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Contingent Convertible Bonds and An Analysis About Their Pricing

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Abstract. This study aims to study contingent convertibles, exploring their elements, trigger mechanisms, and the complex relation between financial variables that influence their valuation. By examining various pricing methodologies as well as empirical studies and conducting a quantitative study using recent market data, this research seeks to contribute to a deeper understanding of the pricing dynamics about Contingent Convertible bonds. This study also contributes to the ongoing discussions regarding CoCos by examining how their pricing dynamics influence their role as regulatory capital for banks and as instruments for bail-in policies.

Keywords. CoCos, Contingent Convertible Bonds, Additional Tier 1, bail-in

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TERM PROJECT

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0.1 Introduction

Contingent Convertible bonds (CoCos) have emerged as a distinctive financial instrument that plays a significant role in banking sector and financial markets, especially after 2008 financial crisis. Faced with the too-big-to-fail problem during 2008 financial crisis, regulators have acknowledged "bailouts" as a solution to achieve financial stability. After crisis, to reduce the reliance on taxpayers' fund for financial stability, authorities focused on CoCos as an important "bail-in" instrument. These hybrid securities, combining features of both debt and equity, have gained prominence in recent years, due to their ability to absorb losses and contribute to the resilience of financial institutions. The main feature of these bonds is that they are converted into equities or write-down to increase a distressed bank's capital adequacy, when its capital adequacy level falls below a certain level. Due to their potential for enhancing resiliency of banks and reducing the likelihood of a failure, along with their role in the resolution of a failed bank [23] CoCos have become a crucial component in the regulatory tools for ensuring the stability of the banking sector.

While the first CoCos issue dates to 2009, international banking rules, Basel III, after 2010 and based on Basel III European Capital Requirements Directive in 2013 incorporated the use of CoCo bonds to satisfy the capital requirements of banks. Basel III defines regulatory bank capital as the sum of Common Equity Tier 1, Additional Tier 1 and Tier 2 Capital. CoCo bonds, depending on their design to meet the eligibility conditions, can be included in Additional Tier 1 or Tier 2 capital by the issuer bank. While Tier 1 is an instrument that can provide capital injection for "going-on basis", Tier 2 capital instrument is used as a "gone-concern basis". Through CoCo issues, banks can gain additional capital, mitigating the dilution costs and decrease the risk of insolvency or bailouts [4].

The regulatory development for CoCos boosted the issue volume especially by European banks. 20 billion EUR amount of Tier 1 type issue by European banks in 2014 increased to 250 billion EUR in 2023. CoCos present an appealing investment opportunity for investors who can take high risks in return for higher yields. Their high return compared to ordinary bonds come from their low priority ranking in case of default, uncertainty regarding their conversion and substantial systematic risk [4].

A recent development regarding CoCo bonds included in Additional Tier 1 (AT1) capital by Credit Suisse have revealed some important findings and provided valuable lessons about these bonds. In March 2023, Credit Suisse Additional Tier 1 capital was written down by The Swiss Financial Market Supervisory Authority (FINMA). What makes this write-down so unique is the unprecedented occurrence of CoCo bonds being written down before shareholders bear the cost in the first place. From the point of FINMA, who uses its power derived from the bond contract, the write-down of the bonds serves not only alleviate the burden of taxpayers and help to recover a distressed bank but also addresses the moral hazard problem caused by bailouts for banks considered to be too-big-to-fail. However, this write-down created a negative reaction from market side as it was considered the breach of "priority order of claims" [4]. Other European countries' regulators did not show any support to Swiss Authority on this act, mostly with an aim to prevent further crisis in AT1 bond market.

The most important finding of this event is that even sophisticated investors are not fully capable of understanding the conversion mechanism, their ranking or risks involving in these instruments [3]. This fact is mostly attributed to the high level of complexity how these bonds are structured [4], [3]. Apparently, this structural complexity leads to problems for market players to fully reflect their risks to their pricing.

CoCos have two main characteristics: the loss absorption mechanism and the trigger that starts it by conversion of the bonds to shares or write down the bond principal [30]. Basel III provisions requires CoCo bond contracts issued for AT1 capital to include a discretionary point of non-viability trigger, as well as an accounting trigger. This implies that the conversion or write-down of CoCo bonds can occur not only when a bank's capital ratio falls below a certain level, but also when regulatory authority independently assesses the point of non-viability of a bank. Therefore, the uncertainty about the trigger event makes to estimate the probability of occurring a trigger event, one of the most essential inputs to price a CoCo bond. [2] finds that issuance of CoCos with accounting trigger lowers issuer bank's CDS spread while CoCos with only discreationary trigger do not have any significant effect on reducing issuer bank's riskiness. This finding can be explained by the uncertainties regarding regulatory decision about trigger event.

Bank for International Settlement, after this development, suggests the revision of Basel III requirements for AT1 instruments in terms of complexity and transparency as well as their loss-absorbing hierarchy [3]

As evident from the literature review section of this study, empirical studies about the pricing of Contingent Convertible bonds are rare due to its complexity and the applicability of suggested models to real financial data is limited. Furthermore, the literature review indicates that the study of pricing models for CoCo bonds, once a popular research topic in financial mathematics when they were first issued in 2009, has lost its popularity over the years. Despite this, the market for CoCo bonds have grown significantly, with banks increasingly issuing them to meet capital requirements, attracting high-yield-seeking investors. [34] indicates the necessity of additional empirical research as the market matures, emphasizing that more explicit conclusions regarding the accuracy of pricing models should be deferred. Considering larger set of bonds and time series availability now, the question of whether market development has changed the dynamics of CoCo bond pricing since their first issuance has been a starting point of this study. Additionally, recent developments in the CoCo market have raised concerns related to the pricing of CoCo bonds, necessitating a re-examination of their pricing models. Therefore, this research paper aims to study CoCos, exploring their pricing models, trigger mechanisms, and the complex relation between financial variables that influence their valuation. By examining various pricing methodologies as well as empirical studies and conducting a quantitative study using recent market data, this research seeks to contribute to a deeper understanding of the pricing dynamics about Contingent Convertible bonds.

This study is organized as follows: Section 2 reviews the literature. Section 3 presents the elements of contingent convertible bonds, methodology, data variables and data sources. Section 4 includes the quantitative analysis and model comparison results. Section 5 concludes the project.

0.2 Literature Review

The literature studies CoCos in three main topics: (i) literature on the relationship between CoCo bond issue and bank stability or bank structure; (ii) literature about the ideal scheme of CoCo; (iii) literature about pricing determinants, models and risk management.

Recent studies regarding CoCo issuance are highly focused on the first category of academic work. The growing significance of this financial instrument in bank resolution policies, coupled with the the rapid expansion of the CoCo market and increased data availability has fostered empirical studies on these subjects. A study results by [2] include a higher likelihood of CoCo issuance for larger and better capitalized banks, a significant decline in issuers' CDS spread after issuance, no significant impact of bond issuance on stock prices. [12] finds that after European policy shift from bail-out to bail-in, banks' funding strategies have moved away from bonds, including CoCos. The impact of this policy shift on CoCo bond yields is studied by [33]. [20] investigates the banks' motives to issue CoCos. [9] analyzes the preferences of CoCo bond buyers and sellers. [11] investigates the characteristics of banks which issue CoCo bonds. [32] finds a positive impact of CoCo issuance on banks' risk-taking incentives.

Some studies such as [8], [22], [24], [25], [26] focus on the second category of topics which is the design of CoCos, especially suggesting the use market trigger rather than accounting based trigger like capital ratio. [15] propose a dynamic capital structure model to study the optimal conversion ratio in the design of CoCos.

The studies in third category, mostly technical papers, suggest pricing models for the valuation of CoCo bonds. Nevertheless, the literature has not compromised on a certain model, yet. The complexity in pricing CoCo bonds arises from their hybrid nature [34], combining features of both bonds and equity. Furthermore, estimating probability of a trigger event which converts bond to equity is a challenging task, particularly due to the linkage of trigger events to a capital ratio in practice.

