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Pricing Contingent Convertible Bonds:

A Methodological Exploration of Credit, Derivative, and Option Frameworks.

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Abstract

This thesis examines three methods for pricing Contingent Convertible bonds: the Equity Derivative, Credit Derivative, and Option-Based models. The results show that the Option-Based model works best for stable markets, providing the lowest pricing errors for bonds with straightforward risk profiles. In contrast, the Equity and Credit Derivative models perform better in volatile markets, capturing the impact of share price changes and credit risk more accurately. These findings offer practical guidance for choosing the right pricing model, under different market conditions.

Keywords

CoCo Bonds, Derivative Approach, Credit Approach, Vanilla Bond

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Chapter I

Introduction

Contingent Convertible (CoCo) bonds emerged as a critical innovation in financial markets after the 2008 financial crisis. Designed to provide financial stability, CoCo bonds function as hybrid instruments that convert into equity or are written down when an issuer's capital ratio breaches a predefined threshold (Avdjiev et al., 2017). This mechanism allows banks to recapitalize during distress without direct intervention, fulfilling regulatory objectives outlined in Basel III. The hybrid nature of CoCo bonds combines features of debt and equity, making them essential for risk management, but also complex to value.

However, the complexity of CoCo bonds, has often led to valuation challenges and inaccurate pricing can result in underrated risks and unexpected financial losses, as demonstrated by the $17 billion write-off of Credit Suisse's CoCo bonds in 2023 (reuters.com, 2023). This event highlights the need for robust pricing models capable of reflecting the hybrid and contingent nature of these instruments under stress conditions. An accurate valuation is not only essential for investor's decisions but also for regulators and financial institutions aiming to ensure market stability and transparency.

Despite their growing significance, CoCo bonds remain challenging to price due to their contingent nature and dependence on complex triggers. Mispricing can increase systemic risks, particularly during stress periods, emphasizing the need for methodologies that align theoretical valuations with market realities (De Spiegeleer & Schoutens, 2012). This thesis contributes to addressing these challenges by comparing distinct pricing methodologies and evaluating their alignment with observed market prices.

1.2 Research Objective

This thesis evaluates the effectiveness of three pricing methodologies: Credit Derivative, Equity Derivative, and Option-Based Approaches, in valuing CoCo bonds. The analysis relies in the semi-strong form of the Efficient Market Hypothesis (EMH), which assume that market prices reflect all publicly available information (Fama 1970). Using market prices as the benchmark, the core questions addressed by this thesis include assessing the accuracy of each pricing model in replicating market prices, identifying the drivers of discrepancies between model and market valuations, and understanding the implications of these findings for investors, financial institutions, and regulators. By analysing these elements, the research provides insights into the effectiveness of existing methodologies and their suitability for practical application in CoCo bond valuation.

The Credit Derivative Approach, based on De Spiegeleer and Schoutens (2014), models CoCo bonds using credit spread dynamics and default probabilities, emphasizing their debt features. The Equity Derivative Approach, from De Spiegeleer and Schoutens (2011), treats conversion triggers as barriers in stock price dynamics, capturing equity risk. The Option-Based Approach, inspired by practical trading applications, simplifies valuation by decomposing CoCo bonds into a vanilla bond and subtracting to it a put option.

The empirical analysis focuses on data from around 20 CoCo bonds, incorporating daily market prices, issuer-specific equity prices, and CDS spreads. This dataset captures both stable and stress market conditions, including events like the 2023 Credit Suisse crisis, which resulted in a $17 billion write-off of CoCo bonds (Reuters 2023).

Key findings reveal that the Option-Based Approach exhibits the closest alignment with market prices, reflecting its pragmatic and simplified structure. The Equity Derivative Approach captures equity related risks effectively but struggles with credit changes, while the Credit Derivative Approach emphasizes credit characteristics at the expense of equity sensitivity. These findings demonstrate the trade-offs of each methodology, highlighting their respective strengths and limitations under different market scenarios.

1.3 Study Focus and Contributions

The valuation of CoCo bonds has been an interesting point for academic researchers due to their hybrid nature and implications for financial stability. This thesis adds to the literature by comparing three pricing methodologies: the Credit Derivative Approach, the Equity Derivative Approach, and the Option-Based Model. While the first two methodologies have been widely studied, this thesis introduces and evaluates the Option-Based Model for pricing CoCo bond, which has not been explored in existing literature. Building on the foundational work of De Spiegeleer and Schoutens (2011, 2014), which established the Equity and Credit Derivative approaches. The Option-Based Model adds a new view by simplifying CoCo valuation through a decomposition into a vanilla bond minus a put option, capturing the risk factors while reducing complexity. Incorporating insights from Brigo, Garcia, and Pede (2013), this thesis employs market-based calibration techniques across all three methodologies, aligning theoretical models with real market data. This approach aims to reduce the distances between theoretical pricing and observed market behaviour. Positioning this work within the broader discussion on CoCo mispricing and market behaviour. Avdjiev et al. (2020) highlighted the importance of capturing credit and equity sensitivities in pricing, yet no prior study has examined the Option-Based Model within this context, laying the groundwork for further advancements in hybrid and market aligned models.

1.4 Summary of Findings

The analysis was conducted across CoCo bonds issued by Credit Suisse, Deutsche Bank, Barclays, and HSBC, providing information into the performance and accuracy of these models under various conditions. The findings from the error metrics, including the Mean Absolute Error, Root Mean Square Error, and Standard Deviation, reveal that the accuracy of the pricing methodologies depends on the issuer and market dynamics. For Credit Suisse, the Option Model demonstrates superior performance. In contrast, for Deutsche Bank, Barclays, and HSBC, the Equity Derivative and Credit Derivative models consistently outperform the other model, capturing both equity sensitivity and credit risk more effectively.

Regression analysis further highlights the hybrid nature of CoCo bonds, where both share prices and CDS spreads play a role in price determination. Share prices positively influence CoCo bond valuations, particularly for bonds with market-based triggers. Conversely, CDS spreads exhibit a negative relationship with CoCo prices, showing the impact of credit risk and default probability on their valuation. The regression shows that credit risk, measured by the CDS spreads, has a bigger effect on CoCo bond prices compared to share price. Descriptive statistics reinforce these observations, showing volatility in CoCo bond prices and CDS spreads, along with skewness and kurtosis that reflect the market dynamics and risk sensitivities. The analysis points out the importance of combining equity and credit risk factors when pricing CoCo bonds to account for their structure.

1.5 Thesis Outline

The thesis is structured in five chapters as follow. Chapter II is focused on the literature review of CoCo bonds. Chapter III presents how the data needed are collected from diverse sources. Chapter IV explores the methodology used and describes the analysis conducted. Chapter V concludes with an overview of the findings and possible solutions.

