambda\mu_j\partial t]\end{aligned} \tag{12}$$

$J(t)$ is the univariate jump process defined in Equation 13.

$$\begin{aligned}J(t) &= \sum_{j=1}^{N(t)}(Y_j - 1) \\ \partial J(j) &= (Y_{N(t)} - 1)\partial N(t)\end{aligned} \tag{13}$$

Again $N(t)$ is a Poisson process with intensity λ and Y_j are independent and identical distributed (i.i.d.) random variables.

A thorough empirical analysis on stock prices is beyond our scope. Stock price dynamics is extensively treated in many other books and articles. We refer interested readers to Tankov and Voltchkova (2009), Kou (2008) or Taylor (2005) for a further discussion on jump-diffusion models.

4.2.3 Valuation Model

Like in the equity derivatives approach and the Pennacchi article, we will use *martingale pricing* as it lends itself very well to the Monte Carlo simulations approach. It is also, given the same inputs, more precise than the reduced form rule of thumb. The price of the CoCo is then calculated according to Equation 14.

$$\begin{aligned}V_{CoCo} &= E^Q\left[\int_0^T e^{-rt}v(t)\right] \\ &= E^Q\left[\int_0^\tau e^{-rt}(r+\lambda)Fdt + e^{-rt}(S_\tau C_r \text{ if } \tau \neq T, F \text{ if } \tau = T)\right]\end{aligned} \tag{14}$$

This is the same formula as Equation 3 where its components are explained, and allows for a floating interest rate where λ is the given spread above the risk-free rate. When pricing fixed coupon CoCos, such as the Credit Suisse issue, $(r + \lambda)$ can be replaced by the fixed coupon c. The conversion ratio, C_r, for the floored Credit Suisse CoCo is defined as in Equation 15, where $\bar{S}$ is the average share price in the 30 days prior to τ, and S_{floor} is the floor price given in the bond contract.

$$C_r = \min\left(\frac{N}{\bar{S}}, \frac{N}{S_{floor}}\right) \tag{15}$$

The Core Tier 1 ratio, which will determine τ, can be simulated by the process in Equation 9, but since martingale pricing requires risk-neutral measures, the process for the share price has to be adjusted as in Equation 16. This is similar to Equation 12 except the for the drift term, where the expected return is replaced by the risk-free drift in the stock price, $r-q$, with q being the continuous dividend yield.

$$\partial(\log S(t)) = \left(r - q - \frac{1}{2}\sigma^2\right)\partial t + \sigma s(t)\partial W(t) + [\log Y_{N(y)}\partial N(t) - \lambda\mu_j\partial t] \tag{16}$$

The risk-free pricing model in Equation 14 discounts coupons at the risk free rate based on the assumption that a bank will not default prior to a contingency event. This seems reasonable, as the trigger is defined such that conversion will happen before the bank is insolvent. However, as the CoCo conversion is reliant on quarterly accounting numbers, there might be instances where a bank defaults prior to a contingency event. In Kuritzkes and Scott (2009) it is argued that the large US banks that either failed, or had to be rescued by the government, were reporting capital ratios far above the minimum requirement of 8 per cent in its last quarterly reports before insolvency. However, with the increased scrutiny on what is to be judged as loss absorbing capital in the Basel III accord, such events will be very unlikely[44].

Moreover, when the trigger happens above the floor price, the investor is not facing a loss in this model, but in reality one might expect a possible negative share price impact immediately after the CoCo gets triggered (Spiegeleer and Schoutens, 2011a). There are three main reasons why such a shock is likely: First, and most importantly, the earnings statement obviously contain negative news about the company, such as big asset write-downs, that might not be fully incorporated in the markets' expectations. Second, the risk is reduced and value

[44] In the Credit Suisse issue the possibility of regulatory intervention should render the possibility of default between earnings releases as negligible.

transferred to the more senior capital holders. Third, big institutional CoCo investors, such as pension funds, might not be interested or eligible to hold equity capital in the bank leading to a big block of shares for sale.

5 Pricing the Credit Suisse Issue

Using the data from the sample of G-SIBs for the Core Tier 1 ratio, and the Credit Suisse specific data for the stock price, this section presents parameters estimates for the two processes and the price of the CoCo.

5.1 Evolution of the CT1 Ratio

To estimate the parameters of the mean-reverting jump-diffusion process (MRJD) of the CT1 ratio, we apply the maximum likelihood estimation (MLE) technique. The result of our estimation is given in Table 2[45], implying a mean-reverting level of 15.8 per cent. This is higher than the actual level in the period due to the slight positive trend in our dataset. As mentioned previously, this does not impede our analysis because this figure will be adjusted according to Credit Suisse's stated risk management strategy.

	α	β	σ	μ_j	σ_j	λ
Base case	0.0015	0.0095	0.0065	-0.0085	0.0334	0.0189

Table 2: MRJD-parameters

Figure 9 shows the density function obtained from simulating the above MRJD-process over 10,000 years. When compared to the normal distribution it is clearly the better fit. The MRJD-process captures both the large peak around zero and the fat tails, producing an excess kurtosis of 15.8. The peak in both the distribution and the MRJD simulation at negative three per cent, represents the losses of three per cent and more.

The distribution is not a perfect fit due to relatively few observations. To assign a measure of accuracy to our parameter estimates, we use the *bootstrap method*, allowing us to estimate the sample distribution of the MRJD-parameters. This was done by drawing several samples of 400[46] successive ratio-values from the data set and estimating their parameters through MLE. The values need to be successive because the process is mean-reverting; hence the values are not independent and identically distributed random variables (i.i.d.)[47].

[45] For quarterly data and simulations.

[46] The number 400 offers an attractive trade-off between number of sets and observations per set.

[47] Drawing completely random numbers would in such a way fail to capture the mean-reverting property of the process.

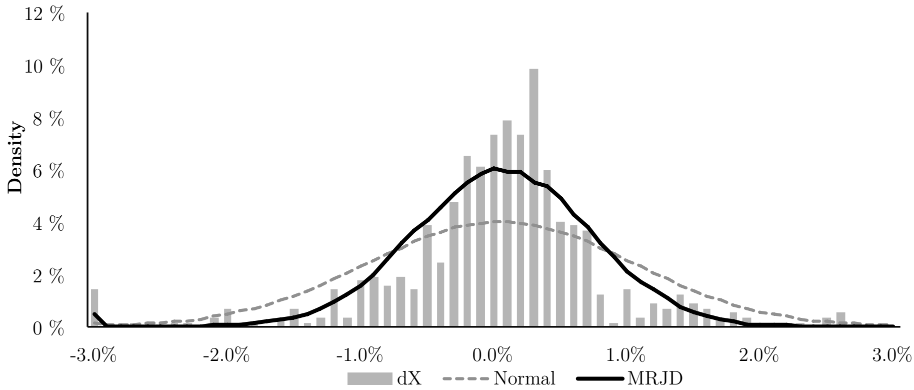


Figure 9: Simulated density function of MRJD-process compared with normal distribution

The variation among the MRJD-process parameters for 100 subsets, each spanning 400 successive ratio-values, is illustrated with a box plot in Figure 10[48].

