University of St. Gallen

Master in Banking and Finance

Master's thesis

Analytical Propositions to Evaluate Contingent Convertible Capital

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Abstract

Switzerland has taken a leading role in proposing new capital requirements that include contingent convertible capital. This paper provides an extensive treatment of this new capital instrument.
With focus on recent literature, a qualitative part discusses its characteristic design features, risk attributes and conversion mechanisms. A quantitative part introduces an analytical credit risk concept based on Ingersoll (1977) and Pennacchi (2010), which simulates a synthetic balance sheet and allows the calculation of fair new issue yields on contingent convertible capital for different contract terms and model specific parameters.

While qualitative and quantitative discussions are available in recent literature, this paper is the first to combine these two topics. Furthermore, this master's thesis is the first to put a quantitative model on contingent convertible capital into a real-world scenario by conducting a case study on the Swiss bank Credit Suisse.

As a result, the paper identifies that the conversion trigger and the conversion design distinguishes contingent convertible capital from existing hybrid debt. Moreover, the counterparty risk, the effect of contagion and the death spiral are among the inherent risks of the new capital instrument.
A further outcome shows that fair new issue yields are higher for lower initial capital ratios and lower conversion thresholds. Yields are also higher if the conversion occurs at a discount and if investors are awarded a fixed amount of shares. The case study ultimately reveals that there is a discrepancy between real-world and modeled yields, leading to the conclusion that there might be an illiquidity / uncertainty premium involved.

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1 Introduction

The first section provides the economic link as to why contingent convertible capital gained so much momentum recently and establishes the urgency of the topic with a special focus on Swiss capital requirements. Subsequently, the research questions are outlined and the methodology of the master's thesis is described.

1.1 Economic Reasoning for Contingent Convertible Capital

Over the last couple of years the banking sector was increasingly driven by moral hazard, lower market discipline and higher returns. The importance, interconnectedness and complexity of financial institutions increased a great deal while at the same time their capital and liquidity ratios decreased, effectively reducing their loss absorption potential (Bank for International Settlements 2010, p. 1; Maes & Schoutens 2010, p. 1).

The excessive risk taking of financial institutions during the recent crisis exposed them to huge losses and revealed major weaknesses in (inter-) national financial regulation and resolution frameworks. Furthermore, the ad-hoc measures taken by supervising bodies providing state guarantees to numerous financial institutions made their systemic relevance to the overall economic welfare apparent (Squam Lake Working Group on Financial Regulation 2009, p. 2).

Obviously, the present supervisory system and capital requirements failed to enforce financial firms to correctly assess the risk of their activities and provide adequate loss absorption potential – an effect which was even amplified by the provision of state guarantees. In fact, Kuritzkes and Scott (2009) found that in 2007 – 2009 most of the firms in distress qualified as "well capitalized" under the Basel framework. One of the reasons for this misjudgment lies in the fact that capital standards according to Basel II and even the forthcoming Basel III are largely based on accounting values. Therefore, book equity value reflects the market value of the firm with a certain *time lag*, which is especially pronounced in times of high volatility (Flannery 2009, p. 2). Due to this time lag *re-capitalization* actions were taken too late, when financial institutions were already in distress. In this respect, highly levered firms might even be reluctant to issue additional equity as they have to deal with the problem of *debt-overhang* (Flannery 2009, p. 2; Squam Lake Working Group on Financial Regulation 2009, p. 2) (cf. section 2.3.2). Moreover, in times of distress a *restructuring* is often not a viable option as this would be a negative signal to the market and could further undermine the confidence on which financial intermediation is built on (Squam Lake Working Group on Financial Regulation 2009, pp. 2-3).

This delay in restructuring decisions is one of the reasons why existing hybrid capital failed to absorb losses as it was supposed to (Flannery 2009, p. 1; Squam Lake Working Group on Financial Regulation 2009, pp. 2-3).

Realizing that the very definition of regulatory capital has disappointed and consequently failed to fulfill its function, the Bank for International Settlements (2010) was quick to put forward new proposals to re-establish credibility. The proposals mainly address the role of Tier 1 and Tier 2 capital with the aim to improve the quality, consistency and transparency of regulatory capital. It is still unclear though whether contingent capital instruments will be allowed for or even required in the forthcoming final regulatory framework (Maes & Schoutens 2010, p. 3).

However, the Chairman of the Federal Reserve System (Bernanke 2009) and the New York Federal Reserve Bank President (Dudley 2009) have given their support, as contingent convertible capital could effectively minimize the likelihood of bankruptcy of financial institutions in distress and at the same time manage the *caveats* raised in the introductory part. The governor of the Bank of England is a bit more cautious but deems contingent capital "worth a try" (King 2009, p. 5).

1.2 A Primer on Swiss Bank Capital Requirements

In this respect, Switzerland recently proposed that its two largest banks - UBS and Credit Suisse - have to hold higher capital requirements amounting to 19% of risk-weighted-assets, of which 9% are allowed to be held in the form of contingent convertible debt (Commission of Experts 2010, pp. 57-58). By allowing financial institutions to partially substitute common equity with contingent capital, regulators can secure an efficient financial intermediation by reducing the overall cost of capital and mitigate the risk of regulatory arbitrage (Albul, Jaffee & Tchistyi 2010, p. 2). Furthermore, too high equity requirements could lead to excessive risk taking by the managers to maintain a target return on equity (Pazarbasioglu et al. 2011, p. 8).

1.2.1 The Swiss Contingent Convertible Capital Proposal

Specifically, the 19% total capital ratio is composed of 10% Common Equity Tier 1 (CET1) and 9% in contingent convertible capital, of which 3% has a high trigger (cf. section 2.2.1) at 7% of CET1 and 6% has a low trigger at 5% of CET1. The former, high trigger type is thought to fulfill the "additional capital conservation buffer", whereas the latter type serves to meet the "progressive component" (Commission of Experts 2010, pp. 57-60) (cf. Figure 1).

The triggers are contractually defined and are linked to common equity ratios in line with the Basel III proposals (Commission of Experts 2010, pp. 25-26). The conversion ratio (cf. section 2.2.2) is not predefined and can be set at the time of conversion or at the time of issuance (Commission of Experts 2010, p. 88). The distinction between high- and low-trigger contingent capital is in line with Basel III's "going-concern" and "gone-concern" respectively (Maes & Schoutens 2010, p. 10). The high-level trigger is expected to inject fresh capital when the bank's capital situation is worsening, thus stabilizing the bank in a going-concern. The low-level trigger contingent capital addresses the gone-concern and is designed to ensure a privatized, orderly resolution and therefore minimize any government support (Commission of Experts 2010, p. 51; Maes & Schoutens 2010, p. 16).

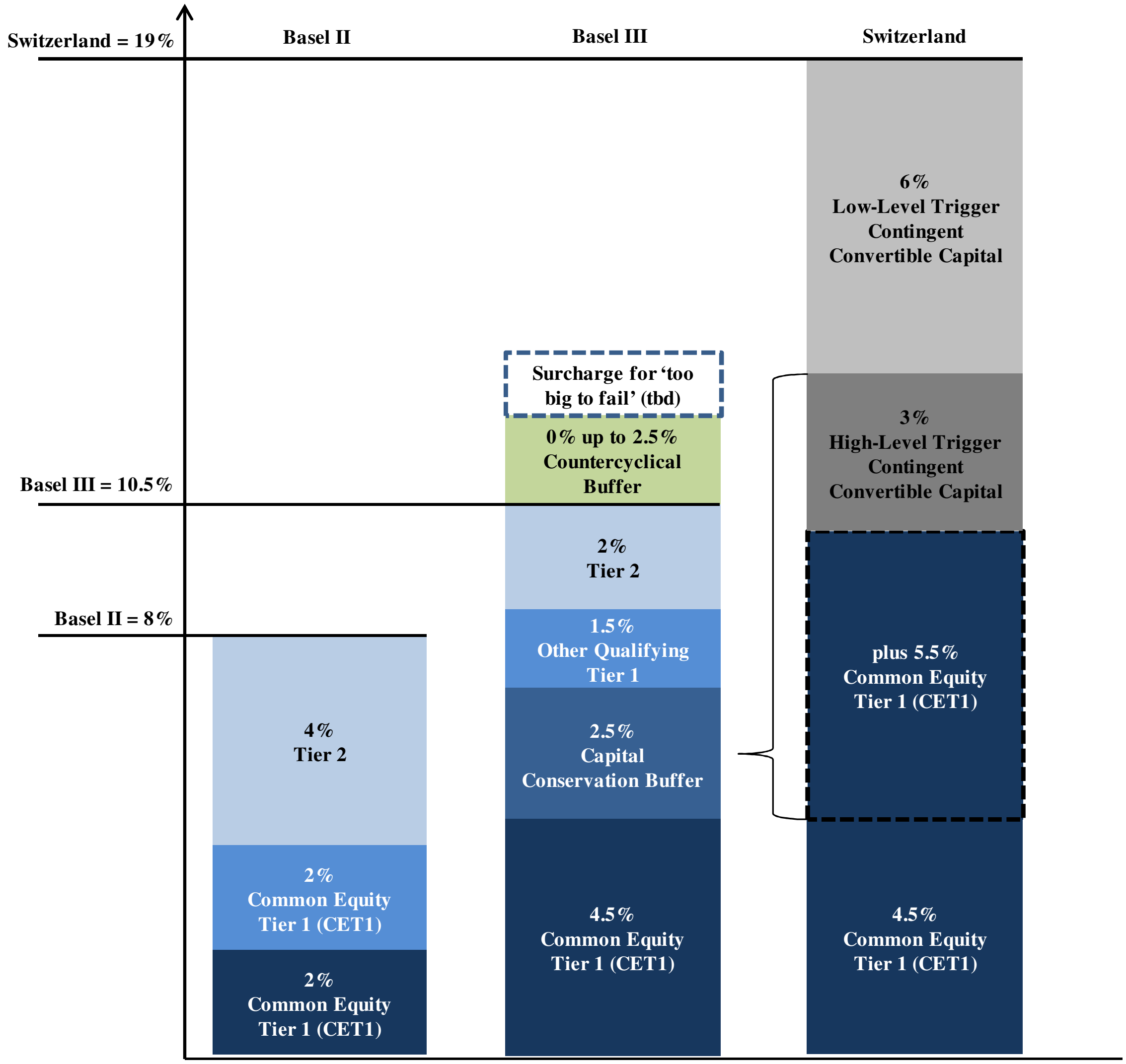

Figure 1: Swiss capital requirement proposal (based on Pazarbasioglu et al. (2011, p. 17))

In absolute terms, the long-term financing of UBS and Credit Suisse combined amount to about CHF 160 billion, where almost half of the new capital requirements are allowed to be met with contingent capital. This means that in Switzerland alone, almost CHF 80 billion could be issued in the form of contingent capital in the near future (Commission of Experts 2010, p. 61). In fact, Credit Suisse has already issued around CHF 8 billion (CHF 6 billion and USD 2 billion respectively) of high-level trigger contingent capital in February 2011, satisfying about 70% of the newly proposed Swiss capital requirements (Credit Suisse 2011a; Credit Suisse 2011b). The markets responded very well to this action as demand was more than ten times higher than the face value of the 2 billion bond denominated in USD, making it highly oversubscribed. Furthermore, also capital markets seemed to welcome this move by Credit Suisse as the cumulative return of their stock amounted to 7.8% from

February 14^{th} to February 18^{th} 2011, whereas in the same period the Swiss Market Index increased by 0.8% (Federal Department of Finance 2011, pp. 42-43).

In addition to the higher capital requirements a leverage ratio has been introduced, which defines a minimum amount of capital-to-debt for UBS and Credit Suisse. This way, the risk of potential shortfalls in the risk-weighted requirements can be mitigated. The target leverage ratio proposed by the financial regulators is >5% in good times (Commission of Experts 2010, p. 33).

On April 20^{th} 2011 the Federal council has adopted the dispatch by the Commission of Experts for parliament. The first chamber can therefore consider the bill during the summer session and the second chamber in the autumn session 2011. Hence, the newly proposed legislative amendments could be binding at the start of 2012. The transition period for the two banks to build up their capital base is set to 2018 and should facilitate the implementation. Furthermore, the Federal Council is considering tax measures to promote the issuance of bonds and contingent capital in Switzerland. This should enable Swiss financial institutions to remain competitive on an international level (Federal Department of Finance 2011, p. 46; The Swiss Confederation 2011).

1.3 Research Questions

The introductory part has established the economic reasoning and urgency of contingent convertible capital. This master's thesis aims at answering the following research questions (RQ):

RQ1: What are the specific design features of contingent convertible capital?

RQ2: What are fair new issue yields on contingent convertible capital for different contract specifications and bank variables?

RQ3: How do fair new issue yields on contingent convertible capital compare vis-à-vis yields on contingent capital bonds issued by Credit Suisse?

1.4 Methodology

Section 2 provides a comprehensive overview of contingent convertible capital and its characteristic design features, to introduce the qualitative framework needed to understand the behavior and the mechanisms of said capital instrument. An intermediary conclusion provides an answer to RQ1.

The subsequent *chapter 3* introduces an analytical credit risk concept based on Ingersoll (1977) and Pennacchi (2010), which simulates a financial institution that issues short-term deposits, long-term or convertible debt and shareholder's equity.

A final *chapter 4* conducts a case study on Credit Suisse by first calibrating the model variables and then providing comparative analysis for fair new issue yields on contingent convertible capital.

A concluding *chapter 5* answers the remaining research questions two and three and provides an outlook.

2 Contingent Convertible Capital

The introductory part has made clear that contingent convertible capital could prove to be very important in future regulatory frameworks. Furthermore, it has been shown that Switzerland has taken a leading role concerning the practical implementation of this new capital instrument. Therefore, this chapter in a first part provides a general description of what contingent capital is. In a second part, the reader is introduced to the characteristic design features and possible risks that could stem from contingent capital bonds. A last part provides a simple numerical example to illustrate how contingent capital works as well as an intermediary conclusion to answer RQ1.

2.1 Description

Contingent convertible capital is a long-term debt instrument that serves the purpose of pre-arranging a re-capitalization under specific conditions with minimal impact on the ongoing business. Specifically, this means that this type of facility converts into common stock when a pre-defined trigger event is breached, leading to a cash increase in the case of unfunded contingent convertible capital or to a change in the liability structure in the case of funded contingent convertible capital (Commission of Experts 2010, p. 88; Federal Department of Finance 2011, p. 42; Maes & Schoutens 2010, p. 4; Squam Lake Working Group on Financial Regulation 2009, p. 4). It therefore enables raising capital even in times of distress and difficult market conditions, effectively reducing the need for fire sales and minimizing the contagion risk during times of systemic stress. Depending on how the trigger and the conversion ratio are chosen, contingent capital can serve to increase capital buffers and increase loss absorbency potential before insolvency occurs. Due to the automatic conversion mechanism, contingent convertible capital would also remedy the problem of debt-overhang, where firms are reluctant to issue new equity to re-capitalize (Pazarbasioglu et al. 2011, p. 7) (cf. section 2.3.2).

Furthermore, contingent convertible capital is treated as a debt instrument just like ordinary debt, such that it adds to the firm's risk bearing capacity and lowers its bankruptcy costs. Additionally, due to the interest payments on contingent capital, it can provide a tax-shield effect, hence increasing the firm's value (Albul, Jaffee & Tchistyi 2010, pp. 22, p. 26; Federal Department of Finance 2011, p. 52).

To fully understand the behavior and to provide the qualitative framework of contingent capital, this paper subsequently treats the specific characteristics.

2.2 Characteristic Design Features

Contingent capital has two key characteristics which distinguishes it from existing hybrid debt:

First, contingent capital has a pre-specified *trigger* event that leads to an automatic conversion if it is breached. Second, when the trigger is tripped it converts at a contractually defined *conversion ratio* as opposed to the conversion of existing hybrids, which is at the discretion of the bank (Pazarbasioglu et al. 2011, p. 8). These two key features are discussed in the following two sections.

2.2.1 Trigger Designs

Probably the most important feature of contingent capital is the trigger at which conversion occurs. This can either be a bank-specific measure, such as a minimum ratio of equity to asset value, or it can be a systemic trigger based on the condition of the entire financial system. A third option would be a combination of aforementioned measures to design a dual-trigger (McDonald 2010, pp. 1-2; Squam Lake Working Group on Financial Regulation 2009, p. 4).