[29] suggests two approaches: credit derivatives model and equity derivates model. Both models assume that a decline in the issuer's stock price below a certain trigger level will initiate the conversion of bonds into equity. This makes both models highly dependent on the presumption of a direct correlation between capital ratio and stock price. Credit derivatives approach calculates a credit spread that will be compatible with the expected loss. Expected loss calculation requires the probability of default estimation which is assumed to be equal to the probability that issuer's share price falls below trigger stock price level. Equity derivatives model, on the other hand, replicates the value of CoCo bonds with the sum of the present value of a portfolio consisting of three different financial instruments: long in a bond and knock-in forwards and short in binary-down-in options.

The structural models studied by [24], [13], [16], [6] offer a different approach than derivates model mentioned above. Given that the trigger events of most CoCo bonds are linked to a capital ratio, these models seek to represent the structure of bank's liabilities and assets. After modelling the process of assets and liabilities, it can impose the conversion when the capital to asset ratio falls below the pre-determined threshold. In addition to this realistic consideration related to trigger event, [24] includes a jump-diffusion process for assets, enhancing the model's ability to capture asset behavior during financial crises. As the main objective of CoCos is to mitigate financial distress during a crisis, jump-risk becomes crucial, in terms of including the inevitable impact of distress on credit spreads of these bonds. However, this model has some drawbacks as it is complicated to implement and requires non-observable variables such as asset volatility, jump intensity and deposit mean-reversion speed [34]. Additionally, balance sheet is released quarterly, which is not compatible with the pricing purposes. Therefore, a practical solution is to utilize the market value of equity, as suggested by [34] to capture the fluctuations in the balance sheet between the financial reporting periods. Nevertheless, it diverges from the initial purpose of constructing a pricing model based on accounting ratio to trigger the conversion. [35] underlines the importance of inputs regarding credibility and volatility essential for valuation of CoCo bonds.

[13] introduces a structural model where a portion of bonds is converted into equity to satify the capital requirements when the capital ratio falls below the accounting trigger. The bond spread is determined by modeling the asset value with Geometric Brownian

Motion. Similarly, [14] studies pricing of convertible bonds with the assumption of assets modeled by a simple Geometric Brownian Motion and capital-based trigger level. They demonstrate that issuing contingent bonds can mitigate default probability and emphasize the significance of selecting an appropriate level of conversion ratio to minimize risk-shift incentives for shareholders.

Recent years, more complex models regarding the pricing of CoCos are studied in the literature. Diverging from the methods mentioned earlier, [10] proposes employing two processes for stock price and capital ratio, aiming to derive a closed-form solution for CoCo pricing based on the assumption that these processes follow correlated geometric Brownian motions. [21] studies to model the accounting trigger and regulatory trigger. [31] recommend the use of the Levy process for pricing, arguing that Black-Scholes model tends to overestimate prices by incorporating jumps into volatility. They suggest that their models correct pricing by considering jump risks. [**?**] study the optimal call strategy for CoCos that can maximize the equity value. A study by [17] incorporates the jumps in stock prices and finds out that the conversion ratio is not unique and follows a stochastic process.

Despite the theoretical work regarding CoCo pricing, the empirical work is limited in the literature. This is not surprising as most of pricing models are not practical enough to be applied in the real-life.

[7] presents a pricing model and assesses its pricing accuracy using Credit Suisse bond data from 2011. This study underlines the challenges associated with uncertainties in pricing of CoCo bonds. Similar to other models in the literature, his model assumes that there is a relationship between the stock price and equity ratio which triggers conversion such as Tier-1 ratio. However, modelling this relationship proves challenging given that the stock price may only partially reflect Tier-1 ratio due to market inefficiencies and lack of detailed information about issuer's asset structure. Additionally, estimating the probability of a decreasing Tier-1 ratio below the trigger level remains problematic.

[34] is one of the first empirical analyses which compares the performance of pricing models using two large volume of bond issues by Credit Suisse and Lloyds Banking Group. They recognized that issuer's share price as a primary determinant of CoCo bond prices, compared to CDS spreads and interest rates. They observed that all methodologies, structural model (SM), equity derivatives model (EDM) and credit derivatives model (CDM), can effectively replicate bond prices. However, when it comes to determining hedge ratios, biases are identified in all models. In summary, their findings indicate that EDM, characterized by its clear parametrization and analysis can be a promising model for valuation and risk management purposes.

Another empirical study comparing pricing models using real data is conducted by [27]. Similar to this project, they choose equity derivatives model and credit default models for accuracy comparison using the Credit Suisse 2014 issue. Their findings reveal that both models give nearly identical results concerning the implied trigger level. They conclude that equity derivatives model provides more accurate outcomes, attributing this accuracy to its more realistic treatment of cash flows. Nevertheless, they point out that the basic assumptions of Black-Scholes model, such as the normal distribution and constant volatility of stock prices pose limitations to these models.

[19] investigate a relationship between model complexity and pricing accuracy, using a dataset of comprising 27 contingent convertible bonds spanning the years 2013 to 2016. They used four models for comparison: The equity derivatives model, an adjusted version of equity derivatives model that includes credit risk, an extended version of these previous models that treats the bonds as perpetual as in reality and a market-based model which uses historical market data to predict price changes using time-series regression. Their results reveal that among theoretical models, the inclusion of credit risk and effective maturity are recommended for better accuracy. Nevertheless, under typical market conditions, the evaluation of accuracy results does not necessitate the adoption of intricate theoretical models whereas in a stressed environment, the utility of more complex models becomes apparent.

0.3 Elements of CoCo Bonds

The fair value of a CoCo bond is determined by a couple of elements. The definitions of these factors carry an important role in understanding the pricing models. Therefore, in this section, these factors are explained shortly.

0.3.1 Trigger Event

It defines an event where the CoCo bond is converted into shares or written down. It is clearly written in the bond prospectus by the issuer bank.

The most common trigger event used by issuers is accounting trigger. This trigger event is tied to a condition related to issuer's capital adequacy. For example, during data gathering phase of this study, it is observed that most bond prospectuses define "trigger event" as the time when the issuer CET1 Ratio is less than 5.125 per cent and/or the Group CET1 Ratio is less than 7 per cent as determined by the issuer or the supervisory authority. The capital adequacy ratio as a trigger event might be preferred because it is calculated on regulatory rules. It has more straight forward relation to the purpose of decreasing the probability of bank default or government bail-out [28]. According to Basel III international banking rules, the minimum trigger level required for a CoCo is 5.125%. On the other hand, accounting trigger has some drawbacks. This measure is backward looking and not continuously updated [28].

The market trigger event is, on the other hand, forward looking and based on continuous market information such as underlying share prices of the issuer. If a share price falls below a pre-defined level, the bonds are converted into shares. Market trigger is commonly used by the academic papers as the pricing models are using it to predict the price of the bonds [29]. However, this trigger event is likely to be under the threat of market manipulations.

Regulatory trigger is another trigger event where the regulatory authority decides to turn the bonds into shares, based on its observations regarding bank's financial health. However, this trigger event is not very popular among both academic world and market participants. The obvious reasons are that government actions might not be predictable input for bond pricing model and that this kind of a trigger gives control to the government.

The relation between trigger level and cost of issue or spread is negative. The lower the trigger level, the possibility of trigger event being actually realized is also lower. While reducing issue costs, low trigger levels simultaneously decrease loss-absorbing capacity. Trigger level should be determined at a sufficiently high level, ensuring timely conversion before the onset of financial trouble [23]. Otherwise, they do not meet the criteria for qualification as additional bank capital. Therefore, the choice of the trigger level by banks is primarily influenced by the balance between cost and eligibility [30].

0.3.2 Conversion Type

Conversion type is determined in the bond contract. There are two kinds of conversion: Equity conversion or principal write down. In the case of a trigger event, bond holders receive shares in return of their bonds in the first type. On the other hand, in the second type, shareholders find that their principal is written down after trigger event. This principal write-down can also be partially or fully.

0.3.3 Conversion Fraction

Conversion fraction is the ratio of the face value that can be converted into shares or written down. Conversion can be fully (when ratio is equal to 100%) or partially. It is also written condition in the bond prospectus.