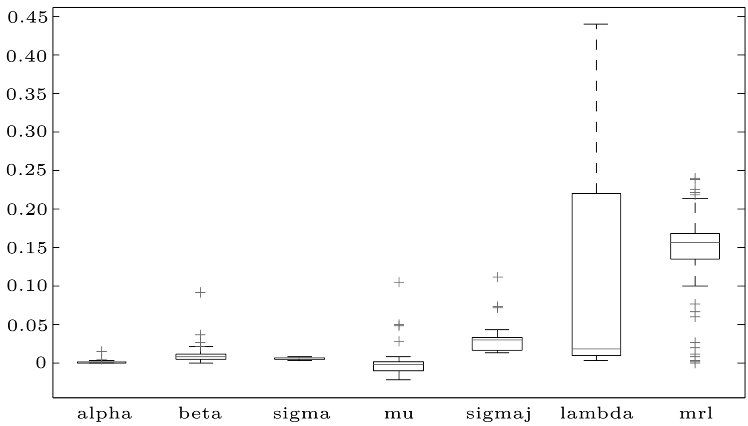


Figure 10: Variation in MRJD-parameters over 100 subsets

The large variations in the parameters could have big implications on the CoCo price as they all influence the trigger probability and the maturity. However,

[48] Because the mean-reverting level explodes when beta approaches zero, sets where the mean-reverting level was calculated to be greater than 50 percent (3 in total) have been removed from the plot.

no single parameter determine the shape of the MRJD density function alone and different parameter combinations can represent the same density function. For example, low convergence power (β) can be compensated by lower variation in the jumps (σ_j) to yield a density function similar to a combination of high convergence power and higher jump variation.

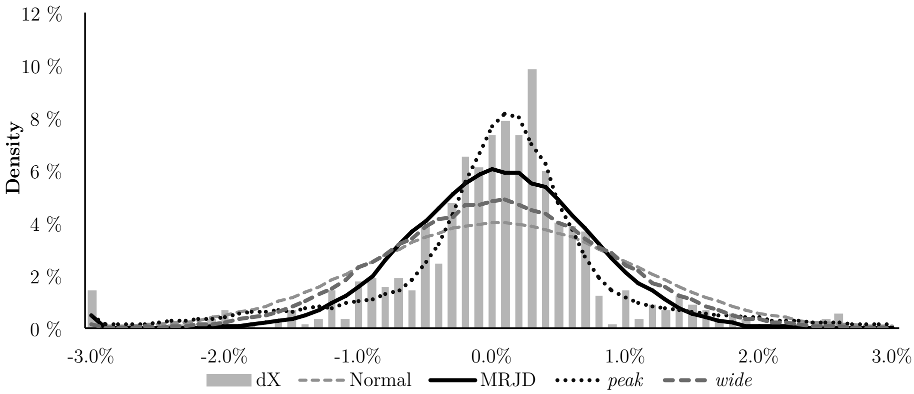


Figure 11: Comparison of simulated density functions for extreme bootstrapping cases

In Figure 11 the two subset density functions deviating most from the complete set function, *wide* and *peak*, are added. The MRJD-parameters for each of the subsets are displayed in Table 3. For the subset density function with the lowest peak (*wide*), the converging power (β) is high while the jumps fluctuate much in size (σ_j) but arrive with a low intensity (λ). This is vice versa for the subset with the highest peak (*peak*). Accordingly, even largely deviating MRJD-parameters can produce density functions that represent the historic data better than the Normal distribution.

	α	β	σ	μ_j	σ_j	λ	Excess kurtosis
Base case	0.0015	0.0095	0.0065	-0.0085	0.0334	0.0189	15.8
Peak	0.0018	0.0080	0.0033	-0.0019	0.0127	0.4245	65.7
Wide	0.0015	0.0104	0.0074	-0.0123	0.0350	0.0087	2.9

Table 3: MRJD-parameters of extreme bootstrapping cases

5.2 Evolution of the Stock Price

To estimate the parameters of the geometric Brownian motion with jumps (GBMJ) process used for modelling the stock price, we again use the maximum likelihood technique. The input dates for the stock price return ends on March 20th 2012, the start of the subscription period, to not base our model on ex post data. The result of our estimation is showed in Table 4.

	μ^{*49}	σ_{bm}	λ_p	μ_y	σ_y
Base case	0.0009	0.0145	0.2026	0.0047	0.0424

Table 4: GBMJ-parameters

As illustrated in Figure 12, our stock price process provides a realistic description of the stock price development, and offers a great improvement to the GBM process. When simulating 50,000 daily returns the model produces a distribution with an excess kurtosis of 5.95, much closer to the excess kurtosis of 8.5 of the inputs. As our stock price process provides a seemingly good fit and is well studied elsewhere, we will not study its sensitivity to the historic data as with the CT1 ratio.

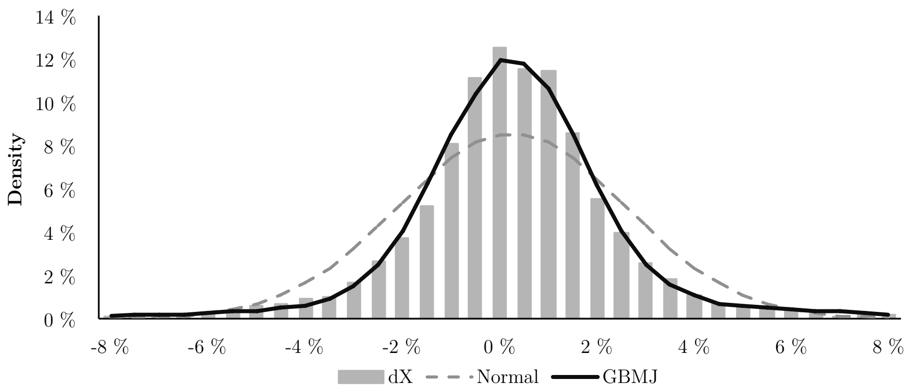


Figure 12: Simulated density function for GBMJ-process compared with the Normal distribution

[49] $\mu^* = \mu + \lambda\mu_j - \frac{1}{2}\sigma^2$

5.3 Pricing the CoCo

The Buffer Capital Notes issued by Credit Suisse in March 2012 has a 7.125 per cent coupon paid annually. It has a 10 year maturity, but is callable at each coupon payment beginning 22nd March 2017, that is after 5 years. Tier 1 & 2 capital is conventionally "always" called on the first call date[50] and priced thereafter (Murphy, 2008). For Credit Suisse, the coupon from the first optional redemption date and onwards is set to the preceding 5-year Swiss Mid-Market Swap rate plus 6.685 per cent. This premium is well above the 5.5 per cent at issue and demonstrates the incentive Credit Suisse should have to redeem the bond. As a consequence, we price the CoCo as if it is called on the first redemption date.