Existing proposals suggest using a market-driven, idiosyncratic measure to avoid accounting manipulation and prevent lagged information, as was the case during the financial crisis. This would remedy the disadvantage of the book-value approach of current capital requirements set by Basel and secure a timely and effective conversion (Albul, Jaffee & Tchistyi 2010, p. 3; Flannery 2009, p. 12). Additionally, using a bank-specific trigger would create the incentive to improve the individual risk management and make the pricing and rating process of contingent capital easier (Maes & Schoutens 2010, p. 12; Pazarbasioglu et al. 2011, p. 9). However, using a market-driven measure based on equity value brings about the risk of market manipulation if the stock price is trading close to the trigger price. Speculators that own contingent convertible capital might exploit a favorable situation and go short in the stock with the aim to lower the stock price to trigger a conversion, such that they can maximize their equity share and therefore gain maximum control of ownership (cf. section 2.2.3). This issue is directly tied to the “fixed dollar” conversion as will be explained later in section 2.2.2. Additionally, stock prices might not reflect the true financial condition of individual financial institutions during times of high volatility (Maes & Schoutens 2010, p. 9; Squam Lake Working Group on Financial Regulation 2009, p. 4). One possible way to overcome these disadvantages would be to make the conversion conditional on a dual-trigger, e.g. to a bank-specific trigger linked with a system-wide trigger, as proposed by McDonald (2010, pp. 1-2) or the Squam Lake Working Group (2009, p. 4). However, Flannery (2009, p. 12) suggests that in such a design, the risk that individual systemically important firms might not be re-capitalized at all greatly outweighs the risk of speculative attacks on the stock price.

A trigger based solely on system wide indicators, such as an index of financial institutions, would most likely be the most efficient way of averting a systemic crisis. It would inject fresh capital to the entire financial system at once, irrespective of an individual bank’s financial situation. However, in contrast to an idiosyncratic trigger, this would not create any incentives to improve risk management and could furthermore leave certain financial institutions over-capitalized after a conversion and therefore hinder a cost-effective financial intermediation (Pazarbasioglu et al. 2011, p. 25).

Instead of setting predetermined triggers, a conversion could also be made contingent upon a supervisor’s discretion. A decision would be made based on the idiosyncratic or overall systemic stress level and an injection could be deemed necessary for single financial institutions or the system as a whole. Such a design would certainly limit any market manipulations but at the same time might increase the uncertainty for investors and therefore increase risk-premia. Ultimately, this could impede the marketability of contingent convertible capital (Maes & Schoutens 2010, p. 12; Pazarbasioglu et al. 2011, p. 25).

In addition to different trigger designs, the *level* at which the trigger is set can have important implications. E.g. a trigger set above a certain distress threshold ensures an early re-capitalization and secures the market access of the financial institution, hence effectively mitigating the systemic risk. Furthermore, market discipline exerted on the management by shareholders and bondholders is higher with a high-level trigger, since said stakeholders step in earlier to monitor risk taking activities (Maes & Schoutens 2010, p. 10; Pazarbasioglu et al. 2011, p. 9). On the other hand, a low-level trigger set at the point of non-viability can ensure the involvement of the private sector during the financial institutions restructuring process (Basel Committee on Banking Supervision 2010, pp. 3-4). In both cases though, the negative signaling effect when the conversion trigger is approached might lower the market's confidence in the bank's financial condition and create liquidity pressures (Pazarbasioglu et al. 2011, p. 11).

Based on aforementioned trigger designs and their respective advantages and disadvantages, the mechanism adopted in the quantitative analysis in section 3 is a single trigger design. It uses observable market values of the bank's shareholder's equity and additionally, in contrast to aforesaid single trigger designs, the observable market value of its contingent capital bonds. Hence, it circumvents the disadvantages of a book-value measure and mitigates the risk of stock price manipulation (Pennacchi 2010, p. 9).

The following matrix provides a comprehensive overview of different trigger designs and their advantages and disadvantages. The following section then outlines the different types of conversion designs.

Overview of Contingent Convertible Capital Trigger Designs

Trigger Type	Advantages	Disadvantages	Example
Bank specific trigger	▪ Incentive to improve the individual risk management ▪ Individual systemically important financial institutions are re-capitalized even in times of no systemic crisis	▪ Might not be sufficiently responsive to indicate a systemic crisis	
(i) Institutional trigger based on an accounting measure	▪ Easier to price ▪ Easier to understand, design and implement	▪ Indicators might lag the actual financial conditions if the reporting periodicity is too low ▪ Definition of underlying measure crucial	▪ E.g. a conversion occurs when the financial institutions Core Equity Tier 1 capital ratio falls below a certain threshold
(ii) Market-driven, bank-specific indicator	▪ Most accurately reflects financial conditions if markets are working efficiently ▪ No time lag as opposed to accounting based measures	▪ Markets might show inefficiencies during highly volatile times ▪ Market manipulation by short selling the stock can lead to premature conversion	▪ A conversion occurs when the financial institutions stock price falls below a certain threshold
(iii) Conversion is at supervisor's discretion when financial stress is considered high	▪ Quick action taking possible by supervisors, therefore providing a timely re-capitalization ▪ Limits market manipulation	▪ Might increase the uncertainty for the investors since the conversion is not automatic ▪ Investors might charge a premium, which could impede the marketability of contingent convertible capital	▪ Conversion occurs if financial supervisor deems that the bank is in financial distress

Trigger Type	Advantages	Disadvantages	Example
Systemic trigger	▪ Possibly most efficient at averting systemic crisis as it provides an automatic re-capitalization to the entire system at once	▪ Trigger conditions are not in the individual bank's control and therefore incentives to take specific actions are reduced ▪ Also financial institutions that are not badly hit by the crisis are re-capitalized, possibly over-capitalizing them	
(i) Pre-determined conditions	▪ Automatic re-capitalization without interference of regulatory bodies ▪ Ex-ante strengthening of confidence among financial institutions	▪ All financial institutions are treated the same ▪ No human element to assess the true necessity of a system wide re-capitalization	Conversion can occur if e.g. cumulative credit loss rises above a certain threshold
(ii) Conversion is at supervisor's discretion	▪ System wide re-capitalization of systemically important financial institutions to avert systemic crisis	▪ No differentiation between firms might make a re-capitalization inefficient ▪ The supervisor's decision might be delayed if negotiations take too long ▪ Investors might charge an additional premium for the uncertainty associated with the trigger event	

Trigger Type	Advantages	Disadvantages	Example
Dual trigger Conversion occurs if there is a systemic crisis and an idiosyncratic trigger is realized	▪ Allows for differentiation amongst banks and can secure a system wide re-capitalization if needed ▪ Can mitigate the risk of market manipulation in the case of a single idiosyncratic trigger	▪ Individual firms might not be re-capitalized at all and go bankrupt	

Table 1: Overview of contingent convertible capital trigger designs (based on Pazarbasioglu et al. (2011, pp. 24-26))

2.2.2 Conversion Designs

Another important feature of contingent convertible capital is the conversion design, which defines the proportion at which the contingent capital is converted into equity when the trigger is tripped. McDonald (2010, pp. 3-4), Pazarbasioglu et al. (2011, p. 11) and the Squam Lake Working Group (2009, p. 4) distinguish between a "fixed share" (i) conversion and a "fixed dollar" (ii) conversion. The former implies that contingent capital holders are on average paying too much when conversion occurs, whereas in the latter option the amount of shares received by contingent capital investors varies to satisfy the bonds par value. Furthermore, the conversion ratio p can be chosen such that the implicit share price at conversion is at a premium, at a discount or equal relative to the trigger price. These different forms of conversion are illustrated in the examples below (McDonald 2010, pp. 3-4):

(i) In t_0 the firm's stock price is $S_0 = \$50$ and it issues contingent capital with a par value of $B = \$500$ that converts into equity when the stock price falls below $S_t \leq \$25$ (therefore the determined conversion ratio is 20 shares if the conversion ratio is $p = 1$). In t_1 the stock price closes at $S_1 = \$23$ (following a non-continuous drop) and the bond holders receive shares in the amount of $20 * \$23 = \$460$. In this example, bondholders receive less than par value and therefore the market should generally demand higher interest rates to make up for the foregone value (cf. section 4.2.1). If the contemporaneous share price were to be exactly at $S_1 = \$25$ then the bondholders would receive par value.

(i bis) It would also be possible to intentionally set the number of shares to be worth less than the original par value of $B = \$500$. In this case, the conversion ratio would be $0 \leq p < 1$ and conversion would occur at a discount. Hence, the risk premium asked by investors should be even higher than in the previous case (cf. section 4.2.1).

(ii) Assuming the same values in t_0 and t_1 and the same contingent capital properties, in a "fixed dollar" conversion the amount of shares is determined ex-post through the market value of equity, such that an investor would receive $\frac{\$500}{\$23} = 21.739$ shares. In this case, the contingent capital holder would receive exactly $\$500$, which corresponds to the original par value $B = \$500$. The risk premium in the case of a variable share conversion should be the lowest, since investors are sure to receive their par value if the remaining total capital can fulfill a full conversion (cf. section 3.5 and section 4.2.1).

(ii bis) Similarly to (i bis), also in the case of a "fixed dollar" conversion the amount of shares received can be at a pre-specified writedown to the original par value, such that $0 \leq p < 1$ and investors would receive at most pB at conversion. The risk premium asked by investors should be an intermediary case to (i) and (ii) (cf. section 4.2.1).

In all examples the ex-ante shareholders suffer from a dilution. However, a “fixed dollar” conversion as illustrated in (ii) leads to a much stronger dilution than a “fixed share” conversion (i). In case (i) the dilution is bounded to the difference of the share price in t_0 and t_1, whereas in case (ii) the number of new shares that have to be issued to service a conversion at par can be much larger (Pazarbasioglu et al. 2011, p. 11).
Additionally, the “fixed dollar” conversion illustrated in example (ii) is most prone to market manipulation, where contingent capital holders might try to exert pressure on the market price to maximize the number of shares they receive (cf. section 2.2.1). This risk could be circumvented easily though by making the conversion ratio conditional upon the average stock price over a longer period (Squam Lake Working Group on Financial Regulation 2009, p. 4).

Similarly to Table 1, which provides an overview of the different trigger designs, the subsequent matrix outlines the possible types of conversion including their advantages and disadvantages.
The subsequent section then treats specific risks than can emerge from contingent convertible capital.

Overview of Contingent Convertible Capital Conversion Designs

Conversion Type		Advantages	Disadvantages
(i)	"Fixed share" at par ($p = 1$)	▪ Pre-specified dilution for ex-ante shareholders ▪ No incentive for stock price manipulation	▪ High issuance cost of contingent capital
(i bis)	"Fixed share" at discount ($0 \leq p < 1$)	▪ Even lower dilution risk than in (i) because the conversion is at a discount	▪ Higher costs of issuance than (i)
(ii)	"Fixed dollar" / variable share conversion at par value ($p = 1$)	▪ Certainty for contingent capital investors that they receive par value (except if total capital is less than par due to a sudden decline in asset values (cf. section 3.5)) ▪ Lower issuance cost of contingent capital than (i) and (i bis)	▪ Possible market manipulation by short selling the stock to force conversion ▪ High dilution for ex-ante shareholders
(ii bis)	"Fixed dollar" / variable share conversion at discount ($0 \leq p < 1$)	▪ Certainty for contingent capital investors that conversion occurs at a pre-defined discount ▪ Firm value can increase due to lower liabilities in case of conversion	▪ Dilution risk is less than at a conversion at par, such that market discipline exerted on managers is lower

Table 2: Overview of contingent convertible capital conversion designs (based on Pazarbasioglu et al. (2011, pp. 27-29))

2.2.3 Risk

This section discusses three specific risks that are inherent to contingent convertible capital and have to be considered when including this instrument in capital structures.

Counterparty Risk

Possible investors for contingent capital can include corporations, institutional investors as well as sovereigns. Especially in the case of unfunded contingent capital (where no funds flow upon issuance of the contingent convertible bond but only in the case when the trigger is tripped), the *counterparty risk* is not to be underestimated. In this case, the contingent capital investor has to provide the contractually agreed liquidity at times when possibly the entire economy is in severe stress, therefore making it questionable if the investor would be able to come up with the necessary funding (Maes & Schoutens 2010, p. 9).

Contagion Effect

In this respect, even funded deals could turn out to be completely useless if contingent capital notes are placed among other financial institutions, since it could create a potential *domino effect*: The newly created equity position in the distressed company - after the contingent capital has converted into equity - could lead to writedowns on the books of the other financial institution, thus possibly forcing conversion of additional contingent capital. Due to the empirically high correlation of asset returns during a systemic crisis, the triggering of one financial institution can fuel speculation, hence raising the triggering probability of contingent capital of other market participants (Maes & Schoutens 2010, p. 9).

Death Spiral

The market manipulations mentioned in section 2.2.1 and section 2.2.2 can ultimately lead to a *"death spiral"* effect. A feasible hedge strategy for contingent capital holders could be short selling the underlying stock to profit from the dilution when contingent capital is converted into equity. This artificial pressure on the share could increase volatility and drive the stock price down even further. Such short sales could even force a firm's stock price to zero, hence destabilizing the system rather than stabilizing it (Flannery 2009, pp. 18-19; Maes & Schoutens 2010, p. 9; Pazarbasioglu et al. 2011, p. 11). This phenomenon was extensively covered in a paper by Hillion and Vermaelen (2001), where they examined 261 companies that issued convertible debt or preferred stock between December 1994 and August 1998. They discovered that in the year following the issuance, the average drop in the stock price of the companies amounted to 34% - although being in a bull market. This empirical evidence clearly supports the possibility of such a *"death spiral"*.

Now that the reader is familiar with the characteristics of the new capital instrument, the next section continues with two simple numerical examples to demonstrate the conversion mechanism and illustrate the issue of debt-overhang.

2.3 Numerical example

This section provides two easy numerical examples to show how contingent capital can effectively restore a firm's solvency and protect its claimholders. The first case serves to clarify the mechanism of conversion, whereas the second case includes the issue of debt-overhang raised in section 2.1. The calculations and assumptions are based on the examples provided by Flannery (2009, pp. 5-6, pp. 29-32) but extended and explained in more detail where the author seems fit. Both cases are treated as a "fixed dollar" conversion (cf. section 2.2.2), such that the contingent capital investors receive the par-value at conversion.

2.3.1 Example 1, Ignoring Debt-Overhang

At t_0 the company has a capital ratio of 10% - amounting to $10 - exceeding the minimum capital ratio of 7% (being equal to the trigger value for the conversion of the contingent convertible capital (CCC)). Assuming that the firm has 10 shares outstanding, then the price per share in $t_0 = \$1$. To illustrate the effect of dilution, it is further assumed that the firm has earnings of $10 or according earnings per share of $EPS = \$1$ in t_0. Earnings are fully paid out as dividend to shareholders.

Assets	Liabilities
$100 Loans	$80 Deposits
	$10 CCC
	$10 Equity (10%)

Table 3: Balance sheet t_0, without debt-overhang
(source: own illustration, based on Flannery (2009, pp. 29-32))

A drop in the asset value by seven dollars in t_1 reduces the loans to $93 and the equity is reduced to $3. Therefore, the equity ratio has dropped to 3.23%. In t_1 the earnings are assumed to be zero, such that the loss has to be absorbed by the equity alone, as shown in Table 4.

Assets	Liabilities
$93 Loans	$80 Deposits
	$10 CCC
	$3 Equity (3.23%)

Table 4: Balance sheet t_1, without debt-overhang
(source: own illustration, based on Flannery (2009, pp. 29-32))

The minimum threshold of 7% has been breached and therefore contingent capital has to be converted into equity to restore the minimum capital ratio of 7%. Assume that the contract specifies that the capital ratio after conversion is targeted at 8%. In this case, equity has to amount to $7.44 after conversion and outstanding contingent capital falls by $4.44 to $5.56.

Assets	Liabilities
$93 Loans	$80 Deposits
	$5.56 CCC
	$7.44 Equity (8%)

Table 5: Balance sheet t_2, partial conversion, without debt-overhang (source: own illustration, based on Flannery (2009, pp. 29-32))

The balance sheet at t_2 shown in Table 5 now fulfills the required capital ratio of 7% again.
It is obvious though that there has been a change in ownership in favor of the contingent capital investors. In t_1 the share price is reduced to $0.3. Therefore, contingent capital investors received 14.8 new shares during the conversion phase and own 59.68% of the outstanding shares ex-post. Assuming that in t_2 the firm had earnings of $10 again the resulting EPS is $0.40. E.g. the original shareholders are diluted by 59.68%.

If the entire amount of outstanding contingent capital would be converted into equity, the balance sheet in t_2 would have $13 worth of equity, amounting to 13.98%.

Assets	Liabilities
$93 Loans	$80 Deposits
	$0 CCC
	$13 Equity (13.98%)

Table 6: Balance sheet t_2, full conversion, without debt-overhang (source: own illustration, based on Flannery (2009, pp. 29-32))

In this case, contingent capital investors would receive 33.33 new shares and own 76.92% of the outstanding shares ex-post. The earnings per share would amount to $0.23.

2.3.2 Example 2, Including Debt-Overhang

The following example is a more likely scenario, which includes debt-overhang, where the market value of the debt can be affected by the drop in asset value. In t_0 example one and two are the same.

Assets	Liabilities
$100 Loans	$80 Deposits
	$10 CCC
	$10 Equity (10%)

Table 7: Balance sheet t_0, with debt-overhang (source: own illustration, based on Flannery (2009, pp. 29-32))

However, in t_1 the drop in asset value affects the credit quality of the firm, which consequently lowers the market value of debt. This effectively transfers value from debt holders to shareholders. This effect is shown in Table 8, where the increased leverage decreases the market value of contingent capital and increases the market value of equity.