0.3.4 Conversion Price

Conversion Price defines the price at which the bonds will be converted into shares. During data gathering process in this study, it is observed that contracts include different kinds of conversion prices. For example, a contract by Lloyds Banking Group fixes conversion price to a certain value, on the other hand, a contract by Banco Santander SA describes conversion price as maximum of a floor share price, higher of current market price of a common share or nominal value of a common share at the time of conversion. In the case where conversion price is equal to stock price at the time of trigger, it would mean the dilution for current equity holders since stock price is expected to be low at that time. However, this potential dilution also provides strong incentives to prevent triggering. On the other hand, setting the conversion rate on a previously specified price would be a solution to high dilution but probably reduce the motivation of shareholders against trigger. In this case, price floor be used to balance these two opposite cases [30].

0.4 Data

In this analysis, I focused on the CoCo bond issues shown in the Table 1. Models require inputs collected manually from the contracts such as conversion price, conversion type and issue spread. Bond contracts are very technical and lengthy documents. In addition to that, another input, trigger market price, must be calibrated for each bond, using the variables at the issue date. Considering this labour-intensive work, a small dataset is preferred to increase the reliability of inputs because using a larger dataset would bring additional assumptions which can decrease the sensitivity of calculations. Larger dataset is also not common among similar studies in the literature review.

In this study, I focused on the bonds issued by large European banks. Basel requirements are known to be strictly applied in large banks operating in European countries compared to U.S. banks or Chinese banks. Among European banks, I focused on large volume of issues. Another criterion used in the sample is that the currency of bond issue is the same as the currency of bank shares. Otherwise, exchange rate risk would interfere with the results. Bonds with different issue years are chosen to test whether result changes with shorter or longer time periods.

Table 1: Sample CoCo bonds description

ISIN	Issuer	Issued Amount (in millions)	Currency	Coupon %	Coupon Frequency	Issue Date	Conversion Fraction
XS2258827034	Natwest Group	1,000	GBP	5.125	Quarterly	12.11.2020	Equity Conversion
XS1884698256	HSBC Holding	1,000	GBP	5.875	Semi-annual	28.09.2018	Equity Conversion
XS2492482828	Barclays	1,250	GBP	8.875	Quarterly	28.06.2022	Equity Conversion
XS2591803841	Barclays	1,500	GBP	9.25	Quarterly	06.03.2023	Equity Conversion
XS2121441856	UniCredit	1,250	EUR	3.875	Semi-annual	19.02.2020	Write-Down

Source: LSEG database, 2023

0.4.1 Description of Variables

Table 2 summarizes the data variables required by the models. Market price of bonds, underlying share price of the issuer, 5-year mid-swap rate for the issuance currency are obtained as daily time series from LSEG database (known previously as Refinitiv). Bond contracts/prospectuses delivered at the time of issue by the issuer are used to find the next call date, coupon rate, nominal value, conversion price and conversion type information for each bond. Bond contracts are available on the LSEG database as well as issuer banks' websites.

0.4.2 Parameter Assumptions

It is compulsory to make some assumptions regarding the variables to apply the models to the CoCo bonds available in the market. Below, these assumptions for each variables used in the models are explained in detail:

Table 2: Description of model variables

Variable	Description	Fixed or Floating	Data Source
N	Nominal value Fixed	Fixed	Prospectus
T	Maturity (Next call date)	Fixed	Prospectus
t	Pricing date	Floating daily	Market data
ci	Coupon payment	Fixed	Prospectus
r	5y Mid-swap rate	Floating daily	Market data
S	Underlying share price	Floating daily	Market data
tsp	Trigger share price	Fixed	Calibrated
CS	Spread for trigger event	Fixed	Calibrated
CP	Conversion Price	Fixed	Prospectus
q	Dividend yield of issuer shares	Floating daily	Market data
σ	Annualized 30-day volatility of share's return	Floating daily	Market data
Alpha	Conversion fraction	Fixed	Prospectus

Source: Each prospectus and market data are obtained from LSEG database, 2023

Interest rate (r): It is observed that currency specific mid-swap rate is used by market players for the pricing of CoCos commonly as continuous risk-free interest rate. For example, the contracts I examined during this study includes coupon payments fixed until first call date. After the first call date, the coupon rate is adjusted according to sum of a fixed spread such as %4.76 and 5-year mid-swap rate at the time of reset date. Moreover, some related academic papers (Wilkens, S. and Bethke, 2014) use mid- swap rates for this variable.

Maturity (T): CoCo bonds are issued as perpetual, meaning that they do not have any maturity. However, they can be callable every 5 years after issue date. The issuer can choose to recall the bond if refinancing conditions are cheaper at the time of call date. The models require to use simplifying assumption regarding the maturity of the bond. Therefore, it is assumed that next call date is maturity date. In the analysis, T value data is shown as "year plus year fraction", for instance; 03.06.2020 is 2022.42192.

Pricing date (t): The model price is computed daily. Variable (t) shows each date starting from issuance. Similar to maturity (T), t value data is shown as "year plus year fraction".

Nominal value (N): It is assumed to be 1000 for each bond.

Trigger share price (tsp): As previously mentioned, academic studies prefer to use market triggers. The models use trigger market "share price" as input, however, the bond prospectuses in banking sector mostly includes accounting triggers as mentioned above. Share refers to the common shares of the issuing bank to which bonds will be converted after trigger event. On the other hand, as [29] assert, regulatory triggers are impossible to predict. Following previous studies [34]; [19], in this study, calibration method is used to determine the trigger market "share price". Calibration is done only at the issue date. Trigger share price is kept fixed for all subsequent dates.

At the issue date, credit spread at the issue date, which is required by the Credit Derivates Model is known and easily be gathered from the database. Similarly, the market price of the bond, which is required by the Equity Derivates Model is equal or very close to 100% at the time of issue. The only unknown parameter at the time of issue is trigger share price. Therefore, it can be obtained by solving the following equations 1, 2 by "fsolve" function in Matlab. In practice, Matlab could not find any solution for only one of the bonds in the data sample.

For Credit Derivatives Model:

$$F(trig) \ - \ CS_{issue} \ = \ 0 \tag{1}$$

where F(x) is the function in equation 4 and CS is the credit spread at the time of issue.

For Equity Derivatives Model:

$$G(trig) \,–100\% \cdot N = 0 \tag{2}$$

where G(x) is the function in equation 11 and N denotes the nominal value of a CoCo bond.

Volatility (Sigma): The volatility is computed as annualized 30-day standard deviation of log returns of issuer's stock return.

Conversion fraction (alpha): The prospectuses of bonds studied in this project include terms with full or partial conversion. However, it is not clear, in prospectuses, the fraction of partial conversion. Including a partial conversion input to the model would further complicate the already complex problem. Therefore, for simplicity, it is assumed that there is full conversion or full write down, meaning that alpha is equal to 1.

0.5 Methodology

0.5.1 Models

For the quantitative analysis section of this study, I focused on "empirically suitable" models following the empirical studies in the literature review section [7], [34], [27], [19]. The selected models are credit derivatives model and equity derivatives model by [29]. These models are considered practical enough to be applied for pricing by the market players compared to other models [18]. These models compared to structural models require less calibration and non-observable data. Besides, the previous empirical research [19] finds that in normal market conditions, the results do not support the use of complex models over simpler models.