The starting value for Credit Suisse's capital adequacy ratio is set equal to the Basel III CT1 ratio[51] in the last quarter of 2011, as the first quarter 2012 earnings report was yet to be published. The input for the ratio, given in the Information Memorandum of the CoCo issue, is then approximately 9.0 per cent. As for the target ratio, we use their stated target, given a planned reduction in risk-weighted assets, of 12.9 per cent (Credit Suisse, 2012). To achieve this mean-reverting level (*mrl*) while preserving the conversion power, we change alpha and hold beta constant.

	α	β	σ	μ_j	σ_j	λ	mrl
Base case	0.00150	0.0095	0.0065	-0.0085	0.0334	0.0189	15.79 %
Adjusted	**0.00123**	0.0095	0.0065	-0.0085	0.0334	0.0189	**12.9** %

Table 5: Base case adjusted to incorporate correct mean-reverting level

There are two additional inputs needed in to price the CoCo: (1) The dividend yield, needed to estimate the risk-neutral drift of the stock price, and (2) the risk-free rate of return. Here we assume a constant risk free rate in order to focus on the separating characteristics of the CoCo[52]. A framework adding stochastic interest rates, such as Ho and Lee (1986), could easily be included.

Using the yield on government bonds in the currency the CoCo is denominated is the theoretically correct choice for the risk free rate, as it is both default-free and consistent with the cash flows being discounted (Damodaran, 2008). However, theory does not work well in the Swiss case. Swiss government bonds

[50]With the notable exception of Deutsche Bank in 2008.

[51]The trigger condition is in terms of the so-called Basel 2.5 CT1-ratio until January 2013, when Basel 3 becomes effective. We exclude this complication from our analysis.

[52]The preferred bond pricing model might vary and thus the set-up is meant to allow for variation according to user preferences and context.

have long been regarded a *safe haven* where pessimistic investors put their money in turbulent markets. As Switzerland is a relatively small economy, this puts a lot of pressure on these securities, exemplified by the current negative short term yield on Swiss Treasury securities.

Theoretically, a lower inflation (or deflation) should adjust for this, making the real return the same. However, in Switzerland this has historically not been the case (Kugler and Weder, 2005), and is definitely not the case now. The Swiss National Bank has recently tried to make its currency less attractive by creating an artificial minimum floor to the Euro, which essentially does not allow the Swiss Franc to appreciate against the Euro. This should imply that Euro-denominated risk-free securities, such as the German government bonds, should have a yield at least as low as the Swiss government bond. This is however not the case at all, with the yield of all other "safe" government bonds being more than twice as high. We therefore, as it bears no inflation risk to CHF, use the yield on 5-year AAA-rated Government Bonds in the Euro zone at 1.522 per cent (March 20th 2012, Reuters EcoWin) as our proxy for the risk-free rate. This should be less influenced by the flight to quality issue and more in line with investors' expected return on risk-free assets.

The dividend yield will be zero in our valuation model although Credit Suisse pays dividends. This is a result of a provision in the Buffer Capital Notes that adjusts the floor price, S_{floor}, accordingly with the dividend payments[53] thereby removing its impact on the CoCo price. This simplifies calculation and makes output more accurate because we do not have to make assumptions about or estimate the relationship between the dividend yield, the CT1 ratio and the stock price.

The starting value for the stock price is CHF 26.8 (March 20th 2012, Reuters EcoWin). When running 100,000 simulations we obtain a fair price of 114.9, shown in Table 6. This compares with the issuing price of 101 (Credit Suisse, 2012). The table also shows the relatively high probability of conversion of a little less than 40 per cent and the average maturity of 1000 days.

	Price	Maturity	Trigger
Base case	114.90	998.9 days	39.2 %

Table 6: Base case

[53] $S_{floor,new} = S_{floor,old} - \text{div}$

6 Discussion and Sensitivity Analysis

The market price of the new Credit Suisse CoCo closed at 101.35 at the end of the subscription period, close to the issuing price of 101. Our pricing model therefore points to significant underpricing of the new Credit Suisse CoCo.

The fact that we get a fair value well above the market price indicates that our model has lower trigger probability and/or lower anticipated loss upon conversion than expected by the market. The price discrepancy might also be explained by some of our other inputs, such as the fixed, historically low interest rate, inflating the price.

This section starts with a discussion of the results we get from using the models reviewed in Section 3 to calculate the price of the new Credit Suisse issue. Next, we relax some of our model's assumptions and investigate how this impacts the price. The new results will be compared with the observed market price. Finally, we discuss which assumptions that are likely incorporated in the market price, and whether the CoCo seems fairly priced.

6.1 What do Other Models Imply?

Comparing our results with those of other approaches is challenging. The equity and credit derivatives approaches, for example, do not provide any indication of what the stock price barrier should be and only provide the implied barrier from the market price of the CoCo. Madan's model, on the other hand, is complex with opaque methodology. Lastly, Pennacchi's structural model only calculates the CoCo price of a hypothetical bank with what Pennacchi calls benchmark parameters. This model is thus not applicable for pricing actual CoCo issues[54] and will not be discussed further.

6.1.1 The Credit and Equity Derivatives Approaches

Spiegeleer and Schoutens' stock price barrier approaches are evaluated first. To get a price equal to the market price, the implied stock price barrier has to be below the floor price. If not, there is no loss for the CoCo investors[55], and the fair yield is equal to the risk-free rate.

[54]It is developed mainly to explore the different dynamics between banks with and without contingent capital. G-SIBs, such as Credit Suisse, are much more complex than his hypothetical bank.

[55]All the models assume the bank cannot default prior to a trigger event.

As discussed in Section 3, the assumption of a stock price barrier is simplistic, and by using the historic average volatility of approximately 38 per cent there are in fact no implied stock price barrier. This volatility estimate gives a maximum spread of 2.85 per cent at a barrier level of CHF 13.1, well below the market spread of approximately 5.6 per cent[56]. There are indeed no solutions for share price volatility below 60 per cent for such a large spread. Moreover, a stock price barrier at CHF 13 seems unlikely as the stock price of Credit Suisse has never been close to these levels (Reuters EcoWin).