Assets	Liabilities
$93 Loans	$80 Deposits
	$8.5 CCC
	$4.5 Equity (4.84%)

Table 8: Balance sheet t_1, with debt-overhang
(source: own illustration, based on Flannery (2009, pp. 29-32))

This extracted wealth from the debt holders ($1.50) would hypothetically be transferred to the initial shareholders, increasing their position to $4.50. But market participants know that a conversion of the contingent capital quickly re-capitalizes the firm, hence averting the wealth decline of the debt holders such that the situation illustrated in Table 8 cannot persist. Therefore, as in example 1, 14.8 new shares are issued at a price of $0.30 leading to the figures in Table 9.

Assets	Liabilities
$93 Loans	$80 Deposits
	$5.56 CCC
	$7.44 Equity (8%)

Table 9: Balance sheet t_2, partial conversion, with debt-overhang
(source: own illustration, based on Flannery (2009, pp. 29-32))

These simple calculations reveal a key insight: If the value of the assets does not jump such that the equity position is not wiped out completely, then the contingent capital is riskless, since in both examples the investors always receive their par value at conversion (Flannery 2009, pp. 31-32) (cf. section 2.2.2 / 3.5 / 4.2.1). But asset values cannot be assessed continuously - rather they move discretely and can include jumps. Therefore, there is a possibility that the equity might become negative and impose losses on contingent capital holders. Hence, the process used in the analytical analysis in the subsequent section 3 uses a jump diffusion process to model asset returns.

2.4 Conclusion

The introduction to the chapter provided a basic description of what contingent convertible capital is. Subsequently, the specific characteristics - namely the *trigger* and *conversion ratio* - of this new capital instrument were discussed at length and furthermore possible *risks* inherent to contingent convertible capital were identified. The numerical example at the end clarified the conversion mechanisms and presented the problem of debt-overhang.

The financial crisis has impressively showed that capital problems could not be reliably addressed as they occurred. A timely re-capitalization of a financial institution in distress could effectively minimize the cost for the public as well as the private sector. Therefore, making advance arrangements in the form of contingent capital could provide the necessary instrument to solve the problem. Not only would it remedy the problem of debt-overhang, but also other natural incentives to defer corrective measures could be circumvented. Furthermore, contingent capital would add to the firm's risk bearing capacity, lower its bankruptcy costs and possibly increase the firm's value due to the effect of the tax-shield.

2.4.1 RQ1

The question as to what the specific design features of contingent convertible capital are, as posed in research question one, can be answered as follows:

The *trigger* at which conversion occurs can depend on an idiosyncratic measure, a system-wide index or a dual-trigger design. Most existing proposals incorporate a market-driven, bank-specific measure to deal with the issues of lagging capital ratios or accounting manipulation. To mitigate the risk of market speculation, the trigger should be conditional upon the average stock price over a longer period. Furthermore, it has been shown that depending on the *level* of the trigger one can distinguish between high-level contingent capital, that serves to avert a systemic crisis, and low-level contingent capital, that ensures an orderly resolution in the case of insolvency.

It has been illustrated that different *conversion designs* can impact the shift in value between shareholders and bondholders. Furthermore, the conceptual analysis showed that the risk-premium is highest in the case of a conversion in a fixed amount of shares at a discount, whereas the required yield is lowest in the case of a conversion in a variable amount of shares at the par value. However, the dilution of ex-ante shareholders would be larger in the latter case.

Contingent convertible capital brings about new types of *risks* that have to be taken into account. Firstly, there is the possibility that the guarantor of contingent capital is not able to come up with the necessary funds at the time of conversion; hence, the issuing company has to correctly assess the *counterparty risk*. Secondly, there could be a *contagion effect* among issuing companies and thirdly, speculative attacks by contingent capital holders on the stock price could lead to potential *death spirals*.

Now that the reader is familiar with the qualitative framework that characterizes contingent convertible capital, the following chapter 3 introduces an analytical credit risk concept to evaluate how different real-world aspects of a financial institution interact with the contractual terms of its contingent convertible capital. The results are then shown within a case study on the Swiss bank Credit Suisse in chapter 4.

3 Analytical Credit Risk Concept

This section introduces an analytical credit risk concept, which is similar to the model developed by Ingersoll (1977) to value convertible securities. Ingersoll (1977) used the technique of modeling the value of assets using a stochastic process, as introduced by Merton (1974), and set up a synthetic balance sheet. Specifically, the assets are assumed to follow a Geometric Brownian Motion and the company's equity, its convertible debt and other debt are valued as claims contingent on the asset process. The model proposed in this paper incorporates certain refinements and extensions based on Merton (1976) and Pennacchi (2010) and allows for the possibility of discontinuous asset returns, stochastic interest rates and mean reverting capital ratios.

The results of this concept are presented in chapter 4 and allow answering the following research questions in the concluding chapter 5:

RQ2: What are fair new issue yields on contingent convertible capital for different contract specifications and bank variables?

RQ3: How do fair new issue yields on contingent convertible capital compare vis-à-vis yields on contingent capital bonds issued by Credit Suisse?

3.1 Jump Diffusion Process for Asset Returns

Asset returns are commonly modeled using a certain mathematical instrument called Geometric Brownian Motion (GBM). However, the continuous sample path of a GBM produces log-normal returns and therefore fails to capture fat-tail events as observed in empirical probability distribution functions. Consequently, this paper introduces a jump diffusion method to model the underlying asset process. Within a jump diffusion model, the change in asset returns is a composite of two types of changes: Firstly, the *continuous marginal change* in the asset returns modeled by a standard GBM and secondly, the *abnormal jumps* (e.g. due to newly available information that has a higher than marginal impact on the asset return) driven by a Poisson process (Duffie & Lando 2001, p. 634; Hull 2008, pp. 563-564; Merton 1976, pp. 127-128).

3.1.1 Brownian Motion

In order to derive the jump diffusion process, one has to start with defining the so called Wiener Process or elementary Brownian Motion. Hull (2008, pp. 265-267) and Seydel (2006, p. 26) provide the following definition:

Definition 3.1 *(Wiener Process, Brownian Motion)*

A Wiener process or Brownian Motion W_t is a time-continuous process with the following properties:

(a) $W_0 = 0$ *with probability one*

(b) $W_t = \phi(0, t)$ *for all* $t \geq 0$*. That is, for each t the random variable* W_t *is normally distributed with mean* $E(W_t) = 0$ *and variance* $Var(W_t) = t$*.*

(c) All increments $\Delta W_t := W_{t+\Delta t} - W_t$ *on non-overlapping time intervals are independent.*

(d) W_t *depends continuously on t.*

The following equation represents a Wiener Process / Brownian Motion, where z is independent and identically distributed and $z = \phi(0,1)$

$$\Delta W_t = z\sqrt{\Delta t} \tag{3.1}$$

If we introduce a drift and a rate of variance, a process X_t is called a Brownian Motion with drift μ and diffusion coefficient σ^2 if

$$\frac{X_t - \mu t}{\sigma} \tag{3.2}$$

is characterized by a standard Brownian Motion (Glasserman 2004, p. 80).

3.1.2 Itô Stochastic Differential Equation and Geometric Brownian Motion

Using the Brownian Motion outlined in equation (3.2) and allowing for the drift parameter μ and the diffusion coefficient σ^2 to be time-dependent, the Itô (1951) stochastic differential equation can be defined (Hull 2008, p. 269; Seydel 2006, p. 32)

$$dX_t = \mu(X_t, t)dt + \sigma(X_t, t)dW_t \tag{3.3}$$

where

$\mu(X_t, t)$ is the drift term,

$\sigma(X_t, t)$ is the diffusion term,

W_t is a Wiener Process.

Now it is possible to focus on the Geometric Brownian Motion X_t, which is a special kind of stochastic differential equation

$$dX_t = \mu X_t dt + \sigma X_t dW_t \tag{3.4}$$

where

μ is the expected rate of return

σ is the standard deviation of the return

W_t is a Wiener Process.

Assuming that X_t is the price of an asset, the GBM implies that the change in price $\frac{dX_t}{X_t}$ in a time interval dt consists of a deterministic μ and stochastic shocks σdW_t (Glasserman 2004, pp. 93-94; Hull 2008, p. 270; Seydel 2006, pp. 34-36).

Now that the reader is familiar with the GBM, the next section introduces the jump diffusion process.

3.1.3 Jump Diffusion Process

The basic element of a jump diffusion process is a Poisson process (Merton 1976, p. 128; Seydel 2006, p. 45). Starting with a Bernoulli experiment with either 1 or 0 as an outcome and an interval length of $\Delta t := \frac{T}{n}$, the respective probabilities $P()$ are

$$P(J_t - J_{t-\Delta t} = 1) = \lambda \Delta t \tag{3.5}$$
$$P(J_t - J_{t-\Delta t} = 0) = 1 - \lambda \Delta t$$

for $0 < \lambda \Delta t < 1$, where λ is the intensity of the jump process and J_t is a counting variable, which counts the discrete time points $t_1 < t_2 < t_n$ at which jumps occur (Merton 1976, p. 128; Seydel 2006, p. 45). Generally, the probability of k jumps occurring in $0 < t < T$ is

$$P(J_t - J_0 = k) = \binom{n}{k} (\lambda \Delta t)^k (1 - \lambda \Delta t)^{n-k} \tag{3.6}$$

which for $n \to \infty$ converges to the Poisson distribution

$$\frac{(\lambda t)^k}{k!} e^{-\lambda t} \tag{3.7}$$

This finding lets us define the Poisson process (Glasserman 2004, pp. 134-135; Merton 1976, p. 128; Seydel 2006, pp. 45-46).

Definition 3.2 *(Poisson process)*

The stochastic process $\{J_t, t \geq 0\}$ *is called Poisson process if the following conditions hold:*

(a) $J_0 = 0$

(b) $J_t - J_s$ *are integer-valued for* $0 \leq s < t < \infty$ *and*

$P(J_t - J_s = k) \frac{\lambda^k (t-s)^k}{k!} e^{-\lambda(t-s)}$ *for k = 0, 1, 2, n*

(c) The increments $J_{t2} - J_{t1}$ *and* $J_{t4} - J_{t3}$ *are independent for all* $0 \leq t_1 < t_2 < t_3 < t_4$

The risk neutral probability of a Poisson event occurring is $\lambda_t d_t$ (Hull 2008, p. 563). Given that an event occurs, there is a discontinuous change at date t_n determined by an assigned identically and independently distributed random variable q_{t_n} from $\phi(\mu_\lambda, \sigma_\lambda^2)$, where μ_λ is the mean jump size and σ_λ is the standard deviation of the jump sizes. The compound Poisson process can then be modeled with the following stochastic differential equation (Seydel 2006, p. 47)

$$dX_t = (q_{t_n} - 1) X_t dJ_t \tag{3.8}$$

where

J_t is a Poisson process

$q_{t_1}, q_{t_2}, q_{t_n}$ are identically, independently distributed random variables

The compound Poisson process can now be superimposed to the GBM in equation (3.4) and divided by $X_t \neq 0$, to arrive at the final jump diffusion process to model the change in asset returns (Glasserman 2004, p. 137; Hull 2008, p. 563; Merton 1976, pp. 128-129; Seydel 2006, p. 47).

$$\frac{dX_t}{X_t} = (\mu_t - \lambda_t k_t)dt + \sigma dW_t + (q_{t_n} - 1)dJ_t \tag{3.9}$$

where

$\mu_t = r_t$ is the date t default-free, instantaneous maturity interest rate (cf. section 3.2)

k_t is the risk-neutral expected proportional jump

σ is the standard deviation of the return

W_t is a Wiener Process

J_t is a Poisson Process

$q_{t_1}, q_{t_2}, q_{t_n}$ are identically, independently distributed random variables

Graphical Illustration

The following figures serve to clarify the difference between a normal GBM as represented in equation (3.4) and the stochastic differential equation including jumps as shown in equation (3.9). Figure 2 represents the evolution of a normal GBM over 500 trading days. The according Quantile-Quantile-plot (QQ-plot) depicted in Figure 3 is nearly linear and therefore indicates that the simulated returns are close to normally distributed.

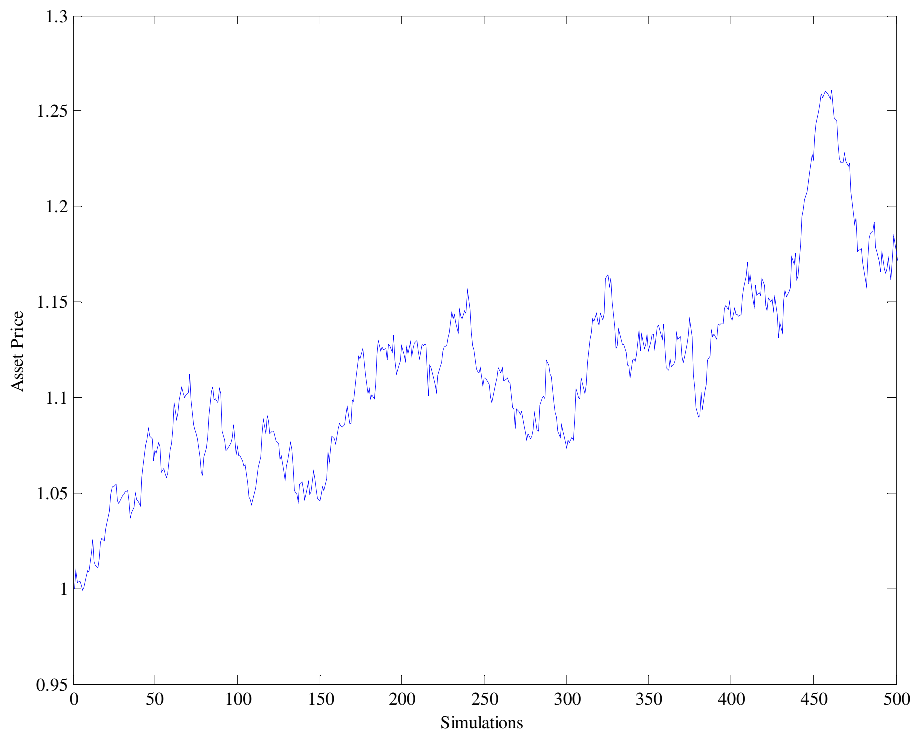

Figure 2: Sample path evolution of GBM with: $X_0 = 1$, $\Delta t = 0.004$, $\mu = 0.07$, $\sigma = 0.1$ (source: own illustration)

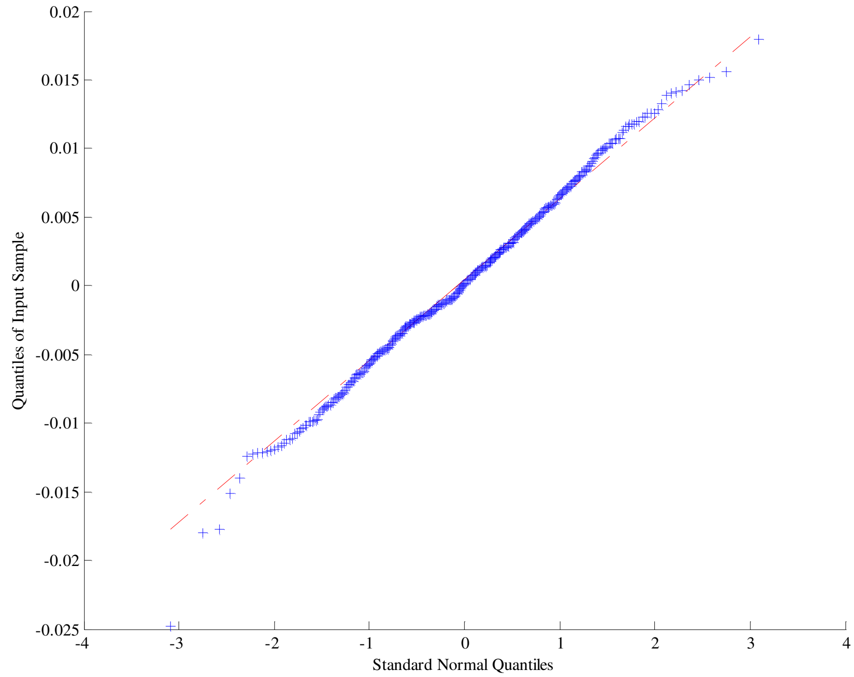

Figure 3: QQ-Plot of GBM sample data versus standard normal with: $X_0 = 1$, $\Delta t = 0.004$, $\mu = 0.07$, $\sigma = 0.1$ (source: own illustration)

The evolution of the jump diffusion process as defined in equation (3.9) is depicted in Figure 4.[2] From this it can be observed that there are obvious up- and downward jumps at discrete points in time.