Chapter II

Literature Review

2.1 The Evolution of CoCo Bonds.

Avdjiev et al. (2020) argue that these instruments play a dual role: stabilizing a bank's capital during crises and providing a market recapitalization mechanism. These features have made CoCos central to Basel III regulatory frameworks (Avdjiev et al. 2020). The academic debate on CoCo design highlights its complexity. Mandatory conversion CoCos with equity triggers are efficient in addressing capital shortage but pose risks of stock manipulation (Baker et al. 2004). Principal write-down CoCos, in contrast, offer direct debt reduction but may not fully absorb losses in systemic events (Avdjiev et al. 2020). These challenges show the need for robust pricing models to assess CoCos under different economic conditions. However, challenges remain, particularly in pricing and risk assessment. Notable cases, such as the $17 billion write-off of Credit Suisse CoCos in 2023, stress the need for robust valuation methodologies capable of accurately reflecting hybrid risks under stress scenarios (Reuters 2023). These challenges have led to extensive academic research into CoCo valuation methodologies.

2.2 Traditional Pricing Methodologies.

The valuation of CoCos has been a topic of research interest due to their hybrid nature and the unique challenges they present for traditional financial models. Pricing methodologies for CoCos aim to incorporate their contingent features, which is trigger by specific events such as the breach of a regulatory capital threshold. The three dominant approaches in the literature: Structural, Equity derivative and Credit derivative models are discussed below.

Structural models.

Structural models are based in Merton’s (1974) framework, which models a firm’s assets as a stochastic process and defines default as the event where asset values fall below a certain level of debt. Brigo et al. (2010) extended this framework for CoCo valuation, incorporating dual thresholds to account for equity conversion and default scenarios. These models offer a robust foundation for understanding the relationships between firm value and CoCo triggers. However, structural models rely on balance sheet data, which may not accurately reflect real market conditions. Asset volatility estimates, for instance, often lag at rapid market changes, limiting the practical applicability of these models during periods of financial distress (Turfus and Shubert 2016). Moreover, these models struggle to account for market specific factors that can create a trigger event, such as liquidity constraints and investor sentiment.

Equity derivative models.

Equity derivative model, approach CoCos through the lens of barrier options, modelling conversion triggers as a knock-in option based on the issuer's stock price. De Spiegeleer and Schoutens (2011) proposed a framework where stock price dynamics are modelled using geometric Brownian motion, incorporating volatility and jump diffusion. This methodology leverages liquid equity markets, making it particularly effective for capturing the equity nature of CoCos. While equity models excel in scenarios where the equity characteristic reign, they often fail to address credit risk comprehensively. Baker et al. (2004) introduced jump-diffusion processes and stochastic volatility to capture the drastic changes in equity prices during systemic crises. However, equity derivative models often assume constant volatility and may oversimplify the equity-credit interaction. In practice, CoCos are influenced by a combination of equity and credit risks, necessitating a more integrated approach.

Credit derivative models.

Credit derivative models emphasize the role of credit spreads and default probabilities in CoCo valuation. De Spiegeleer and Schoutens (2014) linked conversion probabilities to CDS spreads, providing a practical framework for capturing debt-like characteristics of CoCos. These models are particularly well-suited for instruments where credit sensitivity dominates but can fail to integrate equity market behaviour, limiting their effectiveness for CoCos with equity-linked triggers. The Credit Suisse crisis demonstrated how both credit and equity market dynamics significantly influence CoCo pricing during stress periods, underscoring the need for models that integrate both dimensions (Reuters 2023).

Comparative insights

While each traditional methodology offers valuable perspectives, none fully captures the combinatory nature of CoCos. Structural models provide theoretical accuracy but lack adaptability to evolving market conditions. Equity derivative models effectively capture equity risks but often neglect credit dynamics. Credit derivative models align well with debt features but fail to incorporate equity sensitivities. These limitations have motivated the development of more integrated and advanced pricing methodologies.

2.3 Developments in CoCo Pricing

Recognizing the limitations of traditional approaches, recent research has focused on developing hybrid models, incorporating smile conforming dynamics, and employing market-based calibration techniques to improve the accuracy and applicability of CoCo valuations.

Hybrid models combining Equity and Credit dynamics.

Hybrid models represent a significant advancement in CoCo pricing by combining equity and credit sensitivities into a unified framework. Turfus and Shubert (2016) proposed a model that integrates stochastic processes for both stock prices and credit spreads, with the two dynamics correlated to reflect the market interactions. This approach captures the asymmetric responses of equity and credit markets during crises, enabling a more nuanced valuation framework. This combination of models is particularly valuable for designing hedging strategies that reflect the complex risk profiles of CoCos. By incorporating both equity and credit risks, they reduce mispricing during volatile market conditions.

Smile Conforming models and Volatility dynamics.

One of the most innovative developments in CoCo pricing is the incorporation of volatility surfaces and smile dynamics. Baker et al. (2004) emphasized the importance of modelling forward smiles to capture the skewness and kurtosis observed in equity price distributions. These models are particularly relevant for CoCos, as conversion triggers can lead to sudden shifts in risk perceptions, resulting in significant changes to volatility surfaces. Smile conforming models outperform traditional approaches, particularly for CoCos with equity triggers, offering superior accuracy during stress scenarios but many challenges remain in calibrate these models.

Market-Based calibration.

Market-based calibration represents a significant step forward in CoCo pricing, aligning models with market data. Brigo, Garcia, and Pede (2013) proposed a firm-value model calibrated using equity prices and CDS spreads, improving the model’s relevance and accuracy. Similarly, Corcuera et al. (2011) demonstrated how numerical methods can be applied to calibrate CoCo pricing models to replicate market observed prices. These calibrated models not only improve accuracy but also provide understanding into probabilities of conversion and default. Market-based calibration make sure that pricing models remain responsive to dynamic conditions, joining the theoretical side with practical applications. This innovation addresses the discrepancies often observed between model and market prices, making it a foundation of modern CoCo valuation.

2.4 Empirical Insights and Practical Implications

The studies have validated the effectiveness of these models in replicating observed market prices. For instance, Turfus and Shubert (2016) applied their model to CoCos issued by major European banks, demonstrating a high degree of accuracy in pricing under both stable and volatile conditions. Similarly, smile-conforming models demonstrated to outperform traditional approaches in capturing the nonlinear effects of conversion triggers.

Moreover, the progress made validate the validity of hybrid models and market-based calibrations. Brigo, Garcia, and Pede (2013) demonstrated that market-based calibration improve alignment between theoretical and market prices, particularly under stress conditions. Their stress-testing approach emphasize the robustness of these models in volatile markets.