This implies that, given reasonable inputs, the credit and equity derivatives approaches will lead to a price well above the market price. This is a result of the one-to-one relationship between the stock price and the trigger contingency, making them highly dependent on the starting value for the stock price and the barrier level. If the stock price barrier is set too low, conversion will happen very rarely unless the starting price is close to the barrier, whereas if it is set too high, conversion will give too small losses to the CoCo investors.

This serves to illustrate an interesting aspect: Intuitively, one might think an increasing correlation between the CT1 ratio and the stock price always decreases the price of the CoCo, as it makes the stock price more likely to be below the floor upon conversion. However, a too large fixed correlation[57] actually *increases the CoCo price when the initial stock price is high* as conversion becomes less likely.

6.1.2 Madan's Structural Approach

While the equity and credit derivatives approaches suffer from their simplistic assumptions and severely inflate the price, Madan's intricate structural model might boast more accuracy. The methodology and inputs in this model is however not very transparent and hard to reproduce. Fortunately, the specific issue studied is the public Credit Suisse CoCo of February 2011 and all the formulas are tailored to Credit Suisse's asset and liability dynamics, enabling us to approximate the price of the new issue.

$$\mathrm{CAR} = 0.00053572 S^{1.5615} \exp\left(0.2943z - \frac{0.2943^2}{2}\right) \tag{17}$$

Madan's simulations-based, average relationship between the stock price and the capital adequacy ratio for Credit Suisse is restated in Equation 17[58]. The formula

[56]Market spread $\approx$ Coupon − risk-free rate = 7.125% − 1.522% $\approx$ 5.6%
[57]As assumed in the equity and derivatives approaches.
[58]This is calculated using the options surface on March 29th, 2011.

cannot be utilised directly, as it is designed for the USD 2bn Credit Suisse issue in February 2011, where the starting value for the stock price and CT1 ratio was very different from what they are today[59]. However, by assuming the dynamics to be the same we can approximate the CAR process as a function of S by using Equation 18. Using this relationship and simulating the stock price process as in our model, we are able to ballpark the price implied by the model.

$$\begin{aligned} \mathrm{CAR}_{i+1} &= \mathrm{CAR}_i + d\mathrm{CAR}_{i,i+1} \\ d\mathrm{CAR}_{i,i+1} &= 0.00083653 S^{0.5615} \exp\left(0.2943z - \frac{0.2943^2}{2}\right) dS_{i,i+1} \end{aligned} \tag{18}$$

Running 100,000 simulations we obtain the price given in Table 7; well below the market price. The low price is not only a result of the high trigger probability of 84.4 per cent, but also the correlation between the trigger contingency and the stock price that makes conversion below the floor more likely.

	Price	Maturity	Trigger
Madan	95.22	340.8 days	84.4 %

Table 7: Madan's model

The very high probability of conversion seems unlikely, and is a consequence of the fact that Madan's model does not incorporate the stated targets Credit Suisse has for their CT1 ratio, but rather assumes it to be a random stochastic process in line with the stock price. As seen in Section 3[60], this makes the capital adequacy ratio highly volatile, being a direct function of the stock price with an annual standard deviation of 38 per cent and a random normal variate z. Moreover, as the stock price has a positive drift, the capital adequacy ratio will have the same, and the probability of conversion will be higher in the first period of the CoCos life, making the average maturity less than 350 days.

Although the Madan's model looks attractive at first sight, and closer to the market price than our base case, the lower price is a result of questionable assumptions. To explain the discrepancy between the market price and our model, we instead turn to our assumptions, and include properties that are likely incorporated by the market.

[59] The stock price was approximately CHF 40. The Basel III CT1 ratio was not yet used.

[60] In section 3 we find the volatility of Madan's CAR to be in the order of 50-70%, compared with the historic volatility less than 10%.

6.2 Sensitivity Analysis

How well our model describes the dynamics of the stock price and the Core Tier 1 ratio depends on how representative the historic data used in the calibration is of the future. For instance, the probability of conversion could be higher now than the average of the last ten years as a result of the turbulent European markets. Further, it may be that the CT1 ratio of the bank sample used to estimate the process parameters in general is less volatile than that of Credit Suisse, for example due to a survivorship bias[61].

A lower recovery rate, on the other hand, may be because of an assumed correlation between the CT1 ratio and the stock price, historically proved insignificant, making the stock price more likely to be below the barrier than when they are uncorrelated. It can also be caused by share price shocks at the day of conversion, or simply because the stock price is more volatile than the historic average.

This sub-section will take a closer look at how such deviations from the initial assumptions impact the price in our model. Performing a sensitivity analysis will furthermore explore the dynamics of our model and pin-point which assumptions that require most attention.

6.2.1 Parameter Instability in the CT1 Ratio Process

First, we analyse the impact of the parameter instability in our CT1 ratio process calibration[62] explored in Section 5. To assess this uncertainty, we calculate the price with the MRJD-parameters from the two extreme cases in the bootstrap analysis; *wide* and *peak*. Table 8 shows the parameters for the process with alpha adjusted to the mean-reverting level (*mrl*).

	α	β	σ	μ_j	σ_j	λ	*mrl*
Base case	**0.00123**	0.0095	0.0065	-0.0085	0.0334	0.0189	12.9 %
Peak	**0.00104**	0.0080	0.0033	-0.0019	0.0127	0.4245	12.9 %
Wide	**0.00135**	0.0104	0.0074	-0.0123	0.0350	0.1430	12.9 %

Table 8: MRJD-parameters with adjusted mean-reverting level

[61] The banks that went bankrupt during the last crisis are all investment banks not included in our sample.

[62] We do not deal with the fact that our dataset is from a limited time period but rather evaluates the impact of variations within our dataset on the price.

Table 9 shows the variation in the price of the CoCo when using the different parameters, underlining the importance of the CT1 ratio process. With the *peak* parameters the possibility of triggering increases by roughly 20 percentage points from the base case, lowering the price substantially. The *wide* parameters have far less impact, but they too increase the trigger probability and lower the price.

	Price	Maturity	Trigger
Base case	114.90	998.9 days	39.2 %
Peak	109.49	833.8 days	58.9 %
Wide	114.64	978.7 days	40.1 %

Table 9: Price with extreme MRJD-parameters

The fact that both parameter sets produce lower average maturity and higher possibility of triggering can be explained by studying their density functions in Figure 11 in Section 5. While one set has lower (*wide*) and the other higher (*peak*) kurtosis than the base case, they both have a higher possibility of movements in the -1.5 to -2.0 per cent region. This increases number of relatively large negative jumps, causing the CoCo to trigger more often.

Of the 100 sets in the bootstrapping analysis, these are the two opposite outer points. The decrease in the price resulting from using the peak process is therefore among the largest that can arise from the uncertainty in our dataset. Intuitively, we believe a trigger probability of close to 60 per cent is too high and probably not assumed by the market. The reason for the price discrepancy is therefore more likely a result of some of our assumptions, such as the fixed interest rate.