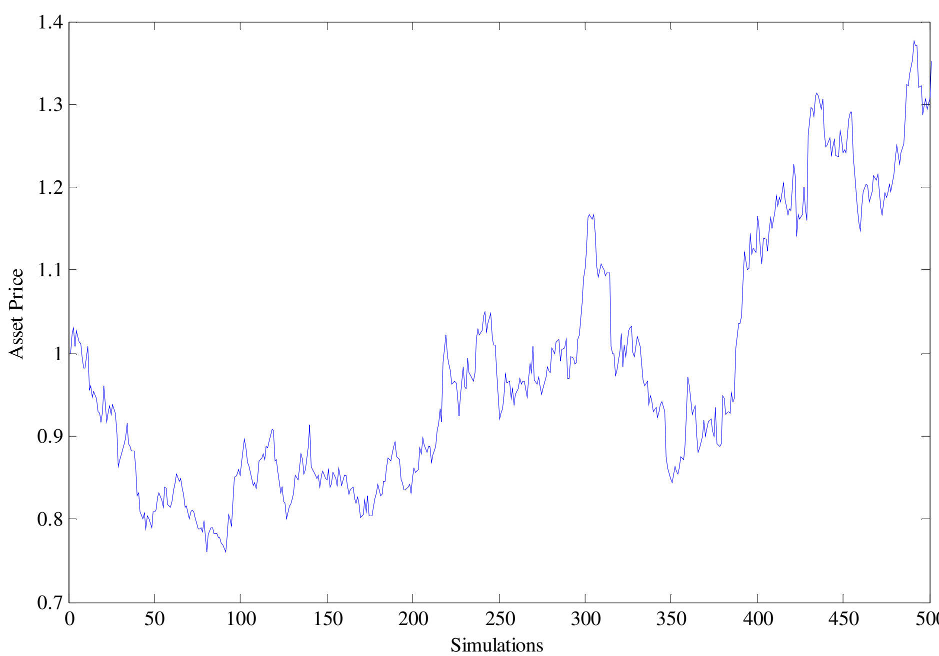

Figure 4: Sample path evolution of a jump diffusion process with: $X_0 = 1$, $\Delta t = 0.004$, $\mu = 0.0526$, $\sigma = 0.2296$, $\lambda = 112.1749$, $\mu_\lambda = -0.0014$, $\sigma_\lambda = 0.0212$ (source: own illustration)

[2] The parameters of the jump diffusion process have been estimated using a maximum likelihood approach on the empirical stock returns of Credit Suisse between May 2009 and April 2011 (Brigo et al. 2007, pp. 18-20; Hull 2008, pp. 467-470). The according Matlab code is provided in the appendix.

Furthermore, the QQ-plot in Figure 5 shows a larger deviation in the negative as well as in the positive quantiles, indicating fat tails as opposed to the normal distribution (dashed line).

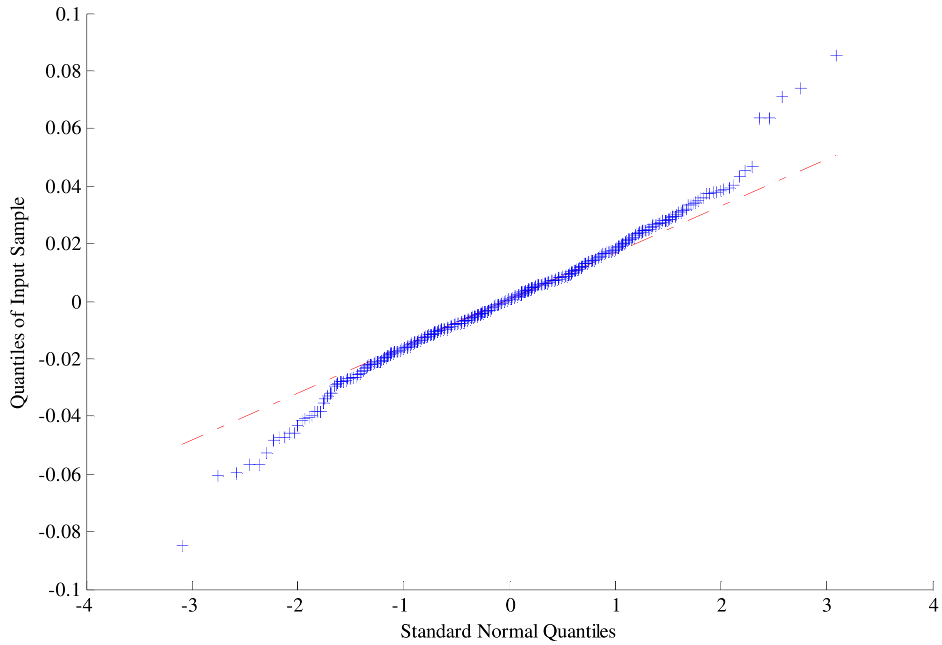

Figure 5: QQ-Plot of sample data of jump diffusion process versus standard normal with: $X_0 = 1$, $\Delta t = 0.004$, $\mu = 0.0526$, $\sigma = 0.2296$, $\lambda = 112.1749$, $\mu_\lambda = -0.0014$, $\sigma_\lambda = 0.0212$ (source: own illustration)

For comparison, Figure 6 shows the empirical path evolution of the Credit Suisse share between May 2009 to April 2011. The corresponding QQ-Plot in Figure 7 of the observed returns clearly shows fat tails.

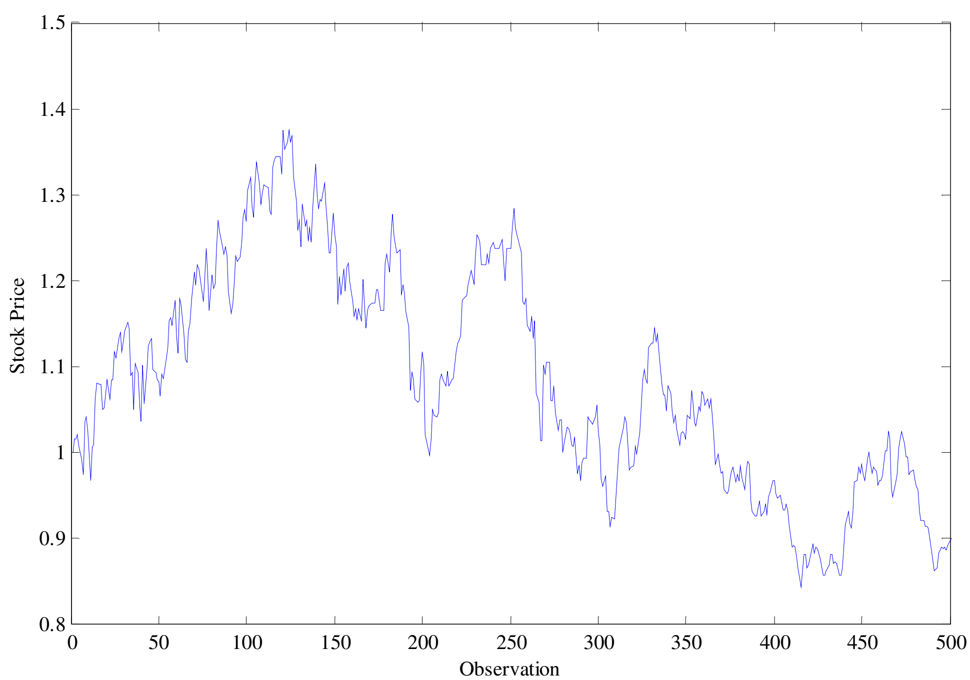

Figure 6: Credit Suisse share price evolution between May 2009 to April 2011, rebased to 1 (source: own illustration, stock prices were acquired from Thomson Reuters Datastream)

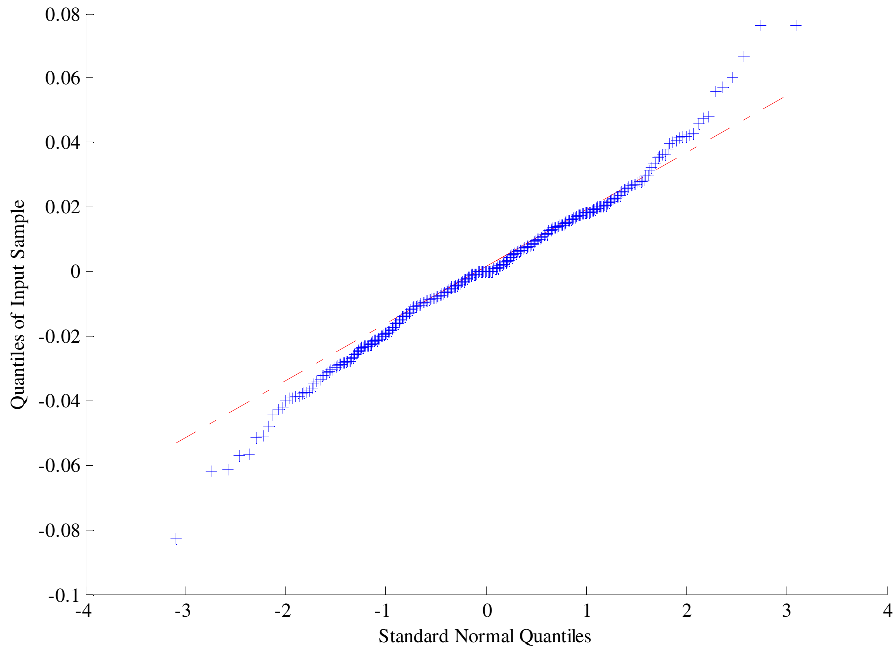

Figure 7: QQ-Plot of sample data of Credit Suisse share returns between May 2009 to April 2011 versus standard normal (source: own illustration, stock prices were acquired from Thomson Reuters Datastream)

The comparison shows that using a calibrated jump diffusion process to simulate asset returns clearly provides a better fit to the empirical data and therefore reflects the inherent riskiness more accurately.

3.2 Default-Free Term Structure

To account for the stochasticity of the interest rate environment, the model should be able to generate different default-free term structures to assess the impact on the fixed- respectively floating-rate coupon payments of the outstanding debt. This paper uses the model developed by Cox et al. (1985), which is basically an extension of an earlier model developed by Vasicek (1977). Therefore, this section in a first part introduces the model developed by Vasicek (1977) and in a second part provides the extension to the model by Cox et al. (1985).

3.2.1 Vasicek Term Structure Model

Vasicek's (1977, p. 185) approach was to model the term structure with a single factor, the continuous short-term interest rate r_t, therefore being the only risk factor for the pricing of all interest rate derivatives. The model specifies that the instantaneous interest rate follows a mean-reverting (Ornstein-Uhlenbeck (1930)) process defined by the following stochastic differential equation (Vasicek 1977, p. 185)

$$dr_t = \kappa(\bar{r} - r_t)dt + \sigma_r dW_t \tag{3.10}$$

where

κ is the speed of convergence

$\bar{r}$ is the long-run equilibrium interest rate

r_t is the continuous short-term interest rate

σ_r is the instantaneous volatility

W_t is a Wiener Process

For the valuation of a default-free zero bond, the model constructs a hedge portfolio with which, excluding the possibility of arbitrage, a formula for the value P as a function of the stochastic factor r_t can be obtained (Vasicek 1977, p. 179)

$$P(t,T) = A(t,T)exp^{-r_t B(t,T)} \quad (3.11)$$

where

$$A(t,T) = exp\left\{\frac{(B(t,T)-(T-t))\left\{\kappa^2\bar{r}-\frac{\sigma^2}{2}\right\}}{\kappa^2} - \frac{\sigma^2}{4\kappa}B(t,T)^2\right\} \quad (3.12)$$

and

$$B(t,T) = \frac{1}{\kappa}\left\{1-exp^{-\kappa(T-t)}\right\} \quad (3.13)$$

Since $P(t,T) = e^{-(R_{T(t)})(T-t)}$, where $R_{T(t)}$ denotes the interest rate for a specific term $(T-t)$ at time t, it follows that

$$R_{T(t)} = \frac{1}{T-t}(B(t,T)r(t) - lnA(t,T)) \quad (3.14)$$

In this way, the entire yield curve can be generated as a function of $r(t)$ and the three endogenously defined parameters $\kappa,\ \bar{r}\ and\ \sigma_r$ (Copeland, Weston & Shastri 2005, p. 267).
However, a potential drawback of this model is that interest rates can become negative, which is an undesirable feature. Therefore, the next section introduces the extension to the model developed by Cox et al. (1985), which provides a solution to this shortcoming.

3.2.2 Cox Ingersoll Ross Term Structure Model

Cox et al. (1985, p. 391) address aforementioned problem of negative interest rates by linking the instantaneous volatility σ_r to the short term interest rate r_t, such that equation (3.10) can be expressed as

$$dr_t = \kappa(\bar{r} - r_t)dt + \sigma_r\sqrt{r_t}dW_t \quad (3.15)$$

where

κ is the speed of convergence

$\bar{r}$ is the long-run equilibrium interest rate

r_t is the continuous short-term interest rate

σ_r is the instantaneous volatility

W_t is a Wiener Process

This ensures that the modeled interest rates are strictly positive.

The price of a zero bond at time t with maturity $t\ to\ T$ is equal to equation (3.11), but where (Cox, Ingersoll & Ross 1985, p. 393)

$$A(t,T) = \left\{\frac{x exp^{y(T-t)}}{y\{exp^{x(T-t)}-1\}+x}\right\}^{z} \tag{3.16}$$

,

$$B(t,T) = \left\{\frac{exp^{x(T-t)}-1}{y\{exp^{x(T-t)}-1\}+x}\right\} \tag{3.17}$$

and

$$x = \sqrt{\kappa^2 + 2{\sigma_r}^2} \tag{3.18}$$
$$y = \frac{\kappa + x}{2}$$
$$z = \frac{2\kappa\bar{r}}{{\sigma_r}^2}$$

A sample evolution of the instantaneous interest rate as modeled by Cox et al. (1985) is shown in Figure 11.[3]

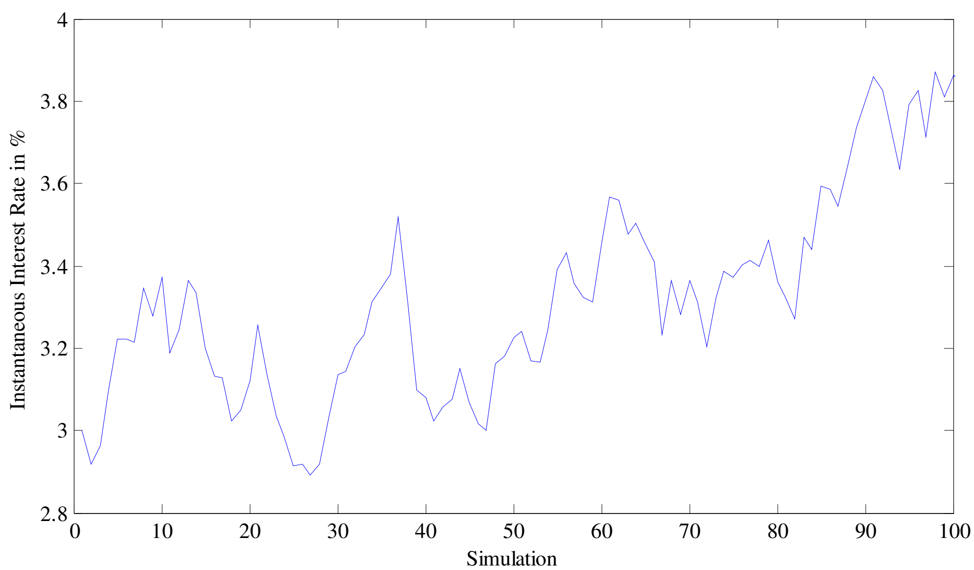

Figure 8: Cox Ingersoll Ross evolution of instantaneous interest rate with: $\kappa = 0.1104$, $\bar{r} = 0.0509$, $\sigma_r = 0.0498$, $r_0 = 0.03$ (source: own illustration)

The fair coupon rate to evaluate the impact on fixed- respectively floating-rate coupon payments can be derived as follows (Pennacchi 2010, pp. 12-13)

$$c_r = \frac{1 - A(t,T)exp^{-B(t,T)r_t}}{\int_0^{(t,T)} A(s)exp^{-B(s)r_t}ds} \tag{3.19}$$
$$\approx \frac{1 - A(t,T)exp^{-B(t,T)r_t}}{\sum_{i=1}^{i=n} A(\Delta t \times i)exp^{-B(\Delta t \times i)r_t}\Delta t}$$

[3] Cf. section 4.1.2 for a sample yield curve and the calibrated model parameters.

where Δt indicates the timestep and $n = (t, T)/\Delta t$ stands for the number of iterations in the simulation.