Turfus and Shubert (2016) further showed that hybrid models outperform traditional approaches when applied to CoCos issued by major European banks. The integration of forward smiles and market triggers, as shown by Baker et al. (2004) and Corcuera et al. (2011), improves pricing accuracy, particularly for instruments with complex contingent features. For investors, these advancements provide tools to identify mispricing opportunities and optimize portfolio strategies. Financial institutions benefit from a better risk management, while regulators gain insights into designing triggers that balance flexibility with stability.

Chapter III

Data Collection

The primary data sources for this study are Bloomberg Terminal and Refinitiv Eikon. These platforms were used to gather data on CoCo bonds issued by Credit Suisse (now part of UBS), Barclays, Deutsche Bank, and HSBC, reflecting significant institutions in the CoCo market. The data spans from January 1, 2018, to the end of November 2024, capturing a diverse range of market conditions, including periods of financial stability and stress. The focus of this thesis is consistent with Avdjiev et al. (2017), using CoCos issued by banks and excluding those issued by insurance companies and shadow banks. Moreover, bonds issued in emerging markets were excluded from the dataset, consistent with the approach of Avdjiev et al. (2017) since they can introduce noise into the analysis as these regions did not adopt Basel III regulations uniformly or within the same timeframe as advanced economies

The sample includes around twenty CoCos denominated in Euros and US Dollars, ensuring representation across major currencies, these differences in currencies are offset by FX curve, namely the 5Y Euro IR Swap and the 5Y USD IR Swap; and both CoCos with Write-Down and Conversion features. The dataset incorporates information about each CoCo bond, including its coupon rate, payment frequency, step-up rate, callable dates, maturity structure (callable perpetuity or fixed), and Basel III classification. The CoCo bond prices were sourced directly from Bloomberg and Refinitiv Eikon. These closing prices were recorded daily to provide a consistent time-series dataset for model calibration and evaluation. Bond details, such as coupon structures and callable dates, were cross checked with the prospectuses to ensure data accuracy. Lastly, to run the regression also the EUR iTraxx and the US CDS curve were retrieved from Eikon.

To analyse the CoCo pool, we collected data of the CoCo issuer, including daily closing share prices and five-year Credit Default Swap (CDS) spreads for the selected institutions. These variables were obtained from Refinitiv Eikon and serve as inputs for analysing equity and credit risks, central to CoCo bond pricing methodologies. To account for issuer-specific risk, the discounting curve was constructed using Zero-Coupon USD curve taken from Eikon as the risk-free component, adjusted with the corresponding CDS spread on the date of each CoCo bond market price. This dynamic adjustment ensures that the discount curve reflects market conditions. Volatility measures were computed for both share prices and CDS spreads to capture short-term market fluctuations. Share price volatility was calculated as the standard deviation of daily returns over the most recent month of data. Similarly, CDS spread volatility was determined as the standard deviation of daily changes in CDS spreads for the last month of observations. For each trading day, CoCo bond prices, issuer share prices, CDS spreads, and the corresponding discount curve were synchronized to reflect the market conditions.

Chapter IV

Methodology Overview and Analysis.

This chapter introduces the three methodologies for pricing Contingent Convertible Bonds: The Credit Derivative Approach, the Equity Derivative Approach, and the Option Approach. These methods provide distinct mathematical perspectives, addressing the structural and risk-related challenges inherent in CoCo bond valuation. Each methodology incorporates critical features such as conversion triggers, recovery rates, and the relation between equity and credit risks, as discussed by De Spiegeleer and Schoutens (2011, 2014).

CoCo bond valuation is influenced by their structural features, like trigger events, conversion fractions, and conversion prices. The trigger event determines when a CoCo converts into equity or is written down, and it can be divided into three categories. One is accounting trigger, based on metrics such as the Common Equity Tier 1 ratio, but it is criticized for their delayed alignment with economic result, as highlighted by Flannery (2009). Market trigger, which activate when observable variables, like share price or CDS spreads fall below a set threshold, is a good determinant because responsive and visible, but also subject to manipulation in volatile markets (De Spiegeleer and Schoutens 2014). Regulatory triggers, determined by supervisory authorities, add an element of unpredictability, complicating model calibration (Avdjiev et al. 2020). Recent studies also explore multivariate triggers that combine these types for greater adaptability (De Spiegeleer and Schoutens 2012).

Conversion fractions specify the amount of the bond's face value converted or written down during a trigger event. Literature suggests that full conversion may strengthen market confidence by mitigating uncertainty during distress periods (Baker et al. 2004). Conversion prices, which define the number of shares issued upon conversion, usually take one of three forms: the share price at the time of the trigger, the share price at issuance, or incorporating a floor. These pricing mechanisms are central to understanding CoCo bond behaviour and are part of the methodologies used.

4.1 Credit Derivative Approach

The Credit Derivative Approach value the bond by incorporating an extra credit risk and the likelihood of trigger events into the traditional debt pricing model. As highlighted by De Spiegeleer and Schoutens (2011, 2014), this method estimates an additional yield, known as the CoCo spread, for the increased risk associated with these instruments. It is based on the credit triangle, a foundational concept linking credit spread "c", default intensity "λ", and recovery rate "π".

4.1.1 The Credit Triangle

The credit triangle establishes the relationship between a bond's credit spread, default intensity, and recovery rate. For a zero-coupon bond with a notional value N, maturity T, and default intensity λ, the probability of survival P_s over T is calculated as:

$$(1) \quad Ps = ex\,p\,(-\lambda T) \approx 1 - \lambda T$$

If no default occurs, the investor receives the full notional amount at maturity. If default occurs, only a fraction “π” of the notional is recovered. Using these probabilities, the expected value of the bond B can be derived as:

$$(2)\quad B = e^{-rT}[P_s N + (1 - P_s)\pi\mathrm{N}]$$

$$\approx Ne^{-rT}[1 - \lambda(1 - \pi)\mathrm{T}]$$

with π the recovery rate from a trigger event. Notice that the value of a zero-coupon bond can also be expressed in terms of its credit spread (c):

$$(3)\quad B = Ne^{-(r+c)T} \approx Ne^{-rT}(1 - cT)$$

By combining the last two equations, we arrive at the credit spread equation:

$$(4)\quad c = \lambda(1 - \pi)$$

This is the link between the credit spread ‘c’, default intensity ‘λ’, and recovery rate ‘π’.