6.2.2 Interest Rate Sensitivity

It is always a question of what the proxy for the risk-free rate should be, and is particularly so for Swiss securities. For the reasons discussed in Section 5, we use the yield on 5-year AAA-rated European government bonds.

Regardless of what rate we use, using a fixed rate does not incorporate the expected changes in the spot rate. The main rationale behind this simplification is to focus on the separating characteristics of CoCos and allow for variation according to user preferences. However, due to the long average maturity, the choice of interest rate will probably have a big effect on the price of CoCos, and considerations are warranted.

Figure 13 presents the historic yield on 5-year AAA-rated Euro Zone government bonds, demonstrating that the current yield is at a historically low level.

The British government yield is included to show the even clearer trend in the longer term[63]. The European Central Bank has forecasted the annual inflation rate in Europe over the next five years to be 2 per cent (ECB Inflation forecast, 2012). This implies that the 1.5 per cent risk-free rate will yield a negative real return for the investors. The current return on high quality Euro denominated bonds is therefore not sustainable in the longer term, and is a result of concerned investors' *flight-to-quality* like in Switzerland (Gerich, 2012), albeit to a lesser degree. Consequently, most bond pricing models used by investors are likely to have higher implied risk free rate when pricing the issue.

Figure 13: The yield on 5 Year AAA-rated Euro-Zone Government bonds and U.K Government bonds

Table 10 shows that the price of the CoCo is highly dependent on the input used as the risk-free rate. As the spread between the coupon yield and the risk-free rate is the main contributor to changes in straight bond prices, this implies that the fixed income property of the CoCo is very important for its price. This is in close coherence with the average maturity of the CoCo in the model being approximately four fifths of that of a bond without conversion properties.

r_f	.5 %	1 %	1.522 %	2 %	3 %	4 %
Price	119.08	117.15	114.90	113.09	109.30	105.68

Table 10: Price when varying the risk-free rate

The market price of 101.35 implies a risk-free yield above 4 per cent. Although the risk-free rate in our base case may be a bit low, this seems unreasonably high,

[63]This holds just as well for Swiss or American risk-free securities.

being higher than the average yield on straight 5 year BBB rated bonds of 3.31 per cent[64]. Accordingly, the input used for the risk-free rate can by itself not explain the difference between the fair value estimate from the model and the market price.

6.2.3 Market Uncertainty – Implied volatility

The current 5-year yield is not the most accurate proxy risk-free rate, and in the real world, an investor uses bond pricing models which incorporate the expectations of the future. Using forward looking measures should also lead to an improved forecast for the stock price development. This could be done by using the traded options surface[65] and risk-neutral pricing to estimate the parameters of the stock price distribution[66]. A thorough discussion of the methodology is found in Taylor (2005), where it is also shown that it improves the volatility forecast compared with the use of historical data.

Figure 14 shows the implied volatilities of the Credit Suisse stock (CSGN.VX) obtained by utilising the Black-Scholes framework on the call option prices at three different maturities. As implied volatility is a measure of the average volatility over the option's life, the call with maturity closest to that of our bond gives most information of the stock price movement during the life of the bond.

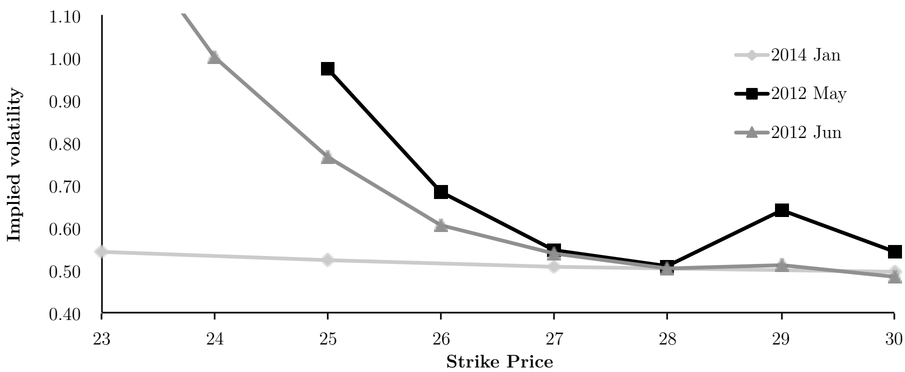


Figure 14: Option surface collected March 20th 2012

[64] The yield on the Euro zone corporate benchmark index for BBB-rated bonds with 5 year maturity on March 20th, 2012 (Source: Reuters EcoWin).

[65] The price of options at different maturities and strike prices.

[66] This approach is taken in Madan's article to calibrate the processes for the assets and liabilities.

As seen in Figure 14, the implied volatility from calls maturing in January 2014, which has the longest maturity of traded options and closest to the maturity of the bond, is relatively constant. This suggests that using the complete set of strike prices to infer the complete distribution will give a relatively small amount of new information (Taylor, 2005). We therefore take a simpler approach, where we exchange the diffusion volatility calibrated to historic data with the corresponding volatility implied by the options price[67].

We furthermore use the implied volatility of the option with strike closest to the current stock price as proposed by Taylor (2005). This volatility estimate is above 50 per cent on an annual basis, well above the historic average around 38 per cent, underlining the uncertainty in the current European economic climate. The new parameters are shown in Table 11, with the changed diffusion volatility parameter emphasised.

	μ^*	σ_{bm}	λ_p	μ_y	σ_y
Base case	0.0009	0.0145	0.2026	0.0047	0.0424
Implied volatility	0.0009	**0.0283**	0.2026	0.0047	0.0424

Table 11: MRJD-parameters for implied volatility

Using implied volatility reduces the price of the CoCo, as shown in Table 12. By increasing the volatility of the stock, the likelihood of conversion below the floor price increases and reduces the expected recovery. Opposite to the holder of a call option, which gets the upside of larger price fluctuations in the underlying, the CoCo holder sees only the downside of increased volatility in the stock price.

	Price	Maturity	Trigger
Base case	114.90	998.9 days	39.2 %
Implied volatility	109.83	998.9 days	39.2 %

Table 12: Price when using implied volatility

The use of implied volatility lowers the price of the bond towards the market price, and this information is likely incorporated by CoCo investors. However, it is not able to explain the full price discrepancy between our model and the market.

[67]The variance of the GBMJ process is $(\sigma^2 + \lambda\sigma_j^2)$, where the last term is the added volatility from jumps. To use the Black and Scholes implied volatility, we change only the diffusion term. The variance of the new diffusion term is then equal to the implied variance less the unchanged variance stemming from the jumps.