3.3 Deposits

In accordance with Adrian and Shin (2010), Flannery and Rangan (2008) as well as Memmel and Rapauch (2010) the model incorporates the finding that banks have target leverage ratios and that deposit growth is positively correlated to the amount of capital. Additionally, as already mentioned in section 1.2.1, Swiss regulators have introduced a leverage ratio, which defines a minimum amount of capital-to-assets for UBS and Credit Suisse, which should exceed 5% in good times (Commission of Experts 2010, p. 33). Therefore, deposit growth $\frac{dD_t}{D_t}$ is linked to the current asset-to-deposit ratio $x_t \equiv \frac{A_t}{D_t}$ in a mean-reverting way, such that

$$\frac{dD_t}{D_t} = g(\hat{x} - x_t)dt \qquad (3.20)$$

where $\hat{x} > 1$ is a target asset-to-deposit ratio and $g > 0$ is the speed of convergence. E.g. if $x_t > \hat{x}$ the financial institution would acquire new deposits. In this setting a bank failure occurs whenever the value of assets falls below the value of deposits, $A_t \leq D_t$, or equivalently $x_t \leq 1$ (Pennacchi 2010, p. 6). Furthermore, the model assumes that deposits are either short-term or represent overnight sources of funding and therefore have an instantaneous maturity. Additionally, deposits pay a continuous return of $(r_t + h_t)D_t dt$, where r_t is the risk-free interest rate (cf. section 3.2) and h_t is a fair credit-risk premium based on the risk neutral expectation of a loss for the depositors (cf. section 3.3.1) (Pennacchi 2010, p. 6).

3.3.1 Credit Spreads

Depositors only suffer losses if the downward jump in asset value surpasses the bank's total capital $A_t - D_t$. Therefore, the fair credit risk premium h_t has to reflect the risk neutral expectation of such a loss (Pennacchi 2010, pp. 13-14). This relationship is shown in the following equation

$$h_t = \lambda_t E_t^Q \left\{ max \left\{ \frac{D_t - q_t A_t}{D_t}, 0 \right\} \right\} \qquad (3.21)$$

Assuming that λ_t is a constant and that the Poisson jump sizes q_{t_n} are identically, independently distributed random numbers from $\phi(\mu_y, \sigma_y^2)$ it can be proven that[4]

$$h_t = \lambda\{\phi(-d1) - x_t\text{-}\exp\{\mu_y + 0.5\sigma_y^2\}\phi(-d2)\} \qquad (3.22)$$

where

[4] See Pennacchi (2010, p. 29) for proof.

$$d_1 = \frac{\ln(x_t) + \mu_y}{\sigma_y} \tag{3.23}$$

$$d_2 = d_1 + \sigma_y$$

This ensures that depositors always receive the fair credit spread for bearing the risk of a potential loss.

3.4 Conversion Threshold

The conversion threshold $\bar{e}$ (trigger, cf. section 2.2.1) is set in terms of the ratio of the observable market value of original shareholder's equity E_t to deposits D_t

$$\bar{e} = \frac{E_t}{D_t} = \frac{A_t - D_t - pB}{D_t} = \bar{x}_t - 1 - pb_t \tag{3.24}$$

In this case, $\bar{x}_t = \frac{A_t}{D_t} = 1 + \bar{e} + pb_t$ is the asset-to-deposit ratio and $b_t = \frac{B}{D_t}$ is the par value of contingent capital-to-deposit ratio at time t (Pennacchi 2010, pp. 9-10).

As illustrated in section 2.2.2, the conversion ratio p can be below one such that conversion occurs at a discount to par value. This implies that the resulting total capital after a conversion might not satisfy the desired target capital ratio.[5] E.g. if $\bar{e} = 2\%, b_{t_h} = 4\%$ and $p = 0.9$ then contingent capital would get converted into 3.6% new equity relative to deposits, such that total capital would be worth only 5.6% instead of 6%, as in the case if $p = 1$. To adjust for this, the conversion threshold $\bar{e}$ at the date of issuance of the contingent capital has to be set according to (Pennacchi 2010, p. 10)

$$\bar{e}_p = \bar{e}_{p=1} + (1-p)\frac{B}{D_0} = \bar{e}_{p=1} + (1-p)b_0 \tag{3.25}$$

or equivalently

$$\bar{x}_t = 1 + \bar{e}_{p=1} + b_0 + p(b_t - b_0) \tag{3.26}$$

3.5 Contingent Convertible Capital

The bank's long-term financing can take the form of contingent capital in place of subordinated debt. The contingent capital has a par value of B and pays a continuous coupon $c_t B d_t$, where $c_t = c$ in the case of a fixed-rate coupon or $c_t = r_t + s$ in the case of a floating-rate coupon. In the latter case, s denotes a fixed spread over the short term interest rate r_t. In both cases, the coupon rate is set such that the bond is valued at par at the time of issuance (Pennacchi 2010, pp. 7-8).

The model is able to accommodate all possible conversion sharing rules as discussed in section 2.2.2. Specifically, conversion of the contingent capital occurs at a contractual conversion value p if a pre-specified asset-to-deposit ratio $\bar{x}_t = \frac{A_t}{D_t} > 1$ is breached (cf. section 3.4). The threshold ratio changes depending on the market value of shareholder's equity E_t and the market value of the contingent

[5] The model assumes a full conversion of the outstanding contingent capital if the threshold is breached. For a model using partial conversion, please refer to Glasserman and Nouri (2010).

capital V_t, since $x_t - 1 = \frac{V_t+E_t}{D_t}$ can be observed at any time between 0 and T. The final value of contingent capital V_{t_c} at the date of conversion t_c is determined by the bank's residual capital $A_{t_c} - D_{t_c}$ and the conversion sharing ratio p (cf. section 2.2.2) (Pennacchi 2010, pp. 7-8).

$$V_{t_c} = \begin{cases} pB & if\ pB \leq A_{t_c} - D_{t_c} \\ A_{t_c} - D_{t_c} & if\ 0 < A_{t_c} - D_{t_c} \leq pB \\ 0 & if\ A_{t_c} - D_{t_c} \leq 0 \end{cases} \tag{3.24}$$

3.6 Subordinated Debt

Subordinated debt can be characterized as contingent capital that has a conversion threshold of $\bar{e} = 0\%$. The risk for subordinated debt holders to receive less than their par value in case of a restructuring is therefore higher than for contingent capital holders because of the lower equity cushion (cf. section 4.2.1).

It is issued with a par value of B and continuously pays a fixed- or a floating-rate coupon analogously to contingent capital (cf. section 3.5), as long as $A_t > B + D_t$. The payoff in case of an insolvency, $A_t \leq B + D_t$, can be characterized as follows (Pennacchi 2010, p. 11)

$$V_{t_c} = \begin{cases} A_{t_c} - D_{t_c} & if\ 0 < A_{t_c} - D_{t_c} \leq B \\ 0 & if\ A_{t_c} - D_{t_c} \leq 0 \end{cases} \tag{3.25}$$

3.7 Shareholder's Equity

Similarly, also the shareholder's equity E depends on the residual value taking into account the final payment to the contingent capital holders pB in case of a conversion, as illustrated in equation (3.26) (Pennacchi 2010, p. 9).

$$E_{t_c} = \begin{cases} A_{t_c} - D_{t_c} - pB & if\ pB < A_{t_c} - D_{t_c} \\ 0 & if\ A_{t_c} - D_{t_c} \leq pB \end{cases} \tag{3.26}$$

In case the bank does not need to convert its contingent capital into equity between time t and T, then the shareholder's equity value at maturity of the debt capital is $E_T = A_T - B - D_T$ where B is the par value of the contingent convertible capital or the subordinated debt respectively.

3.8 Valuation of Contingent Convertible Bonds

The value of contingent capital for a specific coupon rate can be found using the concept of risk-neutral valuation (Copeland, Weston & Shastri 2005, pp. 291-220, p. 890; Hull 2008, pp. 244-245, p. 315, pp. 594-595):

$$V_0 = E_0^Q \left\{ \int_0^T exp^{-\int_0^t r_t ds} v(t) dt \right\} \tag{3.27}$$

where $v(t)$ denotes the cash flows from the coupon payments, Q is the risk-neutral probability and r_t is the risk-free discount rate.

The risk neutral process of the asset-to-deposit ratio of the bank can be expressed by deducting the interest payments on deposits (cf. section 3.3) and contingent / subordinated capital (cf. section 3.5, respectively 3.6) from the original asset return process defined in equation (3.9) and combining it with the deposit growth process defined in equation (3.20) (Pennacchi 2010, p. 16).

$$\frac{dX_t}{X_t} = \left\{(r_t - \lambda_t k_t) - \frac{r_t + h_t + c_t b_t}{x_t} - g(\hat{x} - x_t)\right\} dt + \sigma W_t + (q_{t_n} - 1) dJ_t \tag{3.28}$$

To be able to model the stochastic dynamics of this process one has to apply Itô's lemma (Hull 2008, pp. 273-276; Itô 1951) to arrive at

$$dln(X_t) = \left\{(r_t - \lambda_t k_t) - \frac{r_t + h_t + c_t b_t}{x_t} - g(\hat{x} - x_t) - 0.5\sigma^2\right\} dt + \sigma W_t + lnq_{t_n} dJ_t \tag{3.29}$$

In each simulation step, the instantaneous-maturity interest rate r_t, the asset-to-deposit ratio x_t and the corresponding value of h_t is simulated and equation (3.27) is evaluated. The average over a large number of simulations yields the initial value V_0 of the contingent capital. The corresponding fair coupon c is then found by setting the initial value equal to the par value $V_0 = B$ (Pennacchi 2010, pp. 17-18).

To summarize the model and to give an overview of the plethora of parameters that can be set, the following Table 10 shows the equations involved in the simulation process as well as their respective input parameters.

3.9 Parameter Overview

Jump Diffusion Process for Asset Returns	
$\frac{dX_t}{X_t} = (r_t - \lambda_t k_t)dt + \sigma dz + \left(Y_{q_{t_n}} - 1\right) dq_t$	
Var.	Description
r_t	Date t instantaneous-maturity interest rate
σ	Annual standard deviation of asset returns
λ_t	Annual risk neutral frequency of jumps
μ_y	Risk-neutral mean jump size
σ_y	Standard deviation of jumps

Default-Free Term Structure	
$dr_t = \kappa(\bar{r} - r_t)dt + \sigma_r \sqrt{r_t} dW$	
Var.	Description
κ	Speed of convergence
$\bar{r}$	Long-run interest rate
r_t	Date t instantaneous-maturity interest rate
σ_r	Standard deviation of interest rate changes

Deposit Growth Process	
$\frac{dD_t}{D_t} = g(\hat{x} - x_t)dt$	
Var.	Description
g	Speed of convergence
$\hat{x}$	Target asset-to-deposit ratio
x_t	Asset-to-deposit ratio

Conversion Threshold	
$\bar{e} = \frac{E_{t_h}}{D_{t_h}} = \frac{A_{t_h} - D_{t_h} - pB}{D_{t_h}} = \bar{x}_{t_h} - 1 - pb_{t_h}$	
Var.	Description
$\bar{e}$	Conversion threshold (trigger) (original shareholder's equity to deposits)
p	Conversion ratio
b_{t_h}	Contingent capital to deposit ratio at time t

Global Parameters	
Var.	Description
ϱ	Correlation between Brownian motion returns of the asset process and the changes in the short-term interest rate
T	Maturity in years of contingent capital / subordinated debt
dt	Length of each sub-period

Table 10: Parameter overview (source: own illustration)

4 Case Study and Results

This section puts the theoretical model in a practical context by conducting a case study on Credit Suisse. In a first part, the relevant model parameters are calibrated using specific information from Credit Suisse. In a second part, different contract parameters of contingent convertible capital are chosen to examine how the fair new issue yields are affected.

4.1 Calibration

The analytical credit risk model as described in section 3 allows for a variety of variables to be set (cf. Table 10). Some of the parameters are set according to bank specific data, whereas other variables depend on estimations.

4.1.1 Jump Diffusion Process for Asset Returns

A maximum likelihood approach has been applied to the stock returns of Credit Suisse from May 2000 to April 2011 to get an initial estimate for probable model parameter inputs (Brigo et al. 2007, pp. 18-20; Hull 2008, pp. 467-470). However, a simple back-testing with data on asset values reveals, that the estimation outcome does not deliver an acceptable result, as it grossly overestimates the number of jumps $\lambda \approx 80$ and in turn underestimates the mean jump size $\mu_y \approx -0.05\%$.[6] Therefore, the estimated parameters are backed up using historic rates of return on assets (RoA). Specifically, the time series encompasses the net income and the total assets from the year 2000 to 2010. From this, the standard deviation of the RoA can be computed, which amounts to $\sigma = 0.45\%$.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Net Income	5'785	1'587	-3'309	4'999	5'628	5'850	11'327	7'760	-8'218	6'724	5'098
Total Assets	987'433	1'022'513	955'656	962'164	1'089'485	1'339'052	1'255'956	1'360'680	1'170'350	1'031'427	1'032'005
RoA	0.59%	0.16%	-0.35%	0.52%	0.52%	0.44%	0.90%	0.57%	-0.70%	0.65%	0.49%

Table 11: Return on assets Credit Suisse, 2000-2010 (in CHF million, source: own illustration, the data was acquired from Thomson Reuters Datastream)

The goal is to simulate a similar event that happened during the recent financial crisis. Therefore, λ is chosen to equal 1 and the risk-neutral mean jump size is equal to $\mu_y = -1\%$. Recalling that the risk neutral probability of a Poisson event occurring is $\lambda_t d_t$ and $d_t = \frac{1}{250} = 0.004$, a jump occurs once per year (Hull 2008, p. 563; Merton 1976, p. 129). In this respect, Credit Suisse (2008, p. 71) had net valuation adjustments of roughly 11 billion Swiss Francs in 2008, largely stemming from commercial and residential mortgage backed securities and subprime collateralized debt securities. Relative to the average total assets between 2000 and 2010 of about 1'100 million Swiss Francs, a mean jump size of $\mu_y = -1\%$ is an appropriate approximation. This measure is supported by similar calculations

[6] The complete parameter estimations are as follows: $\hat{\mu} = -0.0541,\ \hat{\sigma} = 0.2090,\ \hat{\lambda} = 79.5441,\ \hat{\mu}_y = -0.0005,\ \hat{\sigma}_y = 0.0213$

performed by the Commission of Experts (2010, p. 29). The estimated standard deviation of the jump size at $\sigma_y = 2\%$ is assumed to be reasonable and is in line with Pennacchi's assumption (2010, p. 18).[7] To correctly set the correlation between the asset process and the instantaneous-maturity interest rate of the model by Cox et al. (1985), the long-run daily correlation (2001-2007) between the changes in five year Swiss sovereign bonds and the return on the Swiss Market Index has been assessed and compared with Pennacchi's (2010, p. 18) approximation of the daily correlation between changes in US treasury bill yields and the S&P 500 stock index returns. The result shows that ϱ is around -0.2, which is consistent with the result of Pennacchi (2010, p. 18). This indicates on the one hand that the correlation between daily changes in Swiss sovereign bonds and the according returns of the Swiss Market Index is nearly similar to the correlation between changes in the yield of US treasury bills and the return on the S&P 500 stock index and on the other hand provides further support that $\varrho = -0.2$ is a reasonable measure.

4.1.2 Default-Free Term Structure

The parameters for the default-free term structure are calibrated using a Kalman-Filter implementation as originally applied by Duan and Simonato (1999, p. 112).[8] Specifically, the Kalman-Filter has been applied to four monthly US treasury bill yield series with maturities of 3, 6, 12 and 60 months.[9] The original data series encompasses 566 observations, spanning a time horizon from April 1964 to April 2011 as shown in Figure 9. The corresponding maturities are indicated on the z-axis and the yield is depicted on the y-axis.

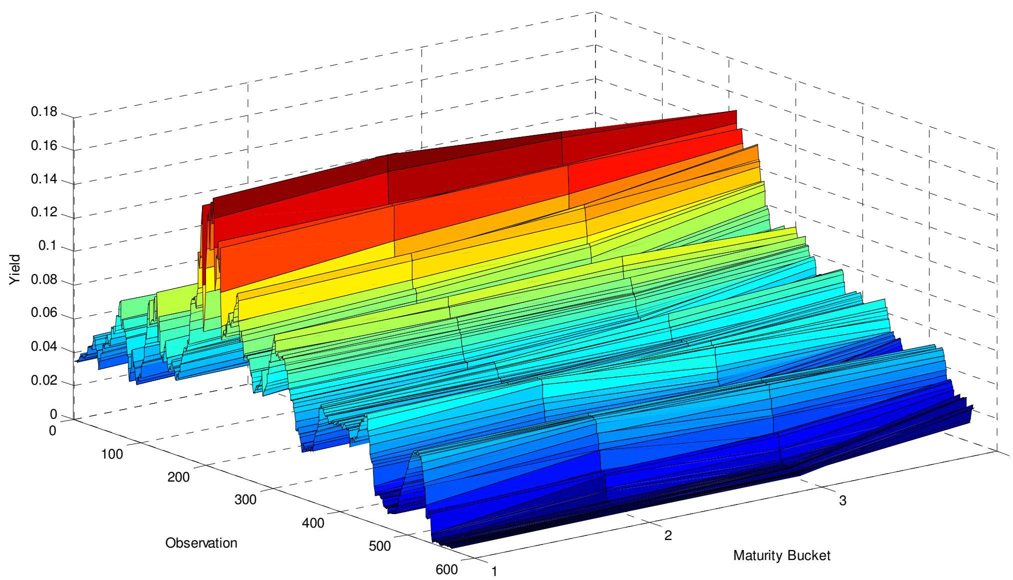

Figure 9: US treasury bill term structure April 1964 to April 2011
(source: own illustration, treasury bill yields were acquired from Center for Research in Security Prices (CRSP))

[7] Assuming a capital-to-asset ratio of 10%, the chosen jump diffusion parameters result in a standard deviation of stock returns of approximately 25%, which is close to the estimated $\hat{\sigma} = 20.9\%$.
[8] A comprehensive description of the Kalman-Filter method can be found in Harvey (1990), chapter 3. The corresponding Matlab code is provided in the appendix.
[9] Seeing that most capital issues are still largely denominated in US dollars, US treasury yield series have been used.