Model Assumptions

Both models follow Black and Scholes framework. Therefore, it is assumed that share prices follow geometric brownian motion. According to this framework, log returns of share prices are assumed to follow the standard normal distribution. Share price movement is shown below[19]:

$$dS_t = (r - q)S_t d_t + \sigma S_t dz_t \tag{3}$$

where r: risk-free rate (5 year mid-swap rate is used in this study)
q: dividend yield of issuer share

σ: standard deviation of the underlying share price
dz_t: increment of a standard Wiener process

The Credit Derivatives Model

This model is based on the idea of calculating a credit spread that takes into account the probability of default and loss percentage in the event of default. Credit spread over risk free interest rate is found by the model as follows:

$$CS = (1 - RR) \cdot \lambda_{trigger} \tag{4}$$

where CS: the credit spread
RR: the recovery rate in case of trigger
(1-RR) : the loss ratio incurred by the bond holder at the time of conversion
$\lambda_{trigger}$: the trigger intensity as calculated in equation 6

Recovery rate (RR) is determined as the ratio of the trigger share price (tsp), in other words, the underlying share price at the moment of conversion, to the conversion price (CP). If conversion price is equal to the trigger share price, the investor will incur no losses as a result of this conversion.

$$RR = \frac{tsp}{CP} \tag{5}$$

with the definitions below:
tsp: trigger share price
CP: conversion price, the price at which the bonds will be converted into shares

$\lambda_{trigger}$ used in the equation 4 to find the credit spread by this model represents the

$$\lambda_{trigger} = \frac{-log(1 - p^*)}{T} \tag{6}$$

where p*: the probability that issuer's share price (S) touches the level of trigger share price (tsp) until maturity (T) as calculated in equation 7

Using the Black Scholes model, p^* is calculated as follows:

$$p^* = N(\frac{log(\frac{tsp}{S}) - \mu T}{\sigma\sqrt{T}}) + (\frac{tsp}{S}^{\frac{2\mu}{\sigma^2}}) \cdot N(\frac{log(\frac{tsp}{S}) + \mu T}{\sigma\sqrt{T}}) \tag{7}$$

where $\mu = r - q - \frac{\sigma^2}{2}$
$N(X)$ denotes the standard normal distribution
q: dividend yield of underlying (issuer) shares
r: 5 year mid-swap rate
σ : standard deviation, representing volatility
S : underlying share price of the issuer

tsp: trigger share price
T : maturity

Using above equations, credit spread of a CoCo bond defined as CS_{CoCo} in equation 4 can be rewritten.

$$CS_{CoCo} = \frac{-log(1-p^*)}{T} \cdot (1 - \frac{tsp}{CP}) \tag{8}$$

with the definitions below:
CP: conversion price, in other words, the price at which the bonds will be converted into shares
p* : the probability that issuer's share price (S) touches the level of trigger share price (tsp) until maturity (T) as calculated in 7
tsp: trigger share price
T: maturity

For comparison with the equity derivatives model results, CDM price has to be calculated. It is calculated by the discounted cash flows with the i-rate (ytm) equal to the sum of 5Y mid-swap rate (r) and credit spread $CS_{CoCo)}$.

$$ytm = r + CS_{CoCo} \tag{9}$$

where ytm: yield to maturity
r: 5 year mid-swap rate
$CS_{CoCo)}$: credit spread for CoCo bond

The formula for the price of the CoCo bond calculated by this model is given below:

$$Price = CF_i \cdot exp(-ytm \cdot t_i) \tag{10}$$

where CF_i denotes the cash flows consisting of coupon payments each coupon payment date (t_i) and nominal payment (assumed to be given at next call date).

The Equity Derivatives Model

This model is based on replication of a Coco by holding a portfolio consisting of three different instruments: long position in an ordinary bond with coupons and a "knock-in forward" and short position in "down-and-in options" [29]. The bond pays a regular coupon payment until the trigger event. The nominal converted into shares at the trigger event is represented by the knock-in forward. In this model, losing the right to obtain coupons after the trigger event is represented by the short positions in down-and-in options.

$$Price = X + Y + Z \tag{11}$$

where Price: the price of a CoCo bond calculated according to this model
X: the price of an ordinary bonds with coupons
Y: the price of a "knock-in forward
Z: the price of a short position in a "down and in options"

The price of an ordinary bonds with coupons (X) is calculated using the formula below:

$$X = N \cdot exp(-rT) + \sum_{i=1}^{k} c_i exp(-rt_i) \tag{12}$$

where N: nominal value of the bond
r: 5 year mid-swap rate
T: maturity
c_i: coupon payments at each t_i
t_i: each coupon payment date
k: number of payments left until maturity, T (assumed to be the next call date)

The price of a "knock-in forward" (Y) is shown by the following formula:

$$\begin{aligned} Y = CR \cdot [S \cdot exp(-qT)(tsp/S)^{2\lambda} \cdot N(u_1) - M \cdot exp(-rT)(tsp/S)^{(2\lambda-2)} \cdot N(u_1 - \sigma\sqrt{T}) \\ -M \cdot exp(-rT) \cdot N(-v_1 + \sigma\sqrt{T}) + S \cdot exp(-qT) \cdot N(-v_1)] \end{aligned} \tag{13}$$

with the definition of M given below:

$$M = CP \tag{14}$$

where CP: conversion price
S: underlying share price
q: dividend yield of underlying (issuer) shares
tsp: trigger share price
N(v_1): standart normal distribution of variable v_1 calculated in equation 16
N(u_1): standart normal distribution of variable u_1 calculated in equation 17
T: maturity (assumed to be the next call date)
r: 5 year mid-swap rate
σ: standard deviation, representing volatility of the underlying (issuer) share
S: underlying share price
λ : as calculated in equation 20 CR: conversion ratio, the number of shares obtained per bond due to the conversion

CR is equal to $\frac{N}{CP}$ with N denoting nominal value and CP representing conversion price when full conversion is assumed.

The price of short position in "down and in options" (Z) is calculated with the formula below:

$$Z = -\alpha \cdot \sum_{1}^{k} c_i \cdot exp(-rt_i) \cdot [N(-v_{1i} + \sigma\sqrt{t_i}) + (tsp/S)^{(2\lambda-2)} \cdot N(u_{1i} - \sigma\sqrt{t_i})] \tag{15}$$

where

$$v_1 = \frac{\log(S/tsp)}{\sigma\sqrt{(T)}} + \lambda\sigma\sqrt{T} \tag{16}$$

$$u_1 = \frac{log(tsp/S)}{\sigma\sqrt{(T)}} + \lambda\sigma\sqrt{T} \tag{17}$$

$$v_{1i} = \frac{log(S/tsp)}{\sigma\sqrt{(t_i)}} + \lambda\sigma\sqrt{t_i} \tag{18}$$

$$u_{1i} = \frac{log(tsp/S)}{\sigma\sqrt{(t_i)}} + \lambda\sigma\sqrt{t_i} \tag{19}$$

$$\lambda = \frac{r - q + \frac{\sigma^2}{2}}{\sigma^2} \tag{20}$$

with S: underlying share price
q: dividend yield of underlying (issuer) shares
tsp: trigger share price
N(v_{1i}): standart normal distribution of variable v_{1i} calculated in equation 18
N(u_{1i}): standart normal distribution of variable u_{1i} calculated in equation 19
T: maturity (assumed to be the next call date)
r: 5 year mid-swap rate
σ: standard deviation representing volatility of the underlying (issuer) share
c_i: coupon payments at each t_i
t_i: each coupon payment date
α: conversion fraction (partial: $\alpha < 1$ or full conversion: α=1) (In this study, it is assumed to be full conversion)

Model Comparison

To measure the model accuracy, in this analysis, market prices for CoCo bonds are used as benchmarks. The root mean squared error (RMSE) is calculated for all bonds in the sample [19], [34]. This measure shows how close model prices reflect the market prices. The aim of this study to compare accuracy across models for each bond.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(model[i] - market[i])^2}{n}} \tag{21}$$

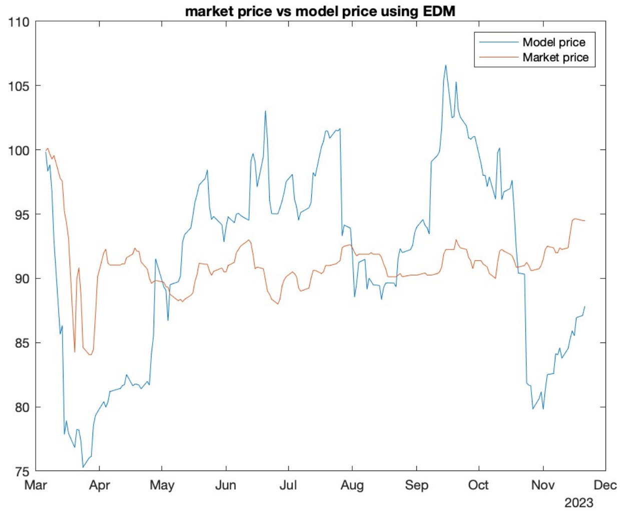

Figure 1: EDM prices for XS2591803841
Source: Market price and model inputs are obtained from LSEG database, 2023

In addition to that, correlation coefficient between market prices and model prices are calculated for each bond. Correlation coefficient takes values between -1 and 1. While a value close to +-1 indicates a strong positive or negative correlation, a value near 0 means no correlation between two prices.