6.2.4 Incorporating Share Price Shocks

Like the stock price distribution, the expected stock price behaviour upon the conversion announcement has an impact on the CoCo price. Incorporating this should consequently, like using forward-looking expectations of the distribution, improve our pricing model.

In our valuation of the bond, we assume that the share price will not react when the quarterly report is released and conversion is a fact. However, as discussed in Section 5, a drop in the share price is likely due to the information content in the quarterly report, the value transfer to senior bondholders and the likelihood of sales pressure on the stock arising from fixed income investors who wish to liquidate their holdings. As the conversion ratio is decided from the average share price over the 30-day period prior to conversion and is set pre-announcement, a drop will be a direct loss to the CoCo investors.

The impact of a share price shock on the CoCo price can also represent the correlation one may expect in the rare events where conversion happens. If the stock price decreases in the period before conversion is a fact, that is when investors might fear insolvency, the average share price will be higher in the 30-day period prior to conversion than at conversion. The relative effect will therefore be the same, with the conversion price being higher than the value of the shares[68].

Unlike the expected the stock distribution, which can be calculated implicitly from option prices, the size of such a shock is hard to predict. To get a picture of how such stock behaviour will impact the price, we therefore perform a sensitivity analysis on the fair price given several percentage drops in the share price immediately after conversion.

Share price shock	0 %	5 %	10 %	20 %	30 %	40 %
Price	114.90	113.26	111.62	108.33	105.04	101.75

Table 13: Price when incorporating share price shock at conversion

Table 13 shows how the price changes with the size of the drop. The relatively big impact of share price shocks can be explained by the trigger rate in the base case; because 38 per cent of the CoCos trigger, even a 10 per cent drop in the stock price at trigger will reduce the price by 3 per cent.

A negative price shock of this size is not unlikely when considering the negative information content in a report which calls for a conversion. The Credit Suisse

[68] Does not include the increased probability of a share price below the floor at conversion

stock most often experienced jumps (positive and negative) in the magnitude of 4.5 per cent and above on the release quarterly reports during 2007 and 2008. Such reports did not include the diluting element of a potential conversion, but point to the effect of the information content, and makes a negative shock greater than 5 per cent plausible.

The results also demonstrate that no correlation between the stock price and the ratio in near-conversion states will result in overpricing. However, by including a shock one might obtain a satisfactory proxy for this correlation. Still, like the case for interest rate and the use of implied volatility, a shock can not by itself explain our discrepancy from the market price unless it is in the order of 40 per cent.

6.2.5 Regulatory Uncertainty

All of the above improvements and add-ons to our base model are generic, and should apply to wide range of issuing banks. This not the case for regulatory uncertainty, which only applies to CoCos issued under the Swiss regime. Specific for these issues is the possibility of conversion triggered by the Swiss regulatory authorities if they judge the bank incapable of improving its solvency even though the CT1 ratio is above the trigger level. This complicates the pricing of the CoCo, as it is impossible to model the regulators actions.

To address this uncertainty, we created a scenario in which the trigger level is gradually increased over time – emulating stricter Swiss capital regulations. The scenario has been created through reducing the difference between the mean-reverting level of the CT1 ratio process and the trigger level. In this way we implicitly account for the possibility that Credit Suisse will change its target ratio to deal with increased capital requirements, but at a lag to account for the time required to improve the capital ratio. Table 14 shows the development of the trigger level in the years 2012-2017 under this alternative scenario.

Year	2012	2013	2014	2015	2016	2017
Base case	7.0 %	7.0 %	7.0 %	7.0 %	7.0 %	7.0 %
Swiss regulations	7.0 %	7.0 %	7.0 %	7.0 %	7.625 %	8.25 %
Scenario	7.0 %	7.0 %	7.0 %	7.0 %	7.500 %	8.00 %

Table 14: Trigger level development

By introducing the stricter capital requirement scenario we increase the likelihood of conversion, resulting in a lower bond price. The price drop is shown in Table 15.

	Price	Maturity	Trigger
Base case	114.80	998.9 days	39.2 %
Scenario	113.10	989.3 days	45.2 %

Table 15: Price when simulating stricter regulatory requirements

It is hard to quantify how the market prices this uncertainty in comparison, but it is most definitely accounted for when investors price the bond. This is evident when observing how the increased capital requirements imposed by FINMA had an immense negative impact on the price of the previous Credit Suisse Buffer Capital Notes issue. In September 2011, the month when the Swiss Parliament approved the TBTF-proposal (Credit Suisse, 2012), the bond went from trading at 96 to 89 (Börse-Berlin). The stock price, on the other hand, rose in the same period indicating that this was not due to expected financial difficulties.

This price drop is substantially greater than that of our model, and is most likely due to a confounding effect in relation to changes in for example the interest rate[69]. Nonetheless, the dramatic impact on the bond price proves that considerations should be made with regards to the regulatory uncertainty when pricing the Credit Suisse CoCo. However, as regulatory trigger is specific to the Swiss issues it does not warrant concern in a general pricing model.

6.3 Is the new Credit Suisse CoCo fairly priced?

None of the above discussed assumptions and extensions of our model can explain the price discrepancy between the market and our model by themselves. However, as one addition does not preclude any other, and several are likely, the issue may still be fairly priced.

Using implied volatility is a natural extension due to its forward looking nature, allowing it to capture the uncertainty in the current European financial markets. A second assumption likely incorporated by the market, is the loss from share price drop at the date of conversion. On observing the large absolute returns seen in the stock on the date of issuance of quarterly reports, a report ensuing

[69] The yield on investment grade corporate bonds rose during the same period from 2.24 % to 2.65 %.

conversion should include the same information amount, as well as the other aforementioned effects.

Table 16 shows the process obtained with different size of the share price drop and interest rate. All values are calculated using the implied volatility. The regulatory uncertainty is excluded from the analysis due to its vague nature.

		Share price shock					
		0 %	5 %	10 %	20 %	30 %	40 %
	.50 %	113.98	112.58	111.19	108.41	105.63	102.84
	1.00 %	111.63	110.26	108.90	106.16	103.43	100.70
	1.50 %	109.83	108.47	107.10	104.37	101.64	98.91
r_f	1.75 %	108.62	107.25	105.88	103.14	100.40	97.66
	2.00 %	107.81	106.45	105.10	102.40	99.69	96.99
	3.00 %	104.27	102.93	101.59	98.90	96.21	93.52
	4.00 %	100.71	99.38	98.06	95.40	92.75	90.09

Table 16: Price matrix with risk-free rate and share price shock at conversion

A likely range for the share price drop is probably around 5 per cent or more, in line with previous observations and allowing for a drop due to expectations of fixed income investors offloading their shares. Moreover, as it is likely to be some correlation between the stock price and the CT1 ratio in near conversion states, the total difference between the conversion price and the value of the shares may be more close to that of a 10 per cent shock.