The resulting factors are $\kappa = 0.1687\,, \bar{r} = 0.0457\; and\; \sigma_r = 0.0678$.

However, empirical studies, e.g. by Hamilton (1987) and Spindt and Tarhan (1987), indicate that there has been a structural break in the interest rates between October 1979 to October 1982 (which can be easily observed in Figure 9 between observation 180 and 220). Therefore, similarly to Duan and Simonato (1999, p. 118), the dataset has been truncated into two time frames: The first time frame includes observations from April 1964 to October 1979 and the second time frame includes observations from October 1982 to April 2011. An exemplary truncated term structure from October 1982 to April 2011 is depicted in Figure 10. In each case, the Kalman-Filter has been applied to extract the according parameters for the Cox et al. (1985) model. The resulting parameters for the first time frame are $\kappa = 0.2461\,, \bar{r} = 0.0650\; and\; \sigma_r = 0.0609$.

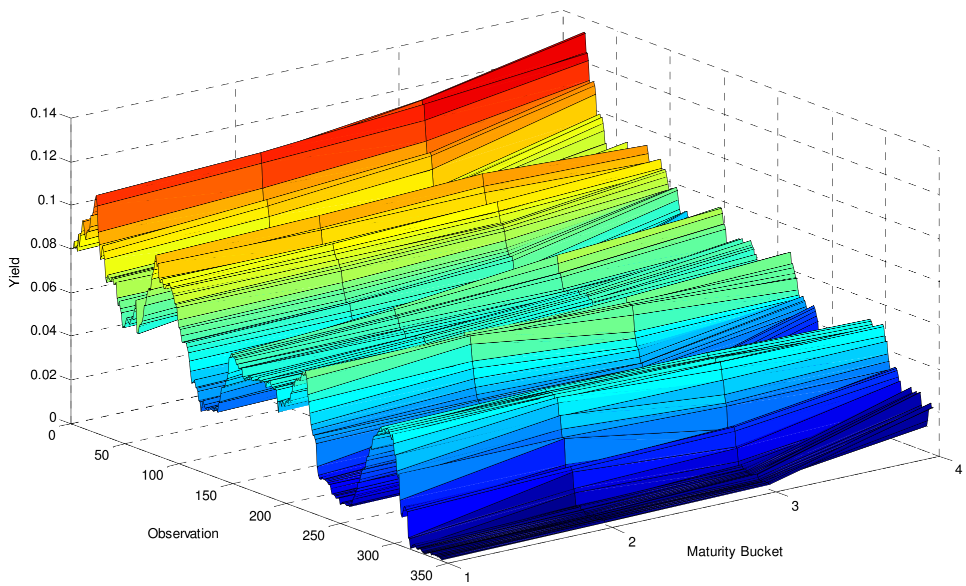

Figure 10: US treasury bill term structure October 1982 to April 2011
(source: own illustration, treasury bill yields were acquired from CRSP)

The resulting parameters for the time frame as shown in Figure 10 equal $\kappa = 0.1104\,, \bar{r} = 0.0509\; and\; \sigma_r = 0.0498$. For the simulations the latter parameter set is used to most accurately reflect the current and foreseeable future interest rate environment.

The following Figure 11 represents three yield curves generated using equation (3.15) with initial instantaneous-maturity interest rates of r_0 = 3%, 6% and 8% respectively. This produces an up- / downward sloping term structure depending on r_0.

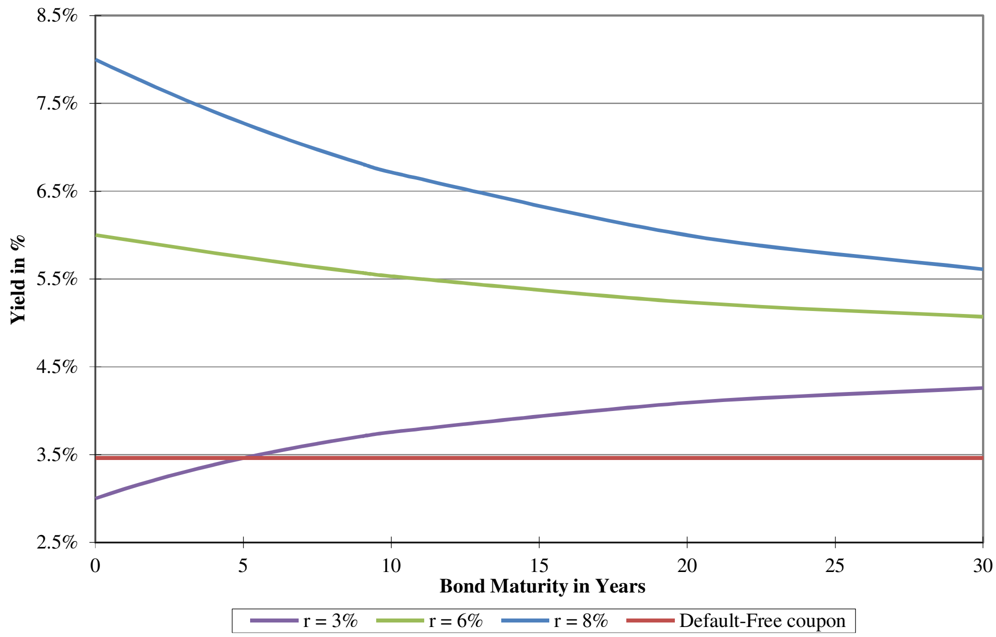

Figure 11: Cox Ingersoll Ross term structure (source: own illustration)

The fair default-free coupon rate for a five-year coupon bond with an initial interest rate of $r_0 = 3\%$ can be derived from equation (3.19) and equals 3.45%.

4.1.3 Deposit Growth Process

As already mentioned in section 1.2.1, Swiss regulators have introduced a leverage ratio which defines a minimum amount of capital-to-assets for UBS and Credit Suisse, that should exceed 5% in good times (Commission of Experts 2010, p. 33). Assuming that a prudent bank has a target capital-to-asset ratio of 6%, the according target asset-to-deposit ratio for the deposit growth process in equation (3.20) is $\hat{x} = 6.4\%$. The speed of convergence g cannot yet reliably be estimated since the leverage ratio has only been implemented in 2008. However, the capital-to-asset ratio for Credit Suisse started at 3.1% in 2008 (Credit Suisse 2008, p. 102) and rose 1.1% to reach 4.2% in 2009 (Credit Suisse 2009, p. 105). At the end of 2010 the capital-to-asset ratio was 4.4% (Credit Suisse 2010, p. 55). Therefore, setting $g = 0.5$ seems like a reasonable choice. This implies that any deviation from the target asset-to-deposit ratio of 6.4% is expected to reduce by approximately one half over the following year (Pennacchi 2010, p. 19).

4.1.4 Conversion Threshold

Recall that the conversion threshold $\bar{e}$ is set in terms of the market value of original shareholder's equity to deposits (cf. section 3.4). However, conversion thresholds of currently issued contingent capital notes rely on a CET1 ratio, which is an accounting based measure (Pennacchi 2010, p. 9). To find an approximate value of $\bar{e}$ for Credit Suisse, the current amount of CET1 capital has been assessed. Specifically, at the end of 2010 Credit Suisse had roughly 219 billion Swiss Francs of risk weighted assets and core tier 1 equity in the amount of 28 billion Swiss Francs. This results in a CET1 ratio of 12.7% (Credit Suisse 2010, p. 56). The already issued contingent capital bonds by Credit Suisse are high-level contingent capital bonds that are triggered at a ratio of 7% CET1 (Press Release 1 2011a; Press Release 2 2011b) (cf. section 4.1.5). Therefore, at the end of 2010, the absolute drop in CET1 capital had to amount to about 13 billion Swiss Francs in order to arrive at a core equity tier 1 ratio of 7% and hence force a conversion. This drop in equity can be translated into a conversion threshold in terms of equity-to-deposits equal to about $\bar{e} = 3\%$.[10]

According to the proposed capital requirements, 35% of tier 1 capital can be met with hybrid instruments such as contingent capital (Commission of Experts 2010, p. 33). The contingent-capital-to-deposit ratio for the corresponding target asset-to-deposit ratio of $\hat{x} = 1.064\%$ is therefore approximately $b_0 = 2\%$ (cf. section 3.4). This would correspond to the case that almost 35% of tier 1 capital is in the form of hybrid capital instruments.

4.1.5 Contingent Capital Issues

In order to conduct a comparative analysis, the results of section 4.2 are compared to contingent capital notes (CCN) that have either been agreed to be issued or have already been issued by Credit Suisse (Press Release 1 2011a; Press Release 2 2011b).

	CCN1	**CCN2**	**CCN3**
Type	Tier 1	Tier 1	Tier 2
Amount	3.5 billion	2.5 billion	2 billion
Currency	USD	CHF	USD
Issue Date	-	-	22.02.2011
Maturity in years	n/a	n/a	30
Coupon Rate	9.5%	9%	7.875%
Trigger	7% CET1	7% CET1	7% CET1
Conversion Ratio	VSP	VSP	VSP

Table 12: Contingent capital issues (source: own illustration)

CCN1 and CCN2 have been agreed to be issued no earlier than October 2013 either in cash or in exchange for USD 3.5 billion of 11% and CHF 2.5 billion of 10% Tier 1 capital notes issued in 2008. CCN3 has been issued on February 22nd 2011 with a coupon of 7.875%, which is reset every five years from August 2016 (Credit Suisse 2011a).

The trigger for all three bonds is set at 7% CET1 according to Basel III and thus qualifies as high-trigger contingent convertible capital (Commission of Experts 2010, pp. 25-26, pp. 57-60) (cf. Figure 1). If the trigger is breached, the contingent capital will be converted at par into a variable amount of shares (VSP), depending on the average weighted daily trading price of the ordinary shares, subject to a minimum floor price of USD 20 / CHF 20 (Credit Suisse 2011a). Additionally, a conversion can be

[10] Likewise, the according drop in order to trigger the proposed low-level trigger contingent capital (5% CET1) would have to amount to about 17 billion Swiss Francs, which, mutatis mutandis, equals an equity-to-deposit threshold of about $\bar{e} = 2.5\%$.

forced by the Swiss Financial Market Supervisory Authority (FINMA), if it decides that Credit Suisse needs public sector support (Credit Suisse 2011a).[11]

4.2 Results

This section performs simulations using the benchmark parameters stated above to compute fair new issue yields on contingent convertible capital for different contract specifications. The benchmark maturity of the contingent capital bond is set to be five years.

4.2.1 Fair New Issue Yields on Contingent Convertible Capital

Fixed Coupon Contingent Convertible Capital

The fair new issue yields for fixed coupon contingent capital for the calibrated benchmark parameters are presented in Figure 12 for different capital-to-deposit ratios $x_t - 1$. The default-free par yield on a five-year sovereign bond is 3.45% and is indicated by schedule 2.

It is evident that with an increasing capital-to-deposit ratio the fair new issue yields decrease. This is intuitive since a possible jump in the asset value could leave total capital less than the par value of contingent capital, $A_{t_c} - D_{t_c} < B$, which can result in a conversion at less than par (Flannery 2009, p. 14; McDonald 2010, p. 17) (cf. section 3.5). At higher initial capital levels, the probability that a jump imposes losses on contingent capital holders is smaller and the risk-premium is lower.

Jumps in Asset Values

Given that no jumps can occur, $\lambda = 0$, the proposed new issue yield is below the default-free yield on a comparable five year bond as seen in schedule 4 in Figure 12. This is in line with the initial numerical example in section 2.3.2 and the finding of Flannery (2009, p. 14), that contingent capital is essentially riskless if the equity position cannot be wiped out completely. The lower than default-free yield can be explained by the fact that the possibility of a conversion reduces the effective maturity of the contingent capital.

Speed of Convergence

Setting a lower speed of convergence, $g = 0.25$ instead of $g = 0.5$, for the deposit growth process results in higher initial coupon rates at lower equity-to-deposit ratios. For higher equity-to-deposit ratios the initial coupon rates are lower than the benchmark case, as depicted in Figure 12 schedule 3. The reasoning behind this is that such a bank is slower to converge to its target asset-to-deposit ratio of $\hat{x} = 6.4\%$. On the one hand, this means that if it starts out undercapitalized (e.g. at a capital-to-deposit ratio of 3.5%) it remains undercapitalized longer and therefore the risk that a jump incurs losses on contingent capital holders is higher. Hence the higher risk versus the benchmark case. On the other

[11] This might give the impression of a dual-trigger design as proposed by e.g. McDonald (2010) (cf. section 2.2.1). However, in his design, the conversion would depend on a bank-specific trigger as well as a system-wide component, whereas the FINMA would only look at Credit Suisse itself. Therefore, simulations only include the case of single-trigger events.

hand, if the bank starts out overcapitalized (e.g. at a capital-to-deposit ratio of 12%) it tends to stay overcapitalized for longer such that the probability of a jump leading to a conversion below par is lower (Maes & Schoutens 2010, p. 14; Pennacchi 2010, p. 20).

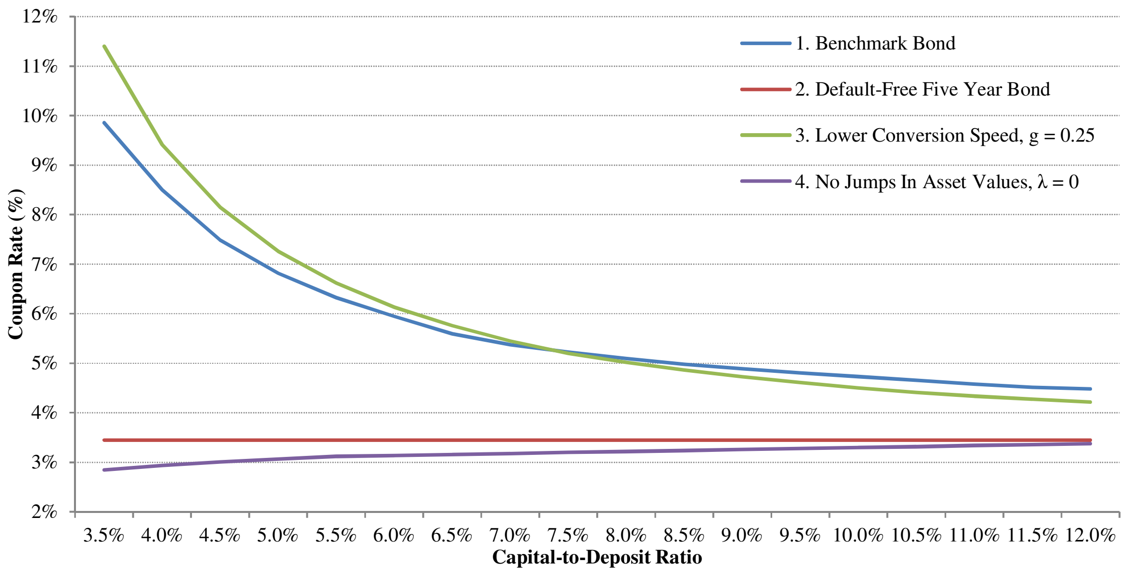

Figure 12: Fixed coupon contingent capital, new issue yields; effects of conversion speed and asset jumps (source: own illustration, based on Pennacchi (2010, p. 33))

Floating Coupon Contingent Convertible Capital

A similar analysis has been done for *floating coupon contingent convertible capital* (cf. section 3.5). On the y-axis in Figure 13 the credit spread over the instantaneous-maturity interest rate is depicted, where a positive spread indicates a default risk. Schedule 1 shows the benchmark case which is in essence equivalent to schedule 1 of the previous Figure 12. Setting $\lambda = 0$ shows that the equilibrium credit spread for contingent capital that converts at par $p = 1$ is zero, indicating that it is default-free as in the case of fixed-rate contingent capital. Additionally, schedule 3 shows the yield for an increased number of yearly jumps $\lambda = 1.25$. Clearly, the risk that a jump occurs and imposes losses on contingent capital holders is higher, hence the higher required risk-premium for all initial capital-to-deposit ratios.