Model results are expected to give us the fair value of this instrument and to be close to the market price. However, the deviations between market price and fair value can be used to earn profit. Market players are mostly interested in these profit opportunities that models can offer.

0.6 Results and Discussion

ISIN XS2591803841 9.250% Fixed Rate Resetting Perpetual Subordinated Contingent Convertible Securities Issued by Barclays PLC

Figure 1 and Figure 2 show the trend of model prices calculated by CDM and EDM in comparison to market price. Figure 3 shows the trend of swap rates and underlying stock price for the period starting from the issue date.

At the issue date, due to calibration of the trigger level as explained before, the model price and the market price match. After that, a sharp decline is observed in both the market and model prices along with the stock price decline. Both model prices exhibit a higher level of sensitivity to the decline in the stock price than the market price does. Comparatively, CDM is more sensitive to the stock price changes, resulting in higher volatility. Lower volatile periods of stock price cause a reduction in the deviation from the market price for both models.

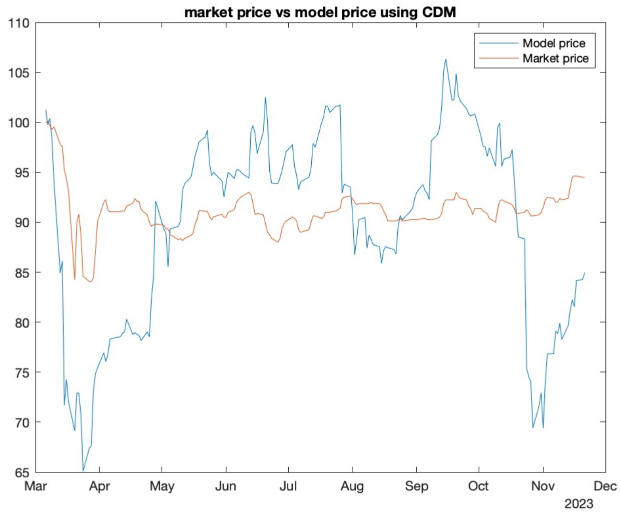

Figure 2: CDM prices for XS2591803841
Source: Market price and model inputs are obtained from LSEG database, 2023

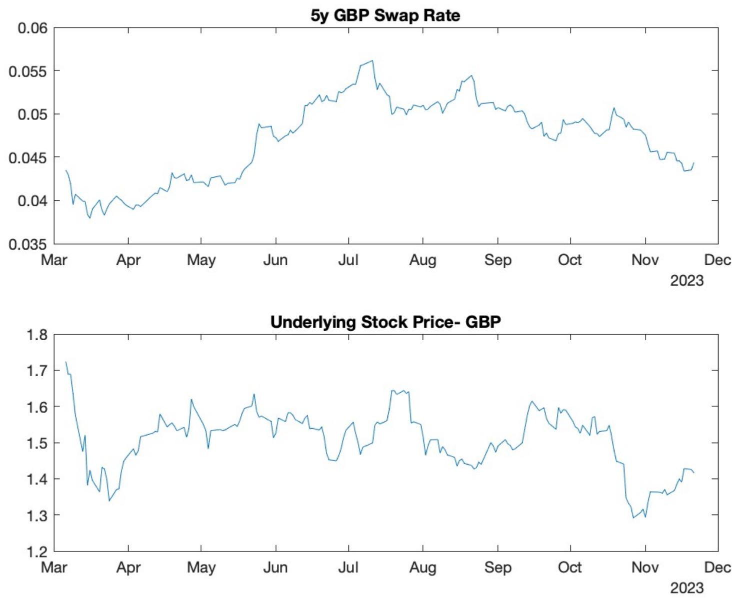

Figure 3: Swap rates and underlying share price for XS2591803841
Source: LSEG database, 2023

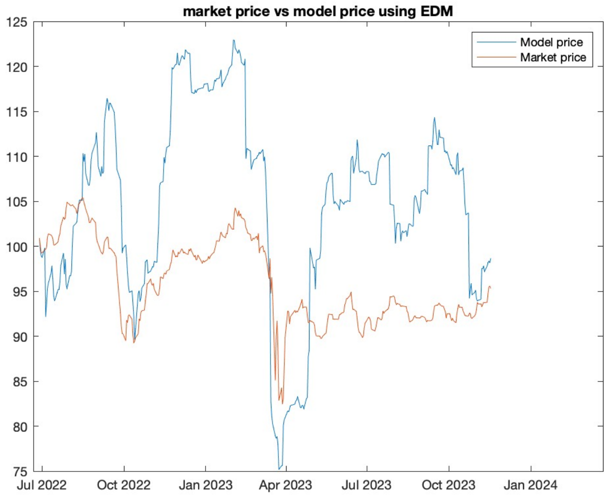

Figure 4: EDM prices for XS2492482828
Source: Market price and model inputs are obtained from LSEG database, 2023

Table 3 shows the trigger market prices computed using the models and model comparison results.

Table 3: Comparison results for XS2591803841

ISIN	Trigger Price EDM	Trigger Price CDM	RMSE EDM	RMSE CDM	Correlation Coefficient EDM	Correlation Coefficient CDM
XS2591803841	1.1352	1.2168	0.0776	1.3523	0.1451	0.1743

As this bond, in its prospectus, has an accounting trigger level which is tied to its capital adequacy level, I calculated trigger market price through calibration for each model and kept it constant for all subsequent pricing dates. The trigger market prices for underlying shares are close for each model. However, trigger price level for EDM is lower, providing an advantage to bondholders as it indicates a lower likelihood of conversion in comparison.

A lower RMSE is preferable as it signifies a more accurate fit. The RMSE levels are lower for this bond compared to other bonds in the sample. This can be partially attributed to shorter duration of observation period. The RMSE comparison indicates a better fit for equity derivates model (EDM) for this bond.

ISIN XS2492482828 8.875% Fixed Rate Resetting Perpetual Subordinated Contingent Convertible Securities Issued by Barclays PLC

Figure 4 and Figure 5 show the trend of model prices calculated by CDM and EDM in comparison to market price. Figure 6 shows the trend of swap rates and underlying stock price for the period starting from the issue date.

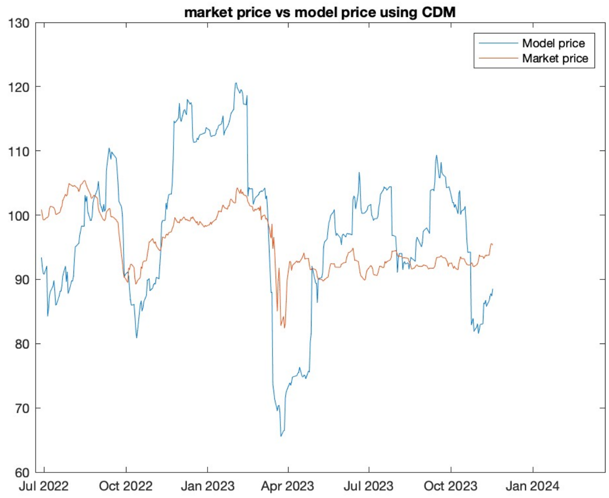

Figure 5: EDM prices for XS2492482828
Source: Market price and model inputs are obtained from LSEG database, 2023

