LISBON SCHOOL OF ECONOMICS & MANAGEMENT
UNIVERSIDADE DE LISBOA

MASTER OF SCIENCE IN FINANCE

MASTER'S FINAL WORK

DISSERTATION

CONTINGENT CONVERTIBLE (COCO) BONDS: AN ANALYSIS OF EMBEDDED OPTIONS

CLÁUDIA DELFINA FERREIRA AMARO

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Abstract

The last financial crisis proved the inability of loss-absorbing products and the need of reinforcing the financial institutions' capital buffers. In that sense a new hybrid product was launched in 2009 – Contingent Convertible Bonds. Their aim is automatically convert either into common equity or their face value suffer a write-down when some pre-specified trigger is reached. In this study it is extended one of the approaches of CoCos' valuation, the Equity Derivatives, from the equity conversion to write-down CoCos. Through a parameters' sensitivity analysis it is demonstrated the great sensitivity of the price even in a Black-Scholes world. Also, through a Monte Carlo Simulation, these products show a low probability of hitting the trigger but, once this happens, the losses are high, especially for write-down products. Finally, applying the model to real products, it presents an overestimation of prices towards its market prices.

Keywords: Contingent Convertible Bonds, Equity Derivatives Approach, Equity Conversion, Write-down, Black-Scholes, Monte Carlo Simulation, Model Fitting.

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List of Abbreviations

CoCos – Contingent Convertible Bonds

ESMA – European Securities and Market Authority

EBA – European Banking Authority

Basel Committee – Basel Committee on Banking Supervision

AT1 – Additional Tier 1

CET 1 – Common Equity Tier 1

CET 1 FL – Common Equity Tier 1 Fully Loaded

RWA – Risk Weighted Assets

ISIN – International Securities Identification Number

CATE - Capital Adequacy Trigger Event

FINMA - Swiss Financial Market Supervisory Authority

ECN – Enhanced Capital Notes

CDE - Capital Disqualification Event

LBG – Lloyds Banking Group

PRA – Prudential Regulation Authority

CSG – Credit Suisse Group

HTCR - High Trigger Capital Ratio

ACT/ACT – Actual/Actual convention

Notation

S* - share price at trigger

(α) - Conversion fraction

C_p - Conversion Price

C_r - Conversion Ratio

S_F - Floored Price

S_0 - Share price at issue

DIC – Down-and-in call

DIP – Down-and-in put

q - Dividend yield

K - Strike Price

H – Barrier Level

EC - Equity Conversion

P_T - Final Payoff

N – Face Value

c_i – Coupon

CB – Corporate Bond

DIF – Down-and-in forward

BDI – Binary Down-and-in

V_t^B - Valuation date bond value

R_f - Risk-free rate

S – Share Price

$\Phi(.)$ - Cumulative Normal Distribution

WD – Write-down

T – Maturity

1. Introduction

Since the last financial crisis there has been an attempt to fix the damages caused by the financial system collapse and avoid future interventions with the taxpayers' money. The aim of the financial supervisors and regulators is to increase the capital buffers, which were not enough to prevent the crunch, and to enhance the capital base in terms of quality, transparency and consistency. See the Basel Committee on Banking Supervision (2010) report. A new form of hybrid capital was launched in 2009 by Lloyds Banking Group (see De Spiegeleer and Schoutens (2011)) with the purpose of reinforcing the regulators capital requirements and the bank's capital structures - the Contingent Convertible Bonds (CoCos). CoCos are a type of bond that automatically converts either into common equity or its face value suffers a write-down when some pre-specified trigger is reached. Such as accounting, market and regulatory triggers.

The loss-absorbing capacity is the main feature of this kind of hybrid security that recapitalizes the financial institution when it is difficult to do so in the markets. Despite its promising effect, efforts have been made in order to improve the product's and to standardize its terms and conditions (see the European Securities and Market Authority Statement, ESMA (2014)). Although this effort there is still no consensus regarding the design, pricing or even the circumstances of its issuance. This leads to confusion and misunderstanding not only for the investors, but also for issuers and supervision authorities.

Since 2009, CoCos have been under scrutiny among academics, practitioners and regulators. Namely, the effects of using contingent capital on banks' capital structures, the properly structure that accomplish its main goals and a valuation framework reflecting its all features. The debate was launched with the The Squam Lake Working Group[1] (2009) recommending the use of such securities that during good times act as long-term debt and in difficult times automatically convert into equity, restoring the bank's health, without costs for taxpayers. Flannery (2010) has also been encouraged the issuance of CoCos allied with the reduction of equity holdings or together with

[1] "The Squam Lake Working Group on Financial Regulation is a nonpartisan, nonaffiliated group of fifteen academics who have come together to offer guidance on the reform of financial regulation." (Squam Lake Working Group, 2009, p. 2).

straight debt and equity, in order to obtain a contingent capital optimal structure (Zeng, 2012). On the regulators' side, The European Banking Authority (EBA) (2011) considers CoCos eligible to meet the capital buffers.