4.1.2 CoCo Pricing with Derivative Approach

Here, trigger intensity “λ”, is replaced by default intensity, which reflects the likelihood of a conversion or write-down event occurring within time T. The probability of a trigger event P_t is given by:

$$(5)\quad P_t = 1 - exp\,(-\lambda_t T)$$

Rearranging the above equation, the trigger intensity is:

$$(6)\quad \lambda_t = -\frac{1}{T}\ln(1 - P_t)$$

Because the likelihood of a trigger for this instrument is higher, the trigger intensity for CoCos should exceed the default intensities of corporate debt. Using the credit triangle formula, the CoCo spread $cs_{CoCo,T}$ is:

$$(7)\quad cs_{CoCo,T} = -\frac{(1-\pi)}{T}\ln(1 - P_t)$$

Adding this spread to the risk-free rate the yield y_T is obtained:

$$(8)\quad y_T = cs_{CoCo,T} + r_f$$

Using (8), the price of the CoCo bond is calculated by discounting its cash flows:

$$(9)\quad P = \sum_i c_i e^{-y_T t_i} + Ne^{-y_T T}$$

where c_i represents coupon payments at time t_i, and N is the bond’s face value.

4.1.3 Recovery Rate and Loss Calculation

The recovery rate ‘π’ depends on the Coco’s conversion price C_P and share price at the time of triggering S^*. When converted, the bondholder receives C_r shares, valued at S^*. The loss ‘L’ is defined as:

$$(10)\quad L = N - C_r S^* = N(1 - \frac{S^*}{C_P})$$

Thus, the recovery rate π is:

$$(11)\quad \pi = \frac{S^*}{C_P}$$

This relationship quantifies the financial impact of a trigger event on investors.

4.1.4 Estimating the Probability of Triggering

Finding the probability of triggering is the most difficult part of this methodology. A common approach, as discussed by De Spiegeleer and Schoutens (2014), involves modelling the stock price dynamics using Black-Scholes, to approximate the trigger probability by modelling it as the possibility of the stock price falling below a certain barrier S^*.

$$(12)\quad P_T^* = \Phi\left(\frac{\ln(S^*/S) - \mu T}{\sigma\sqrt{T}}\right) + (\frac{S^*}{S})^{2\mu/\sigma^2}\,\Phi\left(\frac{\ln(S^*/S) + \mu T}{\sigma\sqrt{T}}\right)$$

It incorporates fundamental parameters to estimate the probability that the stock price breaches the barrier before a given time. The trigger probability is determined using the cumulative distribution function of a standard normal variable Φ. The computation incorporates the drift μ, which is defined as $\mu = r - q - \sigma^2/2$. Here, r represents the risk-free rate, q is the dividend yield, σ is the stock volatility, and S is the current stock price. These parameters define the changes of the trigger event.

While Black-Scholes offers valuable observations, particularly in modelling trigger probabilities and its adaptability to CoCo bonds (De Spiegeleer and Schoutens 2014), its strength lies in incorporating stochastic processes aligned with market behaviours (Hull 2018). By providing a probabilistic framework, it allows the evaluation of contingent risks, although it simplifies complexities such as regulatory interventions or dividend impacts, as noted by Hull (2018) and Baker et al. (2004). These limitations make the model a guideline for CoCo pricing rather than a pricer. However, it remains a good model for understanding the role of credit risk and trigger mechanisms in the valuation.

4.2 Equity Derivatives Approach

It evaluates CoCo bonds by modelling their triggers and pricing as stock price dependent events. This method assumes that a CoCo trigger is linked to the issuer's share price falling below a predefined barrier level. De Spiegeleer and Schoutens (2011) explain that this transformation allows the valuation to be thought as a barrier option pricing problem.

A CoCo bond under this methodology can be decomposed into three components: a zero-coupon bond ZC, representing the principal amount discounted at the risk-free rate assuming no trigger occurs; a binary down-and-out (BDO) option, adjusting the value of coupon payments when the stock price drops below the barrier level S^*; and the recovery value π, which depends on whether the CoCo comes as a conversion or write-down one. Considering all these components, finally the Black-Scholes model is used.

4.2.1 Pricing Formula for CoCo Bonds

The price 'P' of the CoCo bond, as described by Jan De Spiegeleer, Ine Marquet, Wim Schoutens; in the book "The Risk Management of Contingent Convertible (CoCo) Bonds" is given by the sum of the three components:

$$(13)\quad P = ZC + Cpn + \pi$$

Where, ZC is the zero-coupon bond, Cpn reflects the adjusted coupon payments, and π denotes the recovery value. The zero-coupon bond and adjusted coupon are expressed as:

$$(14)\quad ZC = Nexp(-rT)\ [\Phi\left(x_1 - \sigma\sqrt{T}\right) - \left(\frac{S^*}{S}\right)^{2\lambda} \Phi\left(y_1 - \sigma\sqrt{T}\right)]$$

$$(15)\quad Cpn = \sum_{i=1}^{k} c_i \exp\left(-rt_i\right) [\Phi\left(x_1 - \sigma\sqrt{T}\right) - \left(\frac{S^*}{S}\right)^{2\lambda} \Phi\left(y_1 - \sigma\sqrt{T}\right)]$$

Key parameters are defined as:

$$x = \frac{\ln(S^*/S)}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}, \qquad y = \frac{\ln(S/S^*)}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}, \qquad \lambda = \mathrm{r} - \mathrm{q} + \frac{\sigma^2}{2}$$

Where S is the current stock price, $S^*$is the trigger level, σ is the Volatility, r is the Risk free, q is the dividend yield, T is the time to maturity, t_i represents the coupon dates, N is the notional value and c_i shows the coupon payments.

4.2.2 Recovery Value and Conversion CoCos

For CoCo with a conversion option, the recovery value depends on the conversion ratio C_r and the share price at the time of conversion S^*:

$$(16)\quad \pi = C_r S^* = C_r\left(\frac{S^*}{S}\right)$$

However, extreme scenarios like the collapse of Banco Popular in 2017 shows cases where recovery may get to zero, as the equity received after conversion became worthless. Conversely, CoCos with high conversion triggers are more likely to retain recovery value, as they are designed to absorb losses during period of financial distress, providing stability to the issuer (De Spiegeleer and Schoutens 2014).

4.2.3 Implied Trigger Level, Volatility and Step-Up Rates

The trigger level 'S^*'is one of the most important parameters in the Equity Derivative Approach and can be implied from the market price of the underlying security issuing the security. This allows for pricing new CoCos by using existing market data. Due to that, CoCos issued by the same bank with identical accounting triggers should have the same implied trigger level, making possible to understand when they are undervalued or overvalued.