As for the risk-free rate, a rate exceeding 2 per cent seems reasonable, being above the forecasted inflation in Europe (and Switzerland due to the exchange rate floor). With the low current rates, however, the effective risk-free rate during the next five years might not reach these levels as the "recovery time" of the interest rate is uncertain. A rate exceeding two percent is probably too high, as the yield on the 5-year AAA-rated European Corporate Bond Benchmark Index was around 2.10 per cent at date of the issue[70] (Reuters EcoWin). A rate somewhere in between today's 5-year spot rate and 2 per cent may therefore be a reasonable assumption.

Altogether, this yields a fair price somewhere in the shaded area of Table 16, making the recent CoCo issue seem a bit underpriced. However, the price is sensitive to a range of assumptions, and the price discrepancy can possibly be explained by for example the regulatory uncertainty not included in this analysis.

[70]Switzerland does not have such an index.

7 Conclusion

Contingent convertibles have emerged as the most promising alternative in replacing subordinated debt as regulatory, loss-absorbing hybrid capital. What currently prevent CoCos from penetrating the market on a full scale, is their complexity and a limited understanding of their dynamics. A potential increase in demand is thus reliant of the development of well-functioning and transparent pricing models. The main complication in doing this is that the price is dependent on both the movement of the Core Tier 1 (CT1) ratio trigger, an accounting metric, and the stock price, a market measure.

Early contributions have tried to link the evolution of the stock price and the trigger contingency through a market based proxy, implying a significant correlation with the stock price. However, from studying the evolution of the CT1 ratio and the stock price for multiple banks over the last decade, we find this correlation to be insignificantly different from zero. Moreover, the existing approaches generally have a proxy that is too volatile, thereby failing to account for the control the banks can exert on their CT1 ratio.

Based on these findings, we develop a model with (1) independent processes for the CT1 ratio and the stock price, calibrated by their historic evolution (2) a mean-reversion process for the CT1 ratio development, set according to company stated targets. According to our best estimate, including information likely incorporated by investors, the fair value of the 2012 Credit Suisse CoCo is higher than the market price.

Market efficiency would imply that the market price is at the fair value, indicating that our model fails to capture some value-decreasing property of the CoCo. For example, the regulatory risk is likely to be accounted for by sophisticated CoCo investors. Another property that might be better handled by the market, is the correlation between the stock price and the Core Tier 1 ratio, which we assume to be zero.

Alternatively, the CoCo market might be inefficient due e.g. a limited pricing foundation with current theoretical models unable to pick up the full dynamics of CoCos. Influential practitioners, like JPMorgan Chase, base their models on the same flawed fundamentals (Stadelmann, 2011) and thus mispricing could be prevalent.

The market price could be too low due to high assumed correlation between the stock price and the CT1 ratio, while we might overprice the CoCo when assuming the correlation to be zero. However, we also believe that investors are likely to demand an ambiguity premium[71], in addition to the risk premium, as a result of the regulatory trigger (Kogan and Wang, 2003). From the perspective of potential investors, placing the decision on conversion in the hands of a supervisory body introduces a discretionary element into the probability of default occurrence that is very difficult to assess (Zähres, 2011).

Regardless of whether it is the main source of discrepancy between our fair value estimate and the market price or not, the correlation between the stock price and the CT1 ratio is a very interesting topic for future research. To assume a constant correlation, independent of the CT1 value, is simplistic and thus such investigations should allow the correlation to be dependent on the CT1 ratio level.

There are several other possible improvements to our novel approach. We have addressed some in our sensitivity analysis, while other extensions can easily be added due our model's straightforwardness. An obvious improvement is to incorporate all information found in the Credit Suisse stock options surface in the stock price distribution. Regarding the movement of the CT1 ratio, we call for a more thorough analysis on the underlying assumptions. Such an analysis needs to comprise how the banks govern their CT1 ratio to comply with regulations, and how the ratio is affected by sudden shocks.

[71] The premium derived from not knowing the precise odds of outcomes (in addition to the risk premium demanded from not knowing the sure outcome) (Izhakian and Benninga, 2007).

Appendix

Bank	Country of origin	Total assets ($bn)
Banco Bilbao Vizcaya Argentaria	Spain	824
Bank of America	United States	2,264
Citigroup	United States	1,956
Commerzbank	Germany	991
Credit Suisse	Switzerland	1,160
Danske Bank	Denmark	607
Deutsche Bank	Germany	2,681
Banco Intesa Sao Paolo	Italy	935
Handelsbanken	Sweden	355
NG Bank	Netherlands	1,799
JP Morgan Chase	United States	2,246
Misuho Financial Group	Japan	1,943
Nordea	Sweden	860
Santander	Spain	1,786
Skandinaviska Enskilda Banken	Sweden	347
UBS	Switzerland	1,469
UniCredit Group	Italy	1,332
Wells Fargo	United States	1,260

Banks in sample, as of June 2011

References

T. Adrian and H. S. Shin. Liquidity and leverage. *Journal of Financial Intermediation*, 19(3):418–437, July 2010.

C.A. Ball and W.N. Torous. A simplified jump process for common stock returns. *Journal of Finance and Quantitative Analysis*, 18(1):53–65, 1983.

A. K. Bera and M. Jarque. Efficient tests for normality, homoscedasticity and serial independence of regression residuals: Monte Carlo evidence. *Economics Letters*, 7(4):313–318, April 1981.

Bloomberg. How to price an autocallable note with OVSN. Technical report, Bloomberg, November 2009.

M. Bouzoubaa and A. Osseiran. *Exotic Options and Hybrids*. Wiley Finance, 2010.

T. Breuer, M. Jandacka, K. Rheinberger, and M. Summer. Regulatory capital for market and credit risk interaction: Is current regulation always conservative? Deutsche Bundesbank Discussion Paper, No. 14, 2008.

D. Brigo, A. Dalessandro, M. Neugebauer, and F. Triki. A stochastic processes toolkit for risk management. Working Paper, November 2007.

C. Brooks. *Introductory Econometrics For Finance*. Cambridge University Press, 2008.

F. Cannata and M. Quagliariello. The role of Basel II in the subprime financial crisis: Guilty or not guilty? CAREFIN Research Paper No. 3/09, January 2009.

A. Cherny and D. B. Madan. Markets as a counterparty: An introduction to conic finance. *International Journal of Theoretical and Applied Finance*, 13: 1149–1177, 2010.

J. M. Corcuera, A. Ferreiro-Castilla, D. B. Madan, J. Spiegeleer, A. E. Kyprianou, and W. Schoutens. Efficient pricing of contingent convertibles under smile conform models. Working Paper, November 2011.