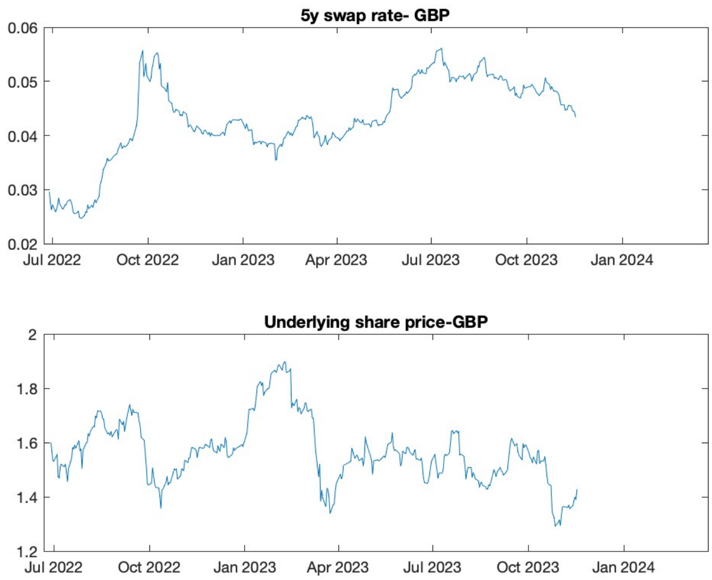

Figure 6: Swap rates and underlying share price for XS2492482828
Source: LSEG database, 2023

At the issue date, due to calibration of the trigger level as explained before, the model price and the market price coincide only for EDM for this bond. For EDM, calibration of trigger level is done through matching issue price. Unlike EDM, trigger market share level for CDM does not result in a match for market price at the time of issue because in case of CDM, calibration is done using issue spread to mid-level swap rates. According to CDM, the issue spread for this bond (695.5 basis point) matches with a higher trigger level which, in turn, results in a lower price than the market price. CDM result indicates that at the time of issue, issue spread of this bond must have been lower, about the level of 450 basis point to match 100% price level.

Table 4 shows the trigger market prices computed using the models and model comparison results.

Table 4: Comparison results for XS2492482828

ISIN	Trigger Price EDM	Trigger Price CDM	RMSE EDM	RMSE CDM	Correlation Coefficient EDM	Correlation Coefficient CDM
XS2492482828	0.7445	0.9443	3.3476	6.1104	0.4644	0.4913

RMSE results indicate better fit for EDM, attributable to the higher level of trigger price calculated by the CDM calibration. If the trigger level of EDM was used for CDM calculations, RMSE would be calculated as 2.6857.

ISIN XS2258827034 5.125% Reset Perpetual Subordinated Contingent Convertible Additional Tier 1 Capital Notes

Figure 7 and Figure 8 show the trend of model prices calculated by CDM and EDM in comparison to market price. Figure 9 shows the trend of swap rates and underlying stock price for the period starting from the issue date.

The model calibrations give close results of trigger share prices. The volatility in both models reflect the volatility in issuer share price in a very sensitive way. However, both the market price and model prices show a downward trend. Unlike other results below, the impact of rising swap rates during the observation period on bond prices are clearly seen in these graphs.

Both models show high correlation coefficient levels in Table 5. Therefore, these model pricing results for both models are perceived as a successful example. Regarding the RMSE, results favor CDM for this valuation. It can be inferred that the model success increases in favor of CDM when the swap rate effect is stronger than stock price because this model diverges from the stock price and emphasizes the similarities between bonds unlike EDM [27].

Table 5: Comparison results for XS2258827034

ISIN	Trigger Price EDM	Trigger Price CDM	RMSE EDM	RMSE CDM	Correlation Coefficient EDM	Correlation Coefficient CDM
XS2258827034	0.2335	0.2244	1.0355	0.3305	0.8125	0.8034

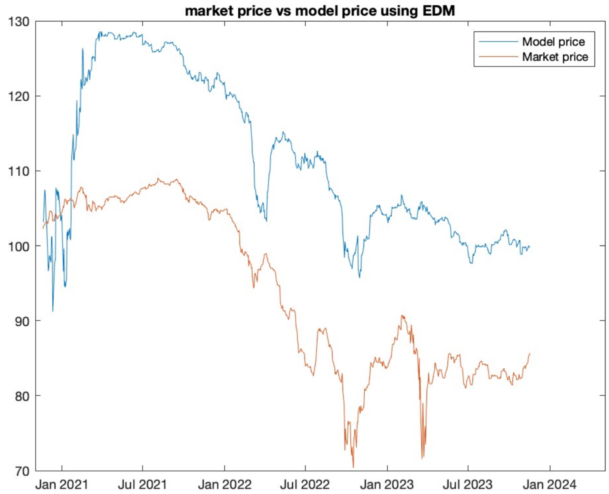

Figure 7: EDM prices for XS2258827034
Source: Market price and model inputs are obtained from LSEG database, 2023

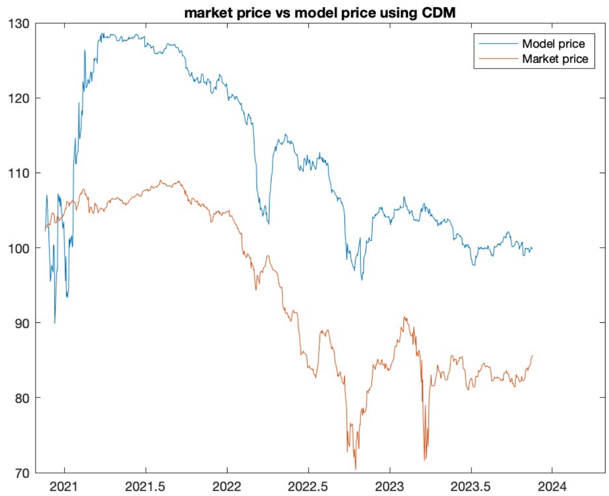

Figure 8: CDM prices for XS2258827034
Source: Market price and model inputs are obtained from LSEG database, 2023

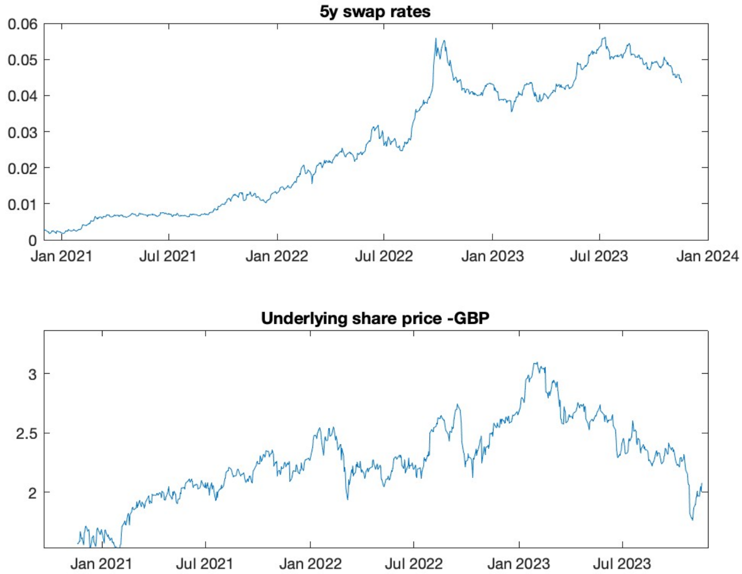

Figure 9: Swap rates and underlying share price for XS2258827034
Source: LSEG database, 2023

ISIN XS2121441856 3.875% Non-Cumulative Temporary Write-Down Deeply Subordinated Fixed Rate Resettable Notes

Unlike other bonds above, this bond writes down the principal rather than converting it to issuer shares in the case of trigger event.

Figure 10 and Figure 11 show the trend of model prices calculated by CDM and EDM in comparison to market price. Figure 12 shows the trend of swap rates and underlying stock price for the period starting from the issue date.

As seen in the figures, market prices are more sensitive to interest rates whereas model prices are highly sensitive to stock prices. Starting from the year of 2022, the rise in both interest rates and stock prices reduce the pricing error.

The RMSE values indicates a better fit for EDM during the observation period in Table 6. On the other hand, the low correlation between the market and model prices suggests that neither of models can reflect the market price changes in an accurate way.