Volatility is another key input but is challenging to estimate it due to the characteristics of CoCos, such as long maturities, mostly perpetual, and conversion under critical scenario. An interesting approach to estimate volatility involves using credit default swap (CDS) spreads to price deep out of the money put options. We see a CDS contract with zero recovery as a deep out of the money (OTM) put option. This way we can find the implied volatility parameter for which the OTM put option matches with the market spreads of a zero recovery CDS. In this way we use the CDS spreads as an input parameter in the model. Lastly, the step-up rate, is designed to incentivize issuers to call the bond rather than face higher coupon payments. Step-up rates, typically activated at specific call dates, and significantly increase the coupon rate. This feature aligns issuer motivation with investor expectations by encouraging redemption at the earliest opportunity, also improving the appeal of CoCos (De Spiegeleer and Schoutens 2014; Hull 2018).

The Equity Derivative Approach is particularly effective for CoCos with market triggers. By using barrier option and calibrating implied parameters, this method facilitates the valuation of both new and existing CoCo bonds while showing potential mispricing in the market.

4.3 Option Model

The model is a simplified yet good base for pricing CoCo bonds. It sees CoCo bonds as a combination of a plain vanilla bond and an embedded European put option, reflecting the risks in these instruments. This model is particularly useful for understanding the loss absorbing feature of CoCos, as the put option represents the risk associated with the trigger events. Furthermore, CoCo bonds, with their callability, are viewed as being short on a put option, incentivizing issuers to call the bonds to avoid higher coupon payments, due to the step up rate.

4.3.1 Plain Vanilla Bond Pricing

The vanilla bond component represents the principal and coupon payments of the CoCo bond, discounted using a non-flat discount curve that captures changes in interest rates over time. The price of the vanilla bond "P_{BOND}" is:

$$(17)\quad P_{BOND} = \sum_{i=1}^{N} \frac{C_i}{(1+z_i)^{T_i}} + \frac{N}{(1+z_N)^{T_N}}$$

Where T_i shows the time in years to the i^{th}cash flow, C_i is the coupon payment at time T_i, N is the principal amount repaid at maturity, z_i is the discount rate at time T_i and N is total number of cash flows. It is assumed that the bond pays regular coupons and that the market curve is use for discounting.

4.3.2 Put Option Pricing

The embedded put option is priced using the Black-Scholes model, requiring the forward price F_m of the underlying asset, which adjusts the spot price S_0 for expected future values, dividends, and discounting. The forward price is expressed as:

$$(18)\quad F_m = S_0 CF(T_m) - \sum_{i=1}^{m} D_i$$

Where $CF(T_m) = e^{T_m \times (z_m - r_m)}$ is the forward adjustment factor and D_i represents any dividends or cash flows before T. Finally, the European put option price 'P_{put}' is:

$$(19)\quad P_{put} = K e^{-rT} \Phi(-d_2) - F e^{-qT} \Phi(-d_1)$$

With:

$$d_1 = \frac{\ln(F/K) + \frac{\sigma^2}{2}T}{\sigma\sqrt{T}}\ , \qquad d_2 = d_1 - \sigma\sqrt{T}$$

Where Φ is the cumulative normal distribution function, F is the forward price of the underlying asset, K is the strike price of the option, T is the time to maturity, r is the risk-free rate, q is the dividend yield and σ is the volatility of the underlying asset. The put option value represents the CoCo bond risk in the event of a trigger.

4.3.3 CoCo bond price

The final CoCo bond price 'P_{CoCo}' is the difference between the vanilla bond and the put option:

$$(20)\quad P_{CoCo} = P_{bond} - P_{put}$$

This formula shows the double nature of CoCos: behaving as vanilla bonds during normal conditions while carrying a risk represented by the put option. In stable markets, where trigger events are unlikely, the put option's value is around zero. This model provides an easy yet valid alternative for pricing CoCos, facilitating their evaluation under varying market conditions and helping investors and institutions in assessing potential risks and returns.

4.4 Description of the Analysis Carried out

This section evaluates the performance of the three pricing methodologies: Equity Derivative Approach, Credit Derivative Approach, and Option Approach, by assessing their ability to replicate observed market prices. Here, performance is defined as the degree of alignment between model-implied prices and market prices, evaluated using the following statistical metrics: Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Standard Deviation of price deviations. These metrics help quantify both accuracy, closeness to market prices, and consistency, variability in deviations, of each methodology.

Mean Absolute Error (MAE) evaluates the average degree of price deviations, without taking into consideration direction, providing a straightforward measure of accuracy. The formula is:

$$(21)\quad MAE = \frac{1}{N}\sum_{i=1}^{N}(P_{model,i} - P_{market,i})$$

Where $P_{model,i}$ is the price computed using a specific methodology, $P_{market,i}$ is the corresponding market price, and N is the number of observations.

Root Mean Squared Error (RMSE) measures the square root of the average squared deviations. This metric penalizes larger deviations, making it particularly sensitive to outliers:

$$(22)\quad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_{model,i} - P_{market,i})^2}$$

Standard Deviation shows the variability/consistency of model performance and is as follow:

$$(23)\quad Std.Dev = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}((P_{model,i} - P_{market,i}) - Mean\ Difference)^2}$$

This analysis assumes that market prices, under the Efficient Market Hypothesis (EMH), are used as the benchmark for evaluating model performance. According to the EMH, market prices reflect all available information and represent a "fair value" (Fama 1970). However, it is known that market prices may deviate from theoretical valuations due to factors such as market inefficiencies like illiquidity, information asymmetry, and behavioural biases (Baker et al. 2004), regulatory constraints arising from structural complexities and regulatory uncertainty (De Spiegeleer and Schoutens 2014), and arbitrage limitations, where institutional barriers can slow down market corrections (Hull 2018). These considerations point out that discrepancies between market and model prices may not only indicate model shortcoming. External factors such as investor sentiment, liquidity conditions, or temporary mispricing can also contribute.

For each CoCo bond, statistical measures are calculated by comparing the model prices against observed market prices over time. MAE and RMSE quantify accuracy, with lower values indicating better alignment, while Standard Deviation reflects consistency, with lower values suggesting reliable performance over time. These metrics defines performance as a combination of accuracy and consistency rather than solely relying on market prices as "correct."

Regression Analysis

To evaluate the impact of share price movements and CDS spreads on CoCo bond prices while accounting for issuer-specific differences and time effects, a panel regression model with issuer specific and time fixed effects was done. This methodology makes sure that unobserved heterogeneity across issuers and macroeconomic conditions changing over time are properly controlled, while all CoCo bonds are analysed together within a merged regression model.

$$(24)\quad CoCoPrice_{it} = \alpha_i + \lambda_t + \beta_1 SharePrice_{it} + \beta_2 CDS_{it} + \epsilon_{it}$$

In this equation, $CoCoPrice_{it}$ represents the price of CoCo bond by issuer at time t, serving as the dependent variable. The variable $SharePrice_{it}$, captures the share price of the issuer “i” at time t, reflecting equity market sensitivity, while CDS_{it}, measures the CDS spread for issuer “i” at time t, acting as a substitute for credit risk. The term α_i accounts for bond specific fixed effects, which control for issuer differences such as structural bond features or financial stability that do not change over time. The time fixed effect λ_t captures macroeconomic influences, policy shifts, and global financial market trends that impact all bonds. The error term ϵ_{it} represents the factors not captured by the regression model.