A. Damodaran. What is the riskfree rate? A search for the basic building block. Working Paper, December 2008.

D. Duffie. Contractual methods for out-of-court restructuring of systemically important financial institutions. Submission Requested by the U.S. Treasury Working Group on Bank Capital., November 2009.

D. Duffie and K. J. Singleton. *Credit Risk: Pricing, Measurement, and Management*. Princeton University Press, 2003.

M. Flannery. *Risk-Based Capital Adequacy*, chapter "No Pain, No Gain": Effecting Market Discipline via "Reverse Convertible Debentures". Oxford University Press, 2005.

M. Flannery. Market value triggers will work for contingent capital instruments. Working Paper, 2009.

M. Flannery. Stabilizing large financial institutions with contingent capital certificates. CAREFIN Research Paper No. 4/10, March 2010.

K. R. French, M. N. Baily, J. Y. Campbell, J. H. Cochrane, D. W. Diamond, D. Duffie, A. K. Kashyap, F. S. Mishkin, R. G. Rajan, D. S. Scharfstein, R. J. Shiller, H. S. Shin, M. J. Slaughter, J. C. Stein, and R. M. Stulz. *The Squam Lake Report*. Princeton University Press, 2010.

J. Gerich. Euro-zone debt worries continuing to push German yields to new lows, May 2012. URL `http://newsroom.nordeamarkets.com/en/2012/05/10/euro-zone-debt-worries-continuing-to-push-german-yields-to-new-lows/`.

P. Glasserman and B. Nouri. Contingent capital with a capital ratio trigger. Working Paper, 2010.

T. S. Y. Ho and S. Lee. Term structure movements and pricing interest contingent claims. *Journal of Finance*, 41(5):1011–1029, December 1986.

J. Hughes. Credit suisse deal offers truer test of CoCos. The Financial Times, February 14th 2011.

Y. Izhakian and S. Benninga. The uncertainty premium in an ambiguous economy. Working Paper, June 2007.

L. Kogan and T. Wang. A simple theory of asset pricing under model uncertainty. Working Paper, February 2003.

T. Koller, M. Goedhart, and D. Wessels. *Valuation: Measuring and Managing the Value of Companies*. Wiley Finance, 5 edition, 2010.

S.G. Kou. *Handbooks in Operations Research and Management Science*, volume 15, chapter 2. Elsevier B.V., 2008.

P. Kugler and B. Weder. Why are returns on Swiss Franc assets so low? Rare events may solve the puzzle. *C.E.P.R. Discussion Papers*, (5181), 2005.

A. Kuritzkes and H. Scott. Markets are the best judge of bank capita, September 23rd 2009.

D. Lucas and R. L. MacDonald. An options-based approach to evaluating the risk of Fannie Mae and Freddie Mac. *Journal of Monetary Economics*, 53(1): 155–176, January 2006.

R. L. MacDonald. Contingent capital with a dual price trigger. Working Paper, 2010.

D. B. Madan. On pricing contingent capital notes. Working Paper, December 2011.

D. B. Madan and W. Schoutens. Conic coconuts: The pricing of contingent capital notes using conic finance. *Mathematics and Financial Economics*, 5: 87–106, 2011.

R. Merton. On the pricing of corporate debt: The risk structure of interest rates. *Journal of Finance*, 29(2):449–470, May 1974.

R. Merton. Option pricing when underlying stock returns are discontinuous. *Journal of Financial Economics*, 3:125–144, 1976.

A. Metzler and R. M. Reesor. Valuation of contingent capital bonds in Merton-type structural models. Working Paper, November 2011.

P. Murphy. Deutsche rattles the bond market, December 2008. URL `http://ftalphaville.ft.com/blog/2008/12/17/50514/deutsche-rattles-the-bond-market/`.

G. Pennacchi. A structural model of contingent bank capital. Working Paper, April 2010.

Risk.net. Credit suisse CoCo oversubscription dispels concerns over investor demand, 2011. URL `http://www.risk.net/credit/review/2031872/credit-suisse-coco-oversubscription-dispels-concerns-structure`.

A. Schleifer. *Inefficient Markets: An Introduction to Behavioral Finance*. Oxford University Press, 2000.

J. Spiegeleer and W. Schoutens. Pricing contingent convertibles: A derivatives approach. Working Paper, June 2011a.

J. Spiegeleer and W. Schoutens. Steering a bank around a death spiral: Multiple trigger CoCos. Working Paper, December 2011b.

J. Spiegeleer and W. Schoutens. *Contingent Convertible (CoCo) Notes: Structuring and pricing.* Euromoney Institutional Investor PLC, 2011c.

M. Stadelmann. On the determination of the fair price of contingent convertible bonds. Bachelor Thesis in Banking & Finance, University of Zurich, July 2011.

S. M. Sundaresan and Z. Wang. On the design of contingent capital with market trigger. FRB of New York Staff Report No. 448, November 2011.

P. Tankov and E. Voltchkova. Jump-diffusion models: a practitioner's guide. *Banque et Marchés*, (99), March-April 2009.

S. J. Taylor. *Asset Price Dynamics, Volatility and Prediction.* Princeton University Press, 2005.

BCBS. *International Convergence of Capital Measurements and Capital Standards.* Bank for International Settlements, 2006.

BCBS. *Basel III: A global regulatory framework for more resilient banks and banking systems.* Bank for International Settlements, 2011.

Credit Suisse. Information memorandum CoCo issuance 2011, February 2011.

Credit Suisse. Information memorandum CoCo issuance 2012, March 2012.

EBA News & Communications. The EBA details the EU measures to restore confidence in the banking sector, October 26th 2011. URL `http://eba.europa.eu/News--Communications/Year/2011/The-EBA-details-the-EU-measures-to-restore-confide.aspx`.

ECB Inflation forecast, April 2012. URL `http://www.ecb.int/stats/prices/indic/forecast/html/table_hist_hicp.en.html`.

FASB. Statement of financial accounting standards no. 157. Technical report, Financial Accounting Standards Board, 2006.

SEC. *Findings regarding the market events of May 6, 2010.* U.S. Commodity Futures Trading Commission and the U.S. Securities and Exchange Commission, 2010.

Swiss Commission of Experts. "Too big to fail" issues. Technical report, Swiss Commission of Experts, 2010.

O. A. Vasicek. An equilibrium characterization of the term structure. *Journal of Financial Economics*, 5:177–188, 1977.

R. Weron and A. Misiorek. Forecasting spot electricity prices: A comparison of parametric and semiparametric time series models. MPRA Paper No. 10428, September 2008.

L. Wu. Modeling financial security returns using Levy processes. Working Paper, December 2005.

M. Zähres. Contingent convertibles: Bank bonds take a new look. Financial Market Special EU Monitor 79, Deutsche Bank Research, May 2011.