In this study, we present the various points of view, regarding the best structure and the role of CoCos as loss-absorbing instruments, discussed in the literature. Similar to Avdjiev et al. (2015) there is a focus not only on equity conversion but also on write-down products, since the majority of the literature have given most attention to the first type. Hence, it is developed in detail one of the possible pricing approaches, the Equity Derivatives, and extended from equity conversion to write-down CoCos. Through a parameter's sensitivity analysis and a Monte Carlo Simulation it is demonstrated that the prices are highly sensitive through oscillations, even in a Black-Scholes world, with the write-down CoCos showing great variations. Also, these products present a low probability of hitting the trigger but, once this occurs, there are high losses to investors. Finally, the model is applied in seven real products and the model prices overestimate the respective market prices.

The remainder of the thesis is organized as follows. Section 2 highlights the main contributions from the literature. Section 3 addresses the structure that these products can have, its characteristics and how its market has been evolved since 2009. Section 4 is related with the methodology. First, it is presented the main pricing approaches that can be used for CoCos valuation. Then, the Equity Derivatives is explained in detail and extended for the write-down CoCos. In Section 5 it is priced a fictitious product, the benchmark case, it is performed a sensitivity analysis, to understand the pricing dynamics, and finally, the theoretical approach is applied in seven real life products. Section 6 concludes.

2. Literature Review

CoCos are intended, primarily, to mechanically absorb losses in hard situations, stabilizing financial institutions or, at the limit, avoid its failure. This seems beneficial, at first glance, but not shared by all. On the one hand, Pennacchi (2010) suggests that its implementation can mitigate financial distress in a practicable and low-cost way, if it is structured to convert at initial stages of distress (in a going-concern phase) and if it incorporates provisions reducing the default risk. Also, its hybrid feature can permit benefiting from tax shields, once debt, and protection from bankruptcy costs, once equity, as substitute for straight debt (Albul et al., 2009). On the other hand, Hart and Zingales (2010) argue that CoCos produce business inefficiencies and the time of default is delayed, keeping inadequate managers operating. As well, concerns about risk-taking incentives and value transfer are also pointed out.

Structures in which the face value is written-down to zero or have a high conversion ratio implies a wealth transfer from CoCo holders to shareholders. This means that the losses are borne by CoCo investors and there is a propensity of incurring in risky actions from equity holders, since they will not be punished from that. It is, therefore advocated that a unique equilibrium in CoCo prices to exist involves no value transfer (Sundaresan and Wang, 2010). Berg and Kaserer (2015) show that the vast majority of all CoCos issued are designed with that transference, where debt overhang and asset substitution problems are intensified[2]. Nevertheless, value transfer is defended if it produces the contrary effect, dilution of existing shareholders (Calomiris and Herring, 2013; Pennacchi, 2010). In extremes cases, Coffee (2011) proposes the creation of naturally risk-averse (initially bondholders) equity holders by conversion into shares with voting rights and cumulative dividends. Berg and Kaserer (2011) suggest Convert-to-Surrender Bonds, setting the conversion price to zero, in order to take over shareholders.

Another important point comprehends CoCos' position on the capital structure, more precisely, which is their role as regulatory capital. In 2009, Basel Committee presented reforms to make the banking sector more resilient against economic and financial shocks, reinforcing global capital and liquidity rules. Those reforms were reflected into what it is well-known as Basel III whose implementation period is from January 2013 to January 2019. The room for contingent convertibles, observed in the Figure 1 below, is on Tier 1 capital (going-concern, as an impact on its value does not mean an event of default) and Tier 2 (gone-concern, loss-absorbing if liquidation) buckets. On Tier 1

[2] Debt overhang (the debt amount is so large that there is no incentive to issue new equity, penalizing debtholders) and asset substitution (increase the riskiness of investments) were firstly discussed by Jensen and Meckling (1976) and Myers (1977) linking capital structure and equity holders' incentives.

capital, CoCos can only be inserted above common equity, as Additional Tier 1. The main differences towards Tier 2 products are coupons' discretion, no maturity and a call date only after five years (see more details on Basel Committee (2010) report).

Minimum capital requirements

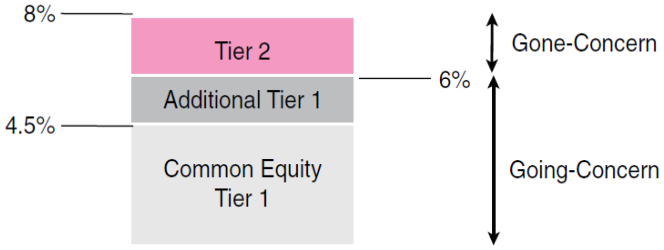

Figure 1 - Minimum capital requirements compliant with Basel III. Source: De Spiegeleer et al. (2014, p. 97)

From a different perspective, some authors have also been paying attention to the anatomy of these products, comprising the mechanism that absorbs losses and the trigger event that activates it (see, for instance, De Spiegeleer et al. (2014)).

3. CoCos' Structure and Market Evolution

In order to obtain a better understanding about the mechanics and role of CoCos, it is fundamental present the two key characteristics of its anatomy. First, the way in which the product will restore the level of capital required by capturing losses, the conversion into shares or the face value write-down. And second, the situation that motivates this absorption, being a decline in institution's share price (market trigger) or in the capital level (accounting trigger). Also, as a young product, its market progress and behavior merit attention and it is addressed.