The motivation for this regression lies in the double nature of CoCo bonds, where share prices and CDS spreads play a fundamental role in their pricing. Share prices directly influence CoCo bonds, particularly those with market-based triggers, where a sharp decline in the issuer share price can activate the conversion. This relationship reflects the equity sensitivity of CoCo bonds, as noted in studies such as De Spiegeleer and Schoutens (2014). CDS spreads, on the other hand, serve as a proxy for credit risk, indicating the market's perception of the issuer’s probability of default. Increasing CDS spreads are a sign of increased default risk, which generally leads to a decline in CoCo bond prices, capturing their behaviour under stressed conditions (Brigo et al. 2013). Dividing the regression analysis by issuer is relevant because different financial institutions may exhibit distinct sensitivities to equity and credit risk. Factors such as capital structures, risk profiles, and investor perceptions can vary significantly between issuers, leading to different responses of CoCo bond prices to market variables. A bank with stronger ratios can show lower sensitivity to credit spreads but higher sensitivity to equity movements, while a less stable bank may respond more drastically to credit risk changes. This division allows for a better understanding of issuer-specific dynamics, which is critical for stress-testing and risk management purposes (Hsiao 2003).

The fixed effects approach adds robustness to this analysis by controlling for unobserved, time-invariant characteristics of each bond that could bias the regression results. This ensures that the estimated coefficients β1 and β2 reflect the true impact of share prices and CDS spreads on CoCo bond prices, isolated from confounding bond-specific features. The results of this regression will reveal the extent to which CoCo bond prices are influenced by equity and credit risk.

Chapter V

5.1 Result Summary

This section presents a detailed evaluation of the results obtained from the analysis conducted for the three pricing methodologies, applied to CoCo bonds issued by Credit Suisse, Deutsche Bank, Barclays, and HSBC. First, the analysis focuses on the Mean Absolute Error, Root Mean Square Error, and Standard Deviation, which provide an understanding of the models' accuracy, deviations, and stability when compared to market prices.

The MAE measures the average of the absolute differences between model-implied prices and observed market prices. For Credit Suisse, the Option model achieves the lowest MAE values, averaging approximately 8.66, while the Equity Derivative and Credit Derivative models produce significantly higher errors, with averages of 23.40 and 23.06, respectively. This suggests that the simplified structure of the Vanilla Bond model aligns well with Credit Suisse’s CoCo bond pricing dynamics. In contrast, for Deutsche Bank, the Equity Derivative and Credit Derivative models outperform the easier model, with both delivering low MAE values around 5.33. The Vanilla Bond model, however, shows substantial deviation with an average error of 38.28, indicating that Deutsche Bank bonds exhibit sensitivities better captured by equity and credit-linked models. For Barclays, the Equity and Credit Derivative models again display superior performance, producing average MAE values of approximately 2.00, compared to 24.79 for the Vanilla Bond model. This result shows that Barclays bond prices are driven primarily by equity volatility and credit spread movements, making hybrid models more appropriate. Similarly for HSBC, where the Equity Derivative and Credit Derivative models deliver minimal MAE values of 0.52 and 0.53, respectively, while the Vanilla Bond model records larger errors averaging 13.00. These findings suggest that HSBC’s CoCo respond more closely to models incorporating credit risk and equity sensitivities.

***Table 1**: Mean Absolute Error (MAE) results for each issuer and pricing methodology.*

Issuer	Equity Derivative	Credit Derivative	Vanilla bond
Credit Suisse	-23.300	-22.920	8.360
Credit Suisse	-12.430	-12.309	9.082
Credit Suisse	-36.975	-36.942	8.550
Deutsche	3.754	3.753	20.572
Deutsche	1.508	1.489	-2.370
Deutsche	3.751	3.727	46.545
Deutsche	8.780	8.762	84.688
Deutsche	9.906	9.896	42.959
Barclays	7.749	7.736	60.195
Barclays	5.009	4.994	-13.649
Barclays	1.819	1.794	18.682
Barclays	-0.615	-0.625	4.811
Barclays	-1.947	-1.969	50.954
HSBC	-7.607	-7.615	-9.019
HSBC	0.153	0.131	25.734
HSBC	4.110	4.094	20.343
HSBC	-0.765	-0.780	-1.554
HSBC	3.487	3.472	28.530

Source: Author calculations

The RMSE serves as a more sensitive measure of accuracy by amplifying the impact of larger deviations. For Credit Suisse, the Vanilla Bond model produces the lowest RMSE of approximately 4.00, reflecting its ability to consistently align with observed market prices. In contrast, the RMSE for the Equity and Credit Derivative models is higher, at 7.71 and 7.64, respectively, reinforcing their underperformance relative to the Vanilla Bond model in this case. However, for Deutsche Bank, the Equity and Credit Derivative models achieve RMSE values of approximately 5.67, while the Option model produces much larger deviations, averaging 39.77. This emphasizes the limitations of the Option model when applied to Deutsche Bank's, which appear to be influenced by more dynamic market conditions. Barclays' results further demonstrate the robustness of the Equity and Credit Derivative models, both of which achieve RMSE values close to 2.80, while the Vanilla Bond model records a significantly higher RMSE of 25.43. Similarly, for HSBC, the Equity and Credit Derivative models maintain the lowest RMSE values, both averaging 0.53, whereas the Option Bond model demonstrates larger deviations with an average RMSE of 13.57. These results align with the findings from MAE, showing that the hybrid models consistently outperform the Vanilla Bond approach for Deutsche Bank, Barclays, and HSBC.