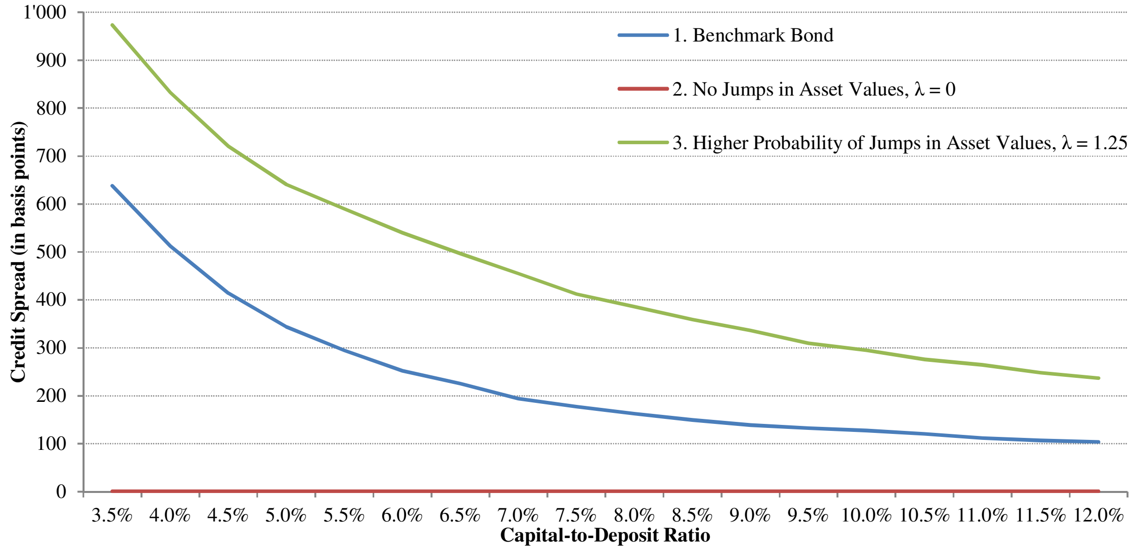

Figure 13: Floating coupon contingent capital, new issue yields; effects of asset jumps (source: own illustration, based on Pennacchi (2010, p. 36))

Conversion Specifics

Lower Trigger Level

The benchmark bond from the previous analysis is again depicted in Figure 14 and corresponds to the high-level contingent capital as proposed by Swiss regulators (cf. Figure 1, section 1.2.1). To see the impact of setting a *lower trigger level*, schedule 3 shown in Figure 14 is evaluated using a conversion threshold of $\bar{e} = 2.5\%$ (cf. section 4.1.4). The results show that a lower trigger level leads to higher required yields. This can be explained by the lower equity cushion close to conversion: At lower capital levels it is more likely that a jump in the asset's value can impose losses on the contingent capital investors (Flannery 2009, p. 14; Maes & Schoutens 2010, p. 14; McDonald 2010, pp. 17-18; Pazarbasioglu et al. 2011, p. 12). This finding is in contrast to e.g. Ammann (2010a, p. 9; 2010b, p. 38), who suggests that yields should be higher for higher level triggers, since the probability of a conversion is higher (cf. section 5.2 for a probable explanation). From a purely risk based perspective though, the conversion threshold and the associated risk show a diametrically opposed relationship.

Subordinated Debt

The yield on *subordinated debt* can be simulated by setting the conversion threshold equal to $\bar{e} = 0\%$. The same reasoning as with contingent capital with a lower conversion threshold of $\bar{e} = 2.5\%$ can be applied in this case. Since there is no equity cushion at all, the risk that a jump imposes losses on the subordinated debt holders is high. This explains the overall higher required yield on this debt instrument. This is shown in schedule 4 in Figure 14.

Conversion at Discount

To evaluate the impact of a *conversion at discount*, the conversion ratio has been set to $p = 0.9$ (cf. section 2.2.2), which equals a conversion at 90% of par value. Accordingly, the conversion threshold has to be adjusted to $\bar{e} = 3.2\%$ using equation (3.25) to ensure the desired capital-to-asset ratio of 6% after conversion (Pennacchi 2010, pp. 10-11, p. 21). It is clear that the required yields are above those of the benchmark bond as shown in schedule 5, since investors want to be compensated for the writedown.

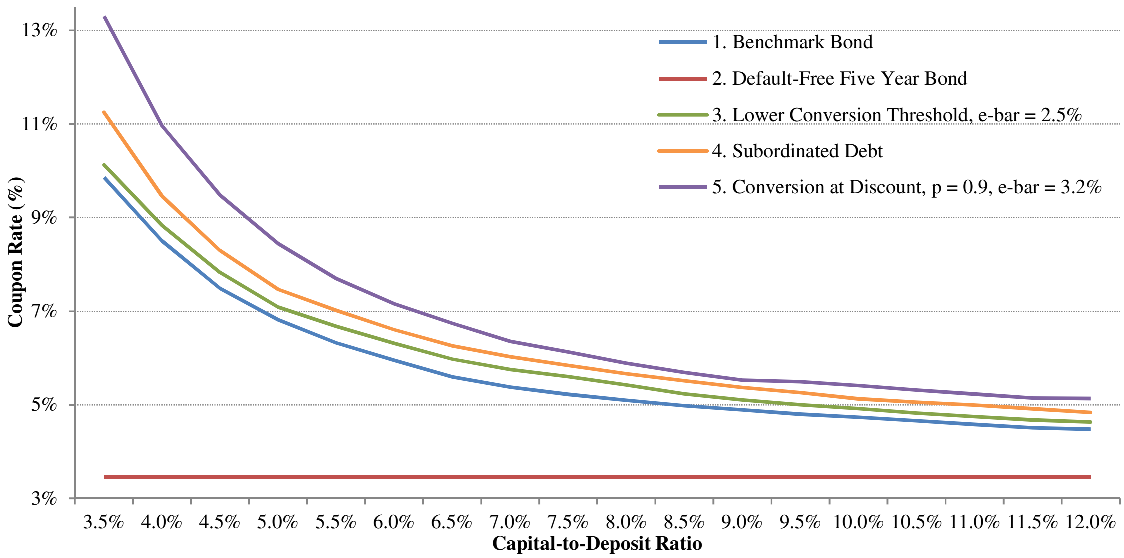

Figure 14: Fixed coupon contingent capital, new issue yields; effects of conversion threshold and conversion ratio (source: own illustration, based on Pennacchi (2010, p. 35))

Time to Maturity

Figure 15 shows different new issue yields depending on the *time to maturity*, which includes 5, 10 and 30 year bonds. The horizontal lines represent the default-free yields, which are 3.45%, 3.72% and 4.12% respectively. It can be seen that with an increasing capital-to-deposit ratio the bonds converge to the respective default-free yield. In line with Merton (1974, p. 459), the required yields are a decreasing function of maturity for bonds with relatively high default risk at lower capital-to-deposit ratios. However, at higher capital-to-deposit ratios and therefore lower default risk, the slightly hump-shaped relationship between the required yield and the time to maturity can be observed (1974, p. 459). At a capital-to-asset ratio between 4% to 6% the required yields for the different bonds are between 6% and 7.5%, indicating that all bonds exhibit roughly the same likelihood that a jump in asset values could impose losses at conversion (Pennacchi 2010, p. 20).

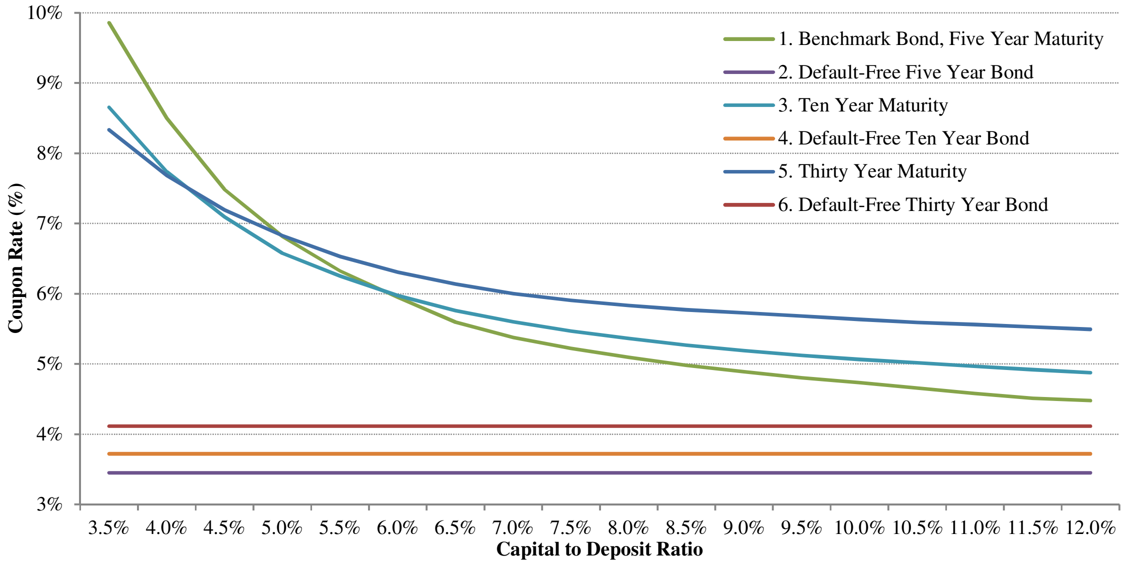

Figure 15: Fixed coupon contingent capital, new issue yields; effects of maturity (source: own illustration, based on Pennacchi (2010, p. 34))

Conversion Sharing Rules

As mentioned in section 2.2.2, one can distinguish between a "fixed dollar" conversion and a "fixed share" conversion (McDonald 2010, pp. 3-4; Pazarbasioglu et al. 2011, p. 11; Squam Lake Working Group on Financial Regulation 2009, p. 4). Figure 16 schedule 4 depicts the impact if contingent capital is converted into a predetermined amount of shares. Following the same reasoning as in section 2.2.2, it is evident that the yields are higher than in the case of a "fixed dollar" conversion, since it is more likely that investors receive a value below par (Pazarbasioglu et al. 2011, pp. 27-29). Schedule 1 resembles the same benchmark bond as in the previous figures, which is a "fixed dollar" bond. Yields are even higher if conversion occurs at a predetermined discount in terms of a fixed amount of shares. This is shown in schedule 5. These results are in line with the conceptual analysis of section 2.2.2.

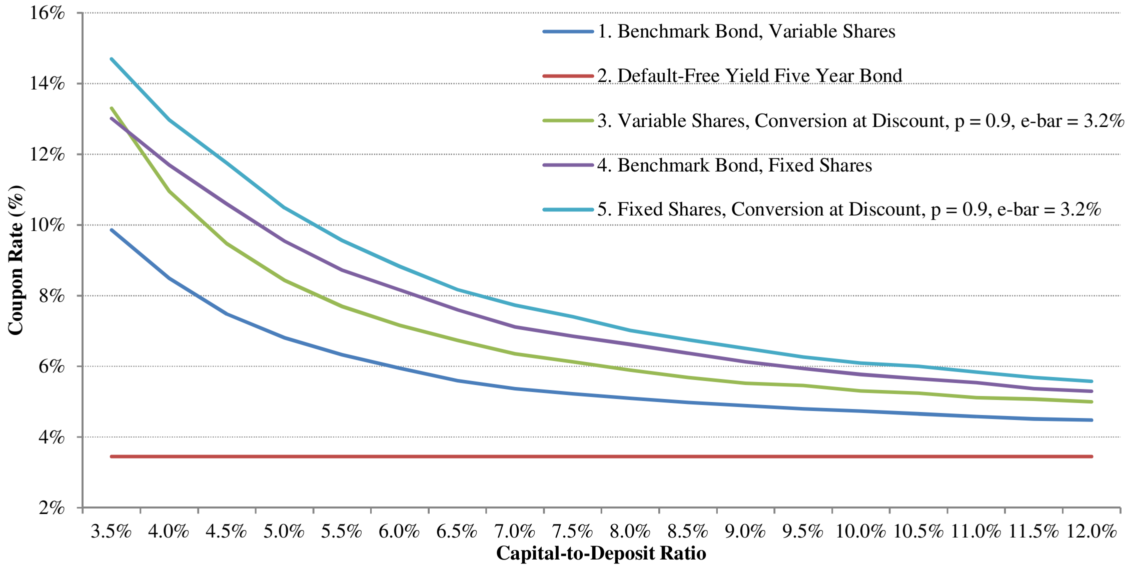

Figure 16: Fixed coupon contingent capital, new issue yields; effects of conversion sharing rule (source: own illustration, based on Pennacchi (2010, p. 41))

Based on these results, the final chapter 5 summarizes the most important findings and concludes by answering research question two and three.

5 Conclusion

The recent financial crisis has showed that current capital requirements set by the Basel II framework were not able to provide the necessary loss absorption potential for individual financial institutions to avert a systemic crisis. In response to this, international financial regulators were quick to put forward new capital adequacy standards, within which contingent convertible capital has enjoyed growing support as a means to meet the higher capital requirements and secure a timely injection of fresh capital in times of distress.

Only few contingent convertible bonds have been issued so far and markets are thus still largely illiquid, making it difficult to value the instrument using a mark-to-market approach. Hence, chapter 3 introduced an analytical credit risk concept to be able to perform mark-to-model valuations in order to derive fair new issue yields on contingent convertible capital. Chapter 4 then put the model into practical context by conducting a case study on Credit Suisse by first calibrating the model parameters to information gathered from said bank and then simulating different scenarios. These findings enable to answer the remaining research questions two and three.

5.1 RQ2

What are fair new issue yields on contingent convertible capital for different contract specifications and bank variables?

It has been shown that fair new issue yields are highly dependent on bank specific variables such as the number of jumps in asset values or contractual mandates such as a conversion at a writedown. Without the risk of possible jumps, it has been proven that contingent convertible capital would essentially be riskless.

The required yields are higher for both fixed- and floating-coupon contingent capital bonds at lower levels of initial equity. Investors will require a lower risk-premium if the conversion occurs at par value instead of a writedown. Additionally, yields will be lower if conversion is set at a variable amount of shares instead of a fixed amount of shares. Moreover, yields exhibit a diametrical relation to the conversion threshold, since a higher conversion threshold will lead to lower required risk-premia.

5.2 RQ3

How do fair new issue yields on contingent convertible capital compare vis-à-vis yields on contingent capital bonds issued by Credit Suisse?

At the time Credit Suisse made the announcements concerning the agreement to issue CCN1 & 2 and the placement of CCN3, it had a capital-to-deposit ratio of about 4.5%. The required yield on the benchmark bond at a capital-to-deposit ratio of 4.5% is roughly 7.5% as shown in Figure 12, schedule 1. This, ceteris paribus, might indicate that the new issue yield of CCN1 & 2 with 9.5% and 9% respectively might be set too high. This is under the assumption that the time to maturity of those bonds is also five years as the benchmark bond (as of this writing the tenor was not yet known). However, as depicted in Figure 15, for longer-term bonds the mispricing would increase since they have lower new issue yields according to the model. Furthermore, CCN1 & 2 will not be issued any earlier than October 2013. Until then, the capital-to-deposit ratio of Credit Suisse should have increased, such that new issue yields according to the model would be even lower.

A comparison of CCN3 shows similar results. This bond has a coupon of 7.875% and a time to maturity of 30 years; the benchmark bond for this case has a fair new issue yield of about 7.2% and can be found in Figure 15, schedule 5. Also in this comparison, the suggested fair new issue yield is lower. However, in the case of CCN3 Credit Suisse has the contractual right to adjust the coupon rate every five years, starting from 2016 (Credit Suisse 2011b). This will allow them to account for the decreasing maturity, increasing capital ratios and changing market environments.

The higher yields suggested by the model indicate on the one hand that the model parameters might underestimate the risk of Credit Suisse's asset process. E.g. the volatility of the asset returns $\sigma = 0.45\%$, the number of jumps $\lambda = 1$, the risk-neutral jump size $\mu_y = -1\%$ or the according volatility of the jump size $\sigma_y = 2\%$ might be set too low. Increasing either of those variables would result in an upward shift of the fair new issue yields.

On the other hand, investors might be charging an uncertainty / illiquidity premium to compensate them for the higher risk of this new type of investment, since markets for contingent capital are only starting to evolve and the definitive outcome of the regulatory changes are still highly uncertain. There might also be a 'conversion-aversion' premium involved, which should be smaller, the lower the conversion threshold is set. The reasoning is that contingent capital investors basically trade in their (certain) coupon payments for (uncertain) dividend payments and stock returns if a conversion occurs. This might (partially) offset the diametrically opposed relationship between the required yield and the conversion threshold and give support to Ammann's (2010a, p. 9; 2010b, p. 38) argumentation, that yields should be lower the lower the conversion threshold is set (cf. section 4.2.1).

5.3 Final Remarks and Outlook

The qualitative as well as the quantitative analysis of contingent convertible capital has showed that it could be a promising and comparably low-cost way for financial institutions to raise the necessary capital to meet the higher capital standards. Issuance costs would most certainly be lower than ordinary equity but it would provide the same protection against bankruptcy costs and at the same time act as a tax-shield. Furthermore, offering financial institutions to issue contingent convertible capital could mitigate financial distress by circumventing the problem of debt-overhang and possibly eliminate the issue of 'too big to fail'.