Table 6: Comparison results for XS2121441856

ISIN	Trigger Price EDM	Trigger Price CDM	RMSE EDM	RMSE CDM	Correlation Coefficient EDM	Correlation Coefficient CDM
XS2121441856	9.3091	9.1659	3.8892	5.1176	-0.2487	-0.2410

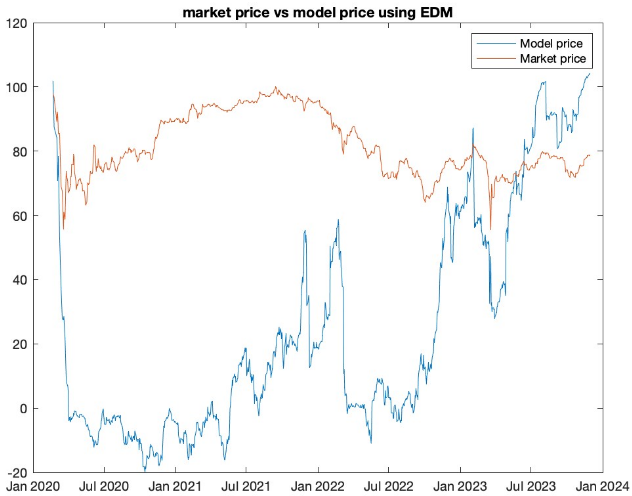

Figure 10: EDM prices for XS2121441856
Source: Market price and model inputs are obtained from LSEG database, 2023

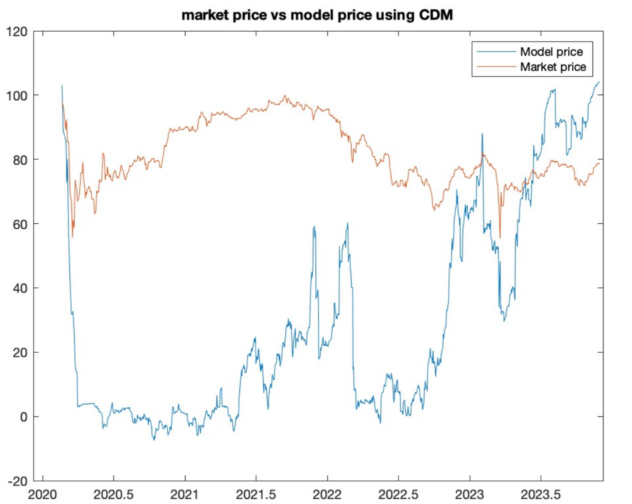

Figure 11: CDM prices for XS2121441856
Source: Market price and model inputs are obtained from LSEG database, 2023

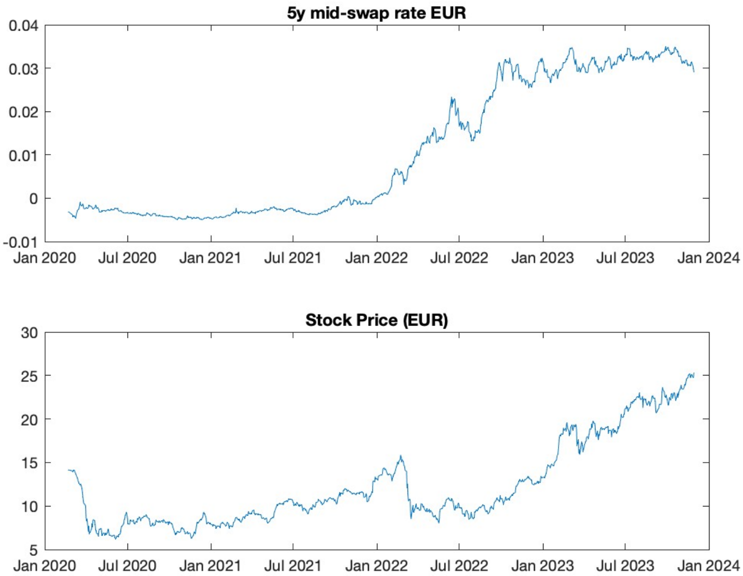

Figure 12: Swap rates and underlying share prices for XS2121441856
Source: LSEG database, 2023

ISIN XS1884698256 5.875% Perpetual Subordinated Contingent Convertible Securities

The results resulted in high RMSE levels as seen in Table 7 because calibration method using "fsolve" command to obtain trigger market stock price give no results in Matlab for this bond. Therefore, the trigger level is obtained through "fminsearch" command in Matlab. As it is seen in Figure 13 and 14, there is a big gap between initial model price and market price due to lack of calibrated trigger market level. This result is important as it shows the importance of trigger level for model pricing error.

Table 7: Comparison results for XS1884698256

ISIN	Trigger Price EDM	Trigger Price CDM	RMSE EDM	RMSE CDM	Correlation Coefficient EDM	Correlation Coefficient CDM
XS1884698256	2.5797	2.3520	13.008	13.0075	0.5756	0.6457

Contrary to this bond results, the bond with ISIN XS2258827034, as mentioned before, has a trigger level successfully obtained by the models through calibration. The table 8 shows how both models' performances worsen when different levels of trigger levels are used for this bond. These two cases exemplify how the trigger market level is very crucial input in model pricing.

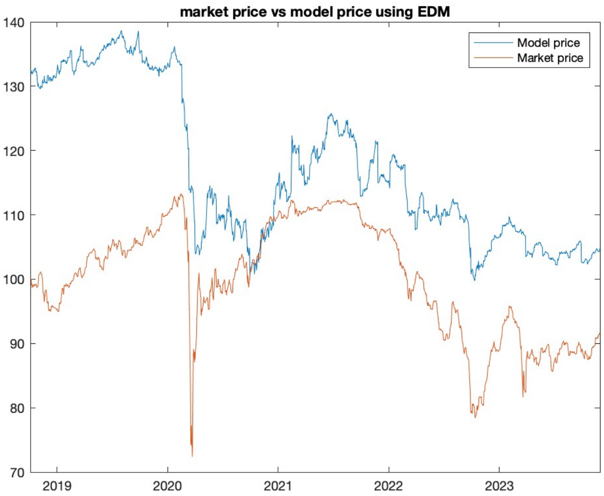

Figure 13: EDM prices for XS1884698256
Source: Market price and model inputs are obtained from LSEG database, 2023

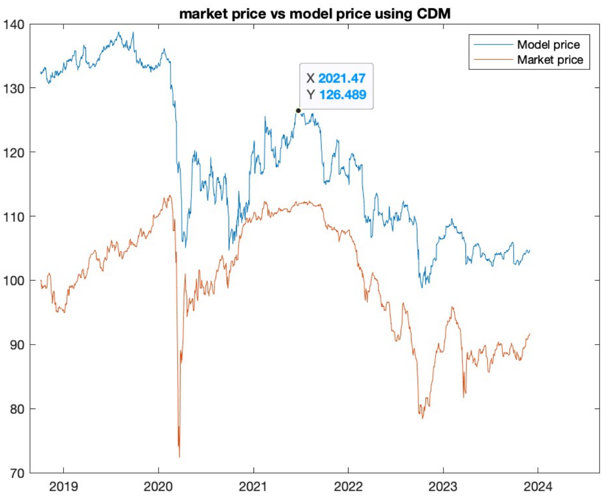

Figure 14: CDM prices for XS1884698256
Source: Market price and model inputs are obtained from LSEG database, 2023

Table 8: Comparison results for XS2258827034

ISIN XS2258827034	Trigger Price EDM	Trigger Price CDM	RMSE EDM	RMSE CDM
Calibrated Trigger Price	0.2335	0.2244	1.0355	0.3305
Trigger +0.2	0.4335	0.4244	17.5445	19.8345
Trigger -0.1	0.1335	0.1244	15.2336	15.4599

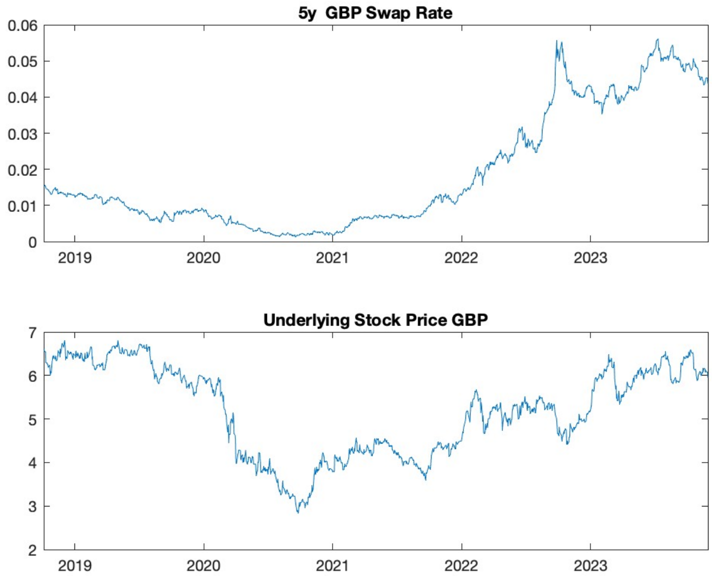

Figure 15: Swap rates and underlying share prices for XS1884698256
Source: LSEG database, 2023

0.6.1 Hedging CoCo Bond with Underlying Shares

Figure 16 shows how price of CoCo (ISIN: XS2258827034) changes for different underlying share prices of Natwest Group PLC under equity derivates model other variables held constant. As the stock price moves away from the trigger market price level of 0.2335, price increases and approaches the maximum value of 100%.