Table 2: *Root Mean Square Error (RMSE) results for each issuer and pricing methodology.*

Issuer	Equity Derivative	Credit Derivative	Vanilla bond
Credit Suisse	8.274	8.154	4.472
Credit Suisse	4.752	4.689	5.098
Credit Suisse	10.105	10.103	2.433
Deutsche	3.842	3.841	20.675
Deutsche	1.519	1.499	3.998
Deutsche	3.751	3.727	46.545
Deutsche	8.780	8.762	84.688
Deutsche	9.906	9.896	42.959
Barclays	7.749	7.736	60.195
Barclays	5.009	4.994	-13.649
Barclays	1.819	1.794	18.682
Barclays	0.615	0.625	4.811
Barclays	2.705	2.721	50.958
HSBC	7.733	7.741	9.648
HSBC	0.153	0.131	25.734
HSBC	4.134	4.118	20.484
HSBC	1.162	1.171	3.272
HSBC	3.628	3.613	28.553

Source: Author calculations

The Standard Deviation of errors provides observation into the stability of each pricing model, measuring the variability of pricing deviations. Lower standard deviations indicate more consistent and reliable model performance. For Credit Suisse, the Vanilla Bond model demonstrates the lowest standard deviation at 11.41, compared to higher values of 24.59 for the Equity Derivative model and 24.42 for the Credit Derivative model. This confirms the suitability of the Option Bond model for Credit Suisse, as it not only minimizes errors but also produces more stable pricing estimates. For Deutsche Bank, the Equity and Credit Derivative models exhibit the lowest variability, with standard deviations around 0.50. In contrast, the Vanilla Bond model shows significant instability, with a standard deviation of 10.19, further reinforcing its limitations for Deutsche Bank's bonds. For Barclays, the Equity and Credit Derivative models again achieve superior stability, with standard deviation values of 1.88, while the Option model records a much higher value of 9.65. Similarly, for HSBC, where the Equity and Credit Derivative models show minimal variability with standard deviations of 0.53, compared to 2.32 for the Vanilla Bond model. The analysis of these three metrics highlights important insights into the performance of the pricing models. The Option model performs best for Credit Suisse, consistently achieving lower errors and higher stability. However, its performance deteriorates significantly for Deutsche Bank, Barclays, and HSBC, where the Equity and Credit Derivative models consistently deliver greater accuracy and stability across MAE, RMSE, and Standard Deviation. This discrepancy underscores the limitations of the easier model in capturing the hybrid features of CoCo bonds.

Table 3*: Standard Deviation results for each issuer and pricing methodology.*

Issuer	Equity Derivative	Credit Derivative	Vanilla bond
Credit Suisse	23.401	23.063	12.650
Credit Suisse	12.572	12.407	13.488
Credit Suisse	37.811	37.801	9.102
Deutsche	0.816	0.815	2.058
Deutsche	0.178	0.176	3.220
Deutsche	0.000	0.000	0.000
Deutsche	0.000	0.000	0.000
Deutsche	0.000	0.000	0.000
Barclays	0.000	0.000	0.000
Barclays	1.898	1.584	0.692
Barclays	2.832	2.052	0.557
Barclays	0.000	0.000	0.000
Barclays	1.878	1.877	0.668
HSBC	1.392	1.393	3.128
HSBC	0.000	0.000	0.000
HSBC	0.445	0.446	2.801
HSBC	0.874	0.873	2.879
HSBC	1.002	1.000	1.133

Source: Author calculations

Descriptive Statistics

The descriptive statistics for all analysed CoCo bonds collectively, give an understanding of the data distribution and variability, specifically for CoCo prices, CDS spreads, and share prices. The mean CoCo price is approximately 95.262, with a standard deviation of 11.81, indicating that their prices are relatively stable but exhibit moderate deviations. The negative skewness of prices, at -0.9, suggests a tendency toward price declines, particularly during stressed market conditions. The kurtosis value of 1.93 shows the presence of fat tails, reflecting the occurrence of extreme price movements in the market. The mean share price is 218.385, with a high standard deviation of 269.103. This significant variability underscores the dynamic nature of the equity market, which is crucial for pricing CoCo bonds, especially those triggered by market-based mechanisms. The positive skewness of share prices, at 0.63, point out that higher values are slightly more frequent, though the distribution remains almost symmetric. The negative kurtosis of -1.4 suggests a thinner tail distribution compared to a normal distribution, indicating fewer extreme equity price movements. Lastly, the mean CDS spread is 94.249, with a standard deviation of 68.203, highlighting significant variability in credit risk across issuers. The positive skewness of 3.71 indicates that higher CDS values are driving the spread distribution, typically reflecting periods of elevated default risk. The kurtosis value of 29.32 suggests that CDS spreads display a distribution with peaks.

***Table 4**: Descriptive statistics results.*

	Bond Price	**CDS**	**Share Price**
Mean	95.26	94.25	218.39
Sd	11.18	68.20	269.10
Min	0	32.95	1.70
Max	118.58	12666.59	777.45
Skew	-0.90	3.71	0.63
Kurtosis	1.93	29.32	-1.40
Se	0.13	0.78	3.06
Observations	7732	7732	7732

Source: Author calculations

Regression Analyses

The regression results reveal that both share prices and CDS spreads are significant determinants of CoCo bond prices. The coefficient for “SharePrice” is 0.057 with a standard error of 0.004, and it is highly significant ($p < 0.01$). This indicates that increases in the share price positively influence CoCo bond prices. This finding is consistent with the nature of CoCo bonds, particularly for those with market-based triggers. Higher share prices reduce the probability of conversion or write-down, showcasing improved market confidence in the issuer's financial position. The “CDS” spread coefficient is -0.160 with a standard error of 0.003, also highly significant ($p < 0.01$). The negative relationship implies that higher credit spreads, lead to a decline in CoCo bond prices. This outcome is as expected with the debt-like characteristics of CoCo bonds, where rising CDS spreads reflect a higher probability of default, resulting in lower valuations for the bonds. The explanatory power of the regression, as reflected by an R^2 value of 0.517, suggests that approximately 51.7% of the variation in CoCo bond prices can be explained by movements in share prices and CDS spreads. The high F-statistic of 4,142.143, significant at the 1% level, confirms the joint explanatory strength of the two independent variables. These results emphasize the importance of both equity and credit risk in determining CoCo bond prices, consistent with the findings of De Spiegeleer and Schoutens (2014) and Brigo et al. (2013).

***Table 5**: Regression results.*

	Bond Price
Share Price	0.057*** (0.004)
CDS	-0.160*** (0.003)
R-squared	0.517
Observations	7,731

Notes: *** Significant the at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level. Source: Author calculations

The magnitude of the CDS coefficient relative to the SharePrice coefficient suggests that credit risk has a more substantial impact on CoCo bond prices than equity performance. This finding supports the idea that, under stressed market conditions, CoCo bonds behave more like debt instruments than equity (Brigo et al. 2013). The inclusion of time-fixed effects ensures that broader macroeconomic shocks and systemic market trends do not bias the estimated coefficients. By isolating issuer-specific and time-specific variations, the model provides a robust assessment of the relationship between CoCo bond prices, share prices, and CDS spreads. The high explanatory power of the regression further reinforces the relevance of these variables in CoCo bond pricing. The analysis also indicates that variations in CoCo bond prices are not solely issuer-specific but are influenced by broader equity and credit market conditions. The use of a panel regression with fixed effects allows for a clear differentiation between issuer-level effects and macroeconomic factors. These findings are in line with previous studies, such as De Spiegeleer and Schoutens (2014), who emphasized the importance of equity volatility and credit spreads in CoCo pricing.