Important topics for future research might be devoted to derivative analysis to assess changes in the risk taking behavior of the banks management. Furthermore, as markets for contingent convertible capital begin to evolve, refinements to the model might be necessary to adequately reflect market prices.

Appendix: Program-Code

The program-code provided in the appendix is either for use in the software GAUSS or Matlab as indicated.

Section 3 and 4: GAUSS Code to Compute Fair New Issue Yields for Fixed- / Floating-rate Contingent Convertible Capital

GAUSS code to evaluate fair new issue yields for fixed- / floating-rate contingent convertible capital depending on different values of initial capital-to-deposit ratios and different coupon rates. Conversion occurs at a variable amount of shares. The code has been provided by George Pennacchi (2010). However, it has been properly described.

```
/* Variable Definition */
/* Number of different coupon evaluations to compute splined roots in Excel */
        ncp = 20;
/* Number of simulations */
        ns = 10000;
/* Length of sub-period (e.g. trading day) */
        dt = 1/250;

/* Bank Assumptions: Input of calibrated variables */
/* Initial ratios of capital-to-deposits ranging from 3.5% to 12.5% */
        x0 = seqa(1.035,0.005,18);
        np = rows(x0);
/* Volatility σ of bank assets for jump diffusion process */
        sga = 0.0045;
/* Annual frequency of jumps λ for jump diffusion process */
        lm = 1;
/* Mean jump size μ_λ for jump diffusion process */
        muy = -0.01;
/* Standard deviation σ_λ of the jump sizes for jump diffusion process*/
        sgy = 0.02;
/* Speed of convergence for deposit growth process */
        g = 0.5;
```

/* Correlation between default-free term structure and jump diffusion process */

rar = -0.2;

/* Target asset-to-deposit ratio */

xs = 1.064

/* Contingent convertible capital parameters */

/* Initial value of contingent capital to deposits */

b0 = 0.02;

/* Conversion ratio at premium or discount */

p = 1;

/* Trigger: Asset to deposit level at which conversion occurs */

xc = 1 + (1-p)*b0 + 0.01;

/* Maturity of contingent capital in years */

tc = 5;

/* Dummy variable that is set to 0 if the desired coupon is fixed / equals 1 if the desired coupon is floating */

ff = 0;

/* Variables for the default-free term structure*/

/* Initial real interest rate */

r0 = 0.03;

/* Mean reversion coefficient κ */

kr = 0.1104;

/* Long-run interest rate $\overline{r}$ */

rb = 0.0509;

/* Standard deviation σ_r of interest rate changes */

sgr = 0.0498;

/* Number of periods for bonds based on maturity and length of sub-period */

mxp = tc/dt;

/* Impact of interest rate shock on Jump-Diffusion process based on the correlation between default-free term structure process and Jump-Diffusion process */

wr = sqrt(1-rar^2);

/* Risk-neutral expected jump size */

k = exp(muy+0.5*sgy^2) - 1;

/* Computation of the risk-free Cox, Ingersoll, Ross coupon bond yield */

```
i = 1;
dsum = 0;
```

/* Computation of $x = \sqrt{\kappa^2 + 2\sigma_r{}^2}$ */

```
thet = sqrt(kr^2+2*sgr^2);
do until i >mxp;
t=i*dt;
```

/* Computation of $A(t,T) = \left\{\frac{xexp^{y(T-t)}}{y\{exp^{x(T-t)}-1\}+x}\right\}^z$ for sub-periods*/

```
ati = ((2*thet*exp((thet+kr)*t/2))/((thet+kr)*(exp(thet*t)-1)+2*thet))^(2*rb*kr/sgr^2);
```

/* Computation of $B(t,T) = \left\{\frac{exp^{x(T-t)}-1}{y\{exp^{x(T-t)}-1\}+x}\right\}$ for sub-periods*/

```
bti = 2*(exp(thet*t)-1)/((thet+kr)*(exp(thet*t)-1)+2*thet);
```

/* Computation of $\sum_{i=1}^{i=n} A(\Delta t \times i)exp^{-B(\Delta t \times i)r_t}\Delta t$ */

```
dsum = dsum + ati*exp(-bti*r0)*dt;
i = i + 1;
endo;
```

/* Computation of $A(t,T) = \left\{\frac{xexp^{y(T-t)}}{y\{exp^{x(T-t)}-1\}+x}\right\}^z$ for entire tenor of contingent capital*/

```
atc = ((2*thet*exp((thet+kr)*tc/2))/((thet+kr)*(exp(thet*tc)-1)+2*thet))^(2*rb*kr/sgr^2);
```

/* Computation of $B(t,T) = \left\{\frac{exp^{x(T-t)}-1}{y\{exp^{x(T-t)}-1\}+x}\right\}$ for entire tenor of contingent capital*/

```
btc = 2*(exp(thet*tc)-1)/((thet+kr)*(exp(thet*tc)-1)+2*thet);
```

/* Computation of the fair coupon rate $\frac{1-A(t,T)exp^{-B(t,T)r_t}}{\sum_{i=1}^{i=n} A(\Delta t \times i)exp^{-B(\Delta t \times i)r_t}\Delta t}$ */

```
ccir = (1 - atc*exp(-btc*r0))/dsum;
```

/* Store output to text file /*

```
output file = c:\cccmstxFxBenchmark.out reset;
outwidth 240;
```

/* Initialize auxiliary vector to store average value of risk-neutral coupon bond payoff */

```
vs = zeros(np,ncp);
```

/* Initial coupon rates for fixed rate contingent capital; depends on dummy variable ff */

```
cp = seqa(ccir+0.001,0.004,ncp);
" coupons = ";;cp;
```

```
/* Initial coupon rates for floating-rate contingent capital; depends on dummy variable ff */
/* Coupon for floating-rate contingent capital */
/* cp = seqa(0.005,0.0035,ncp);
/* Screen output of coupon rates /*
        " coupon spreads = ";;cp; */
        " ";
        i = 1;
/* Loop for each simulation ns */
        do until i > ns;
/* Update output each time 1000 simulations are done */
        if fmod(i,1000) == 0;
        " Simulation = ";;i;
        endif;
/* Generation of three normally distributed random variables for each period */
        ep = rndn(mxp,3);
/* Generate a poisson count for each period with probability λtdt */
        psn = rndu(mxp,1).<(lm*dt);
/* Entering loop for a given initial coupon and simulation */
        ic = 1;
        do until ic > ncp;
/* Initialization of coupon rate */
        c = cp[ic,1];
/* Entering loop for different initial asset-to-deposit ratios, initial coupon and simulation */
        ix = 1;
        do until ix > np;
/* Initialization of asset-to-deposit ratio */
        x = x0[ix,1];
        t = 0;
/* j is the index variable used as proxy for time t */
        j=1;
        val = 0;
/* Initialization of interest rate */
        r = r0;
/* Initialization of par value of contingent capital to deposit ratio */
        bt = b0;
/* Initialization of discount factor */
        dsf = 1;
```

```
/* Execute loop for each sub-period over tenor of bond */
        do until t > (tc-dt);

/* Calculation of fair deposit credit spread h_t */
        d1 = (ln(x)+muy)/sgy;
        d2 = d1+sgy;
        h = lm*(cdfn(-d1)-x*exp(muy+0.5*sgy^2)*cdfn(-d2));
        if h < 0;
        h = 0;
        endif;

/* Update asset-to-deposit ratio for next period according to equation (3.29) */
        x=x*exp((r-lm*k-(r+h+(c+ff*r)*bt)/x-g*(x-xs)-
        0.5*sga^2)*dt+sga*sqrt(dt)*ep[j,1]+psn[j,1]*(muy+ sgy*ep[j,3]));
        dsf = dsf*exp(-r*dt);
/* Check if trigger xc is breached */
        if x > xc;
/* End of period discounted coupon added to value. */
        val = val + dsf*(c+ff*r)*b0*dt;
        if t > (tc-dt - 0.000001);
/* Add final principal payment to value */
        val = val + dsf*b0;
        endif;
/* Updating interest rate for next period */
        r = rb*kr*dt + r*(1-kr*dt) + sgr*sqrt(r*dt)*(rar*ep[j,1]+wr*ep[j,2]);
/* Updating contingent convertible par value to deposit ratio */
        bt = bt*exp(-g*(x-xs)*dt);
        t = t + dt;
        j = j + 1;
/* If trigger xc is breached, check if full conversion is possible and compute value */
        elseif x > (1+p*bt);
        val = val + dsf*p*b0;
        t = tc + 1;
/* If trigger xc is breached and full conversion is not possible, then execute partial conversion and
compute value */
        elseif x > 1;
        val = val + dsf*(x-1)*b0/bt;
```

```
            t = tc + 1;

/* Else exit program, value not incremented */
            else; */
            t = tc + 1;
            endif;

/* Endo for time period */
            endo;
            vs[ix,ic] = vs[ix,ic] + val/ns;
            ix = ix + 1;

/* Endo for asset-to-deposit ratio */
            endo;
            ic = ic + 1;

/* Endo for coupon */
            endo;

/* Update output each time 1000 simulations are finished */
/* " Simulation = ";;i; */
            i = i + 1;
/* Endo for each simulation */
            endo;

/* Display output of initial values of contingent capital for given coupon and asset-to-deposit ratio and
risk free yield */
            " ";
            " Risk free yield ";;ccir;
            " ";
            " vs = ";
            vs;
            " ";
            " ";
        output off;

/* End of program */
```

Section 3.1.3: Matlab Function to Generate Evolution of GBM / Jump Diffusion Process

```
% The implementation follows Glasserman (2004, pp. 137-139)
% Inputs:
% N_Sim = number of simulations, scalar
% T = Timeframe, scalar
% dt = Timestep, scalar
% params = [μ, σ, λ, μ_λ, σ_λ, X_0]
function S = JGBM_simulation(N_Sim ,T,dt,params,S0)
mu_star = params(1);sigma_=params(2);lambda_=params(3);
mu_y_ = params(4);sigma_y_=params(5);
M_simul = zeros(N_Sim ,T);
for t = 1:T
        jumpnb = poissrnd(lambda_*dt,N_Sim ,1);
        jump = normrnd(mu_y_*(jumpnb-lambda_*dt),sqrt(jumpnb)*sigma_y_);
        M_simul(:,t) = mu_star*dt + sigma_*sqrt(dt)*randn(N_Sim,1) + jump;
end
        S=ret2price(M_simul, S0);
end
```

Section 3.1.3: Matlab Function to Estimate Jump Diffusion Process Parameters using Maximum Likelihood Methods

```
% The implementation follows Brigo et al. (2007, pp. 18-20)
% Inputs:
% 'data' = vector of stock price
% dt = scalar, e.g. 0.004 for a trading day
% params = [μ, σ, λ, μ_λ, σ_λ]
function [ mu_star sigma_ lambda_ mu_y_ sigma_y_ ] = JGBM_calibration(data, dt, params)
returns = price2ret('data');
dataLength = length('data');
options = optimset ('MaxFunEvals', 100000,  'MaxIter', 100000);
params = fminsearch( @FT_JGBM_LL , params , options )
mu_star = params (1); sigma_ = abs( params (2)); lambda_ = abs( params (3));
mu_y_ = params (4); sigma_y_ = abs( params (5));
function mll = FT_JGBM_LL( params );
mu_= params (1); sigma_ = abs( params (2)); lambda_ = abs( params (3));
mu_y_ = params (4); sigma_y_ = abs( params (5));
Max_jumps = 5;
```

```
factoriel = factorial(0: Max_jumps);
LogLikelihood = 0;
for time =1: dataLength
ProbDensity = 0;
for jumps =0: Max_jumps -1
        jumpProb = exp(- lambda_ *dt )*( lambda_ *dt )^ jumps / factoriel( jumps +1);
        condVol = dt* sigma_ ^2+ jumps * sigma_y_ ^2;
        condMean = mu_*dt+ mu_y_ *( jumps - lambda_ *dt );
        condToJumps = exp (-(data(time)- condMean )^2/ condVol /2)/ sqrt (pi *2* condVol );
        ProbDensity = ProbDensity + jumpProb * condToJumps;
end
LogLikelihood = LogLikelihood + log(ProbDensity);
end
mll = -LogLikelihood
end
end
```

Section 3.2.2: Matlab Function to Generate Cox et al. (1985) Evolution of Instantaneous-Maturity Interest Rate

% The implementation follows Glasserman (2004, p. 124)

% CIR process r_t is defined by $dr_t = \kappa(\bar{r} - r_t)dt + \sigma_r\sqrt{r_t}dW_t$

% Inputs:

% Number of simulations “t” in the form of an n*1 vector

% κ = speed of convergence, positive scalar

% $\bar{r}$ = long-run equilibrium interest rate, positive scalar

% σ_r = standard deviation of interest rate changes

% r0 = starting value

function[r] = cirpath(t, κ, $\bar{r}$, σ_r, r0)

```
if ~isvector(t)
error('Input argument "t" must be a vector')
end
if any(t < 0)
error('Input vector "t" must contain non-negative values')
end
dt = diff(t(:));
if any(dt < 0)
```

```
error('Input vector "t" must contain increasing values')
end
par = {'a','b','s','r0'};
	for i = 1:4
	y = eval(par{i});
	if ~(isscalar(y) && y > 0)
	error(['Input argument "' par{i} '" must be a positive scalar'])
	end
end
n = length(t);
r = [r0; nan*dt];
v = s^2;
d = 4*a*b/v;
e = exp(-a*dt);
c = v.*(1-e)/(4*a);
for i = 1:(n-1)
	l = r(i)*e(i)/c(i);
	r(i+1) = c(i)*ncx2rnd(d,l);
end
```

Section 4.1.2: Matlab Function to Calibrate Cox et al. (1985) Parameters

```
% This code has been acquired from http://www.mathfinance.cn/kalman-filter-finance-revisited
% accessed at 20.04.2011
% Inputs:
% Excel sheet (‘placeholder.xls’) with 3, 6, 12, 60 month yield series
function [para, sumll] = TreasuryYieldKF()
Y = xlsread('placeholder.xls');
[nrow, ncol] = size(Y);
tau = [1/4 1/2 1 5];
para0 = [0.05, 0.1, 0.1, -0.1, 0.01*rand(1,ncol).*ones(1,ncol)];
[x, fval] = fmincon(@loglik, para0,[],[],[],[],[0.0001,0.0001,0.0001, -1,
0.00001*ones(1,ncol)],[ones(1,length(para0))],[],[],Y, tau, nrow, ncol);
para = x;
sumll = fval;
end
% Aforementioned code invokes the following sub-function loglik:
function sumll = loglik(para,Y, tau, nrow, ncol)
```

```
theta = para(1); kappa = para(2); sigma = para(3); lambda = para(4);
sigmai = para(5:end);
R = eye(ncol);
for i = 1:ncol
    R(i,i) = sigmai(i)^2;
end
dt = 1/12; %monthly data
initx = theta;
initV = sigma^2*theta/(2*kappa);
mu = theta*(1-exp(-kappa*dt));
F = exp(-kappa*dt);
A = zeros(1, ncol);
H = A;
for i = 1:ncol
    AffineGamma = sqrt((kappa+lambda)^2+2*sigma^2);
    AffineBeta = 2*(exp(AffineGamma*tau(i))-
    1)/((AffineGamma+kappa+lambda)*(exp(AffineGamma*tau(i))-1)+2*AffineGamma);
    AffineAlpha =
    2*kappa*theta/(sigma^2)*log(2*AffineGamma*exp((AffineGamma+kappa+lambda)
    *tau(i)/2)/((AffineGamma+kappa+lambda)*(exp(AffineGamma*tau(i))-
    1)+2*AffineGamma));
    A(i) = -AffineAlpha/tau(i);
    H(i) = AffineBeta/tau(i);
end
AdjS = initx;
VarS = initV;
ll = zeros(nrow,1);
for i = 1:nrow
    PredS = mu+F*AdjS;
    Q = theta*sigma*sigma*(1-exp(-kappa*dt))^2/(2*kappa)+sigma*sigma/kappa*(exp(-
    kappa*dt)-exp(-2*kappa*dt))*AdjS;
    VarS = F*VarS*F'+Q;
    PredY = A+H*PredS;
    PredError = Y(i,:)-PredY;
    VarY = H'*VarS*H+R;
    InvVarY = inv(VarY);
    DetY = det(VarY);
```

```
        KalmanGain = VarS*H*InvVarY;
        AdjS = PredS+KalmanGain*PredError';
        VarS = VarS*(1-KalmanGain*H');
        ll(i) = -(ncol/2)*log(2*pi)-0.5*log(DetY)-0.5*PredError*InvVarY*PredError';
end
        sumll = -sum(ll);
end
```

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Declaration of Authorship

I hereby declare

- that I have written this thesis without any help from others and without the use of documents and aids other than those stated above,
- that I have mentioned all used sources and that I have cited them correctly according to established academic citation rules.

May 23, 2011 / Marc Erismann, Beinwil am See