If the stock price is well above the trigger market level implied by equity derivates model and issuer has healthy financials, the probability of a trigger event is low. Still, some investors might want to hedge their risks from CoCo bonds. In this case, shorting underlying shares can be hedging strategy.

[34] finds EDM more practical and straightforward in terms of hedging since credit derivatives model is lacking a market instrument that could be used for hedging against the trigger spread.

Equity derivates model is constructed based on the idea of splitting CoCo bond features into similar exotic options. Changes in the price of CoCo with respect to changes in share price for XS2258827034 bond, Delta, is shown in Figure 17, when the remaining maturity (next call date) is assumed one year. It gets a lower value for higher stock prices. On the other hand, when stock price is very close the trigger market level, it can go high above 3000. This number is expected to be higher when maturity is less than 1 year. Therefore, [29] points out that this hedging strategy can accelerate the conversion since it will further pull the stock prices further down ("death spiral"). As a remedy, floor conversion price or limited issue size are offered against this kind of market influence. In real life, trigger

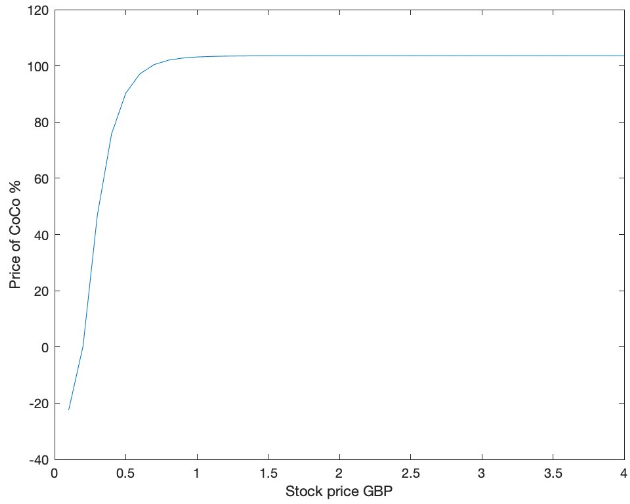

Figure 16: Stock price sensitivity of CoCo bond prices for XS2258827034
Source: Stock price and model inputs are obtained from LSEG database, 2023

events are mostly tied to capital adequacy ratio. Therefore, a conversion probably would not be triggered because of the delta hedge. Still, it can cause concern or panic, which might have consequences for the issuer bank.

0.7 Conclusion

Contingent convertible bonds have been a novel financial instrument in response to the 2008 financial crisis, aiming to mitigate taxpayer burdens associated with bailing out 'too big to fail' banks and prevent systemic crises. From a policy perspective, these instruments were strategically designed to implement a bail-in approach during times of bank distress. However, recent events, such as the Credit Suisse CoCo bond write-down, have revealed discrepancies between theoretical intentions and practical outcomes. The complex nature of these bonds, particularly the loss absorption mechanism and discretionary trigger levels, poses challenges for market pricing. This study explores contingent convertible bonds, aiming to enhance understanding of this hybrid instrument and contribute to the valuation field. Unlike prior studies, the research uses a dataset of CoCo bonds in a market that has substantially grown, incorporating the time of the unprecedented write-down of Credit Suisse bonds in March 2023, a unique event in the instrument's history.

The results of comparative quantitative analysis in this study reveals that credit derivatives model and equity derivatives model are practical enough to be implemented by using mostly market data and less calibration. However, these models have also some drawbacks due to its simplifying assumptions: asset prices following Black-Scholes model, non-inclusion of jump risk [1], maturity at the next call-date [18], market based trigger level in place of accounting or discretionary trigger [27].

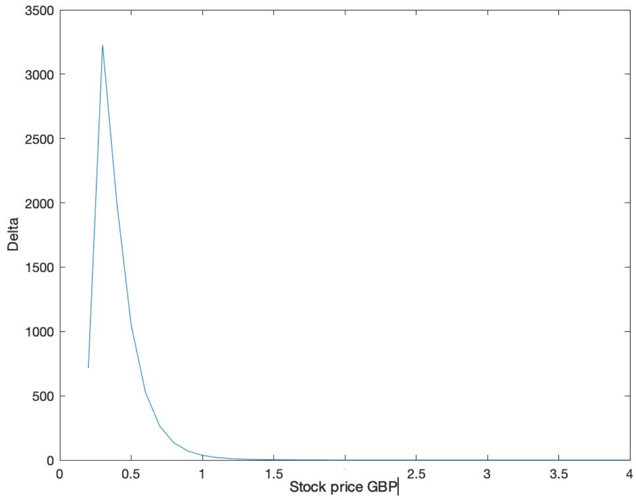

Figure 17: Delta for XS2258827034 bond
Source: Stock price and model inputs are obtained from LSEG database, 2023

Despites their drawbacks, models exhibit the potential to achieve high correlation with market prices in certain instances. In other cases, they are largely able to track market prices. Both models exhibit a higher level of sensitivity to the volatility of stock prices than observed market price does. Overall, EDM performs well compared to CDM. This could be attributed to its construction, combining cash flows from three different instruments with an aim to replicate the cash flows of CoCo bonds. This result is parallel to the results of other empirical studies [34], [27], [19].

It is observed in this study that when the swap rate on the substantial rise, especially for CDM, model prices align more closely with the market prices as they behave more like bonds. It can be inferred that market players tend to regard CoCo bonds as a bond instrument rather than equity instrument. This result also confirms one of the main lessons drawn by Basel authority [3] following the Credit Suisse write-down. The recent case revealed that the market players may not fully grasp the risk of "conversion to equity" to reflect it to their pricing. They are more likely to perceive this instrument as a high-yielding bond.

Additionally, this study confirms that both models' success is highly dependent on the calibration of the market trigger based on stock price. Trigger level is essential to estimate the probability of conversion to equity. As used in these models, a market trigger is easier to determine compared to the point of non-viability trigger or accounting trigger. However, the results are important as it shows how considerably pricing of bonds changes with the different trigger levels. Therefore, the uncertainty about the trigger level arising from the contractual features of CoCos should be the focus of related investors and policy makers. Investors should be cautious regarding the accounting trigger levels, often realized high above the minimum trigger capital ratio required by Basel III, for European banks.

To effectively assess the probability of conversion under discretionary trigger levels, closely monitoring the stress test scenarios of banks and differentiated capital ratio requirement by the regulatory authority may provide the investors with valuable insight for the valuation of their investments. Policymakers should encourage banks to increase transparency regarding their capital adequacy levels under normal or stressed conditions. Furthermore, regulators can consider simplifying the requirements of these instruments aligning with suggestions in the literature, such as, adopting market-based trigger level or an option with a pre-determined strike share price in place of CoCo bonds [5].

In conclusion, the presence of discretionary triggers makes CoCo pricing a challenging research area for developing an accurate and practical model. On the other hand, recent papers studying on complex models offer valuable guidance to policy makers in assessing their policy tools. Future studies may choose to focus on revising the structure of contingent convertible bonds as an appealing policy and investment instrument.

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