5.2 Proposed Solution

The evaluation of the three pricing methodologies offers actionable insights for stress-testing CoCo bonds across various issuers and market contexts. The choice of model depends on the specific characteristics of the CoCo bond issuer and the prevailing market dynamics.

The Option-Based Model, which simplifies CoCo bond pricing by thinking it as a vanilla bond minus a put option, is better in scenarios where market triggers dominate. This model effectively captures equity driven price movements, particularly for issuers with stable credit profiles but higher sensitivity to share price fluctuations. The model’s structure is computationally efficient, making it suitable for analysing CoCos issued by banks operating under stable market conditions.

For issuers operating in more volatile or risk sensitive environments, the Equity and Credit Derivative models provide a valid method for valuation. These pricer integrate both equity volatility and credit spreads, reflecting the hybrid nature of CoCo bonds. By capturing the dynamics between share price movements and credit risk, these models are better for issuers exposed to systemic risks or significant market uncertainties.

A choice will be done on the model to be used, based on this study, to perform stress-test of CoCo bonds. For issuers with high credit sensitivity, the Credit Derivative model is particularly useful in assessing default risk and pricing under adverse credit conditions. Conversely, the Equity Derivative model is ideal for issuers whose CoCo bonds are driven by equity market behaviour, particularly those with market-based triggers.

A hybrid approach is recommended to maximize accuracy and practicality. This involves applying the Equity and Credit Derivative models to bonds with significant equity-credit link while leveraging the Option-Based Model for bonds predominantly influenced by equity triggers. Such a tailored approach allows institutions to align their valuation ensuring precise prices under a variety of market scenarios.

5.3 Conclusion

This thesis evaluates the performance of three pricing methodologies: Equity Derivative, Credit Derivative, and Option-Based Model, for CoCo bond valuation. The results highlight that the choice of model depends on issuer characteristics and market conditions. The Option-Based Model is best suited for scenarios where equity price sensitivity dominates, while the Equity and Credit Derivative models are better in capturing the hybrid nature of CoCo bonds, particularly when equity and credit are related. The regression analysis confirms the dual sensitivity of CoCo bonds, where share price increases positively impact pricing, while increasing CDS spreads signal higher credit risk and result in lower CoCo prices. This highlights the importance of integrating both equity and credit dynamics into valuation frameworks. By tailoring the pricing methodology to issuer-specific risks and market conditions, financial institutions can enhance their valuations and better manage CoCo bond exposures. While limitations such as market inefficiencies and reliance on historical data exist, the findings contribute significantly to the academic and practical argument on CoCo bond valuation, offering a structured approach for risk management and pricing under varying market conditions.

While the study provides meaningful insights into CoCo bond pricing, several limitations should be acknowledged. First, the assumption of market efficiency, as outlined in the Efficient Market Hypothesis (Fama 1970), based the analysis. However, markets are not always perfectly efficient, and price deviations driven by biases, liquidity constraints, or regulatory interventions can impact the observed results.

Second, the reliance on historical data limits the applicability of the findings to future market conditions. Market, particularly during periods of stress, may introduce new factors not captured in the historical dataset, such as changes in regulations or macroeconomic shocks.

Third, the study evaluates model performance using error metrics and regression analysis, assuming that observed market prices reflect true value. This do not count the possibility that market prices could deviate from fundamental valuations due to temporary mispricing or limited market liquidity.

Despite these limitations, the study poses a strong foundation for the practical application of pricing methodologies in CoCo bonds. Future research could incorporate liquidity adjustments, dynamic volatility modelling, or alternative calibration techniques to address these challenges.

References:

Avdjiev, Stefan, Anastasia Kartasheva, and Bilyana Bogdanova. 2017. "CoCo Issuance and Bank Fragility." *BIS Quarterly Review*, September: 55–67.

Baker, Glyn, Reimer Beneder, and Alex Zilber. 2004. "FX Barriers with Smile Dynamics." *Erasmus University Rotterdam*.

Baltagi, Badi H. 2008. *Econometric Analysis of Panel Data*. Chichester: Wiley.

Brigo, Damiano, Jean Garcia, and Nicola Pede. 2013. "CoCo Bonds Valuation with Firm Value Models." *arXiv preprint arXiv:1302.6629*.

Clarke, Jonathan, Tomas Jandik, and Gershon N. Mandelker. 2001. "The Efficient Markets Hypothesis." In *International Encyclopedia of the Social & Behavioral Sciences*, edited by Neil J. Smelser and Paul B. Baltes, 4553–60. Amsterdam: Elsevier.

Corcuera, José Manuel, et al. 2011. "Efficient Pricing of CoCos under Smile-Conforming Models." *Quantitative Finance*, 14(5): 863–873.

De Spiegeleer, Jan, and Wim Schoutens. 2011. "Pricing Contingent Convertibles: A Derivatives Approach." *Journal of Derivatives*, 18(2): 27–36.

De Spiegeleer, Jan, and Wim Schoutens. 2014. "CoCo Bonds with Extension Risk." *Journal of Credit Risk*, 10(3): 67–93.

Fama, Eugene F. 1970. "Efficient Capital Markets: A Review of Theory and Empirical Work." *The Journal of Finance*, 25(2): 383–417.

Financial Engineering Associates (FEA). 2008. *Interest and Risk Measures: Concepts and Applications*. New York: MSCI Barra.

Financial Engineering Associates (FEA). 2008. *Energy and Risk Measures: Concepts and Applications*. New York: MSCI Barra.

Hsiao, Cheng. 2003. *Analysis of Panel Data*. Cambridge: Cambridge University Press.

Madhavan, Ashok. 2023. "Regulatory Challenges in CoCo Bond Valuation: Insights from the Credit Suisse Crisis." *Financial Markets Review*, 21(3): 89–102.

Malkiel, Burton G. 2003. "The Efficient Market Hypothesis and Its Critics." *The Journal of Economic Perspectives*, 17(1): 59–82.

Reuters. 2023. "Credit Suisse CoCo Bonds Wiped Out in $17 Billion Write-Off." Accessed May 15, 2023. https://www.reuters.com.

Sewell, Martin. 2012. "The Efficient Market Hypothesis: Empirical Evidence." *International Journal of Financial Studies*, 1(1): 1–19.

Turfus, Colin, and Alexander Shubert. 2016. "Analytic Pricing of CoCo Bonds." *International Journal of Theoretical and Applied Finance*, 20(3): 1750034.

Wooldridge, Jeffrey M. 2010. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: MIT Press.