3.1 Loss absorption mechanism

Once the trigger event arises, the securities are converted in shares or the face value (N) suffers a cut.

3.1.1 Conversion into shares

Firstly, the conversion fraction (α) reflects the percentage of the face value that it is converted ($\alpha = 1$ means full conversion). And, there is the choice of converting all CoCos outstanding or just a portion. While Calomiris and Herring (2013) support a total conversion, Coffee (2011) and Glasserman and Nouri (2010) defend a partial and gradual conversion to satisfy the capital requirements in each moment, so as to avoiding a conversion happening too early or at the latest moment. On the trigger moment, an implied price in which the shares will be acquired is given by the conversion price $\left(C_p\right)$. This price returns the gain or loss incurred by the investor and it is calculated according to Equation 1 below:

$$C_p = \frac{\alpha N}{C_r} \quad (1)$$

Naturally, a trade-off arrives between CoCo holders and existing shareholders, as CoCo holders prefer a low C_p, but this harms shareholders through dilution. The C_p choice can include three possibilities:

i. a price established to be equal to the *share price at trigger* $\left(S^*\right)$. CoCo investors will benefit, since is very likely that the price will be at a lower level, at the conversion moment, and the initial shareholders will be diluted.

ii. a pre-defined price as the *share price at issue* $\left(S_0\right)$. Where the opposite situation may emerge. The price may be higher, implying a low conversion ratio and more losses for the investors.

iii. and a *price with a floor* can be established, being the maximum between S* and a floored price $\left(S_F\right)$. This prevents the case where the share price suffers a severe decline. An example is the CoCo issued on October of 2013 by Banco Popular with a floored price of €2.015 (Finsterbusch and Henriques, 2015).

3.1.2 Write-down

This mechanism can be used in the same circumstances as the previous one, but it can be identified some aspects where a haircut on the face value can be preferred. Namely, if the bank has no listed shares, as it was the leading case of Rabobank on March of

2010, and if it does not want to impose losses on the existing equity holders, diluting them. There is also the situation of determined funds with the possibility of investing solely in bonds because of its management policies and investment objectives. Following, this mechanism can be imposed in certain ways. Pennacchi (2010) argues a higher new issue spread required by investors, if a write-down is mandated in the conversion terms.

i. A *full write-down* CoCo is when the notional amount is completely written-off, at the occurrence of the trigger event. Probably, the most extreme contingent convertible structure, as the CoCo holder loses 100%. The four write-down CoCos analyzed in Section 5 belong to this type.
ii. In a *partial write-down* case, a percentage of the face value is wiped-out, while the reminiscent is returned to the investor. But in the opinion of Bleich (2014), this can create liquidity pressure, as the bank has to make a cash payment for the "rescued" value, and uncertainty regarding its future solvency position.
iii. The *staggered write-down* is similar to an on-going conversion in shares, since the product suffers a cut only up to the amount necessary to restore the capital required.

Finally, these securities can get a *permanent/temporary write-down*. In the latter situation there exist the chance of recovery, as the institution can make discretionary write-ups, in addition to other instruments, dependent on future financial health (Lereste and Decque, 2013). An example of a partial temporary product is the one issued by Deutsche Bank on May of 2014 (Finsterbusch and Henriques, 2015).

3.2 Trigger Event

The trigger defines the contingency that activates the equity conversion or write-down. Despite the various forms proposed in literature, all products so far consider capital ratios attached, or not, with regulatory triggers and this is another topic of discussion in what concerns CoCos' structures. First of all, in order to a trigger to accomplish its goals it must be clear, objective, transparent, fixed and public (Spiegeleer and Schoutens, 2011).

3.2.1 Accounting trigger

When the bank uses an accounting trigger, the product loss-absorption is connected to a capital ratio. For instance, if the CoCo's trigger is a CET1 (Common Equity Tier 1) ratio equal to 4.5%, this means that if the bank reaches a Common Equity Tier 1 capital divided by the RWA (risk weighted assets) of 4.5%, the product will be converted or written-down. But the 4.5% is the minimum ratio required, so, a trigger above this ratio will prevent the bank reaching such a limit. Indeed, the trigger can be close to the capital ratio or at a superior level. Albul et al. (2009) believes that regulatory benefits increase the higher the trigger. However, basing the contingency event in accounting values may be problematic, since they are not public available in real time (on a quarterly or semiannual basis only), delivering lagged information, and subject to a discretionary treatment. Moreover, Kuritzkes and Scott (2009) concluded that the US failed banks in 2008 were better capitalized compared to the non-failed banks[3]. Similarly, Gunther (2013) proposes market triggers as alternatives.

3.2.2 Regulatory trigger

Most of the cases it is connected to an accounting trigger. A regulatory entity can at any time trigger the bond if it considers the occurrence of a Viability event, for instance, meaning that the institution does not have conditions to operate in a solvent way, clause in the Credit Suisse CoCo presented hereafter. Notwithstanding, some criticized this trigger. Martynova and Perotti (2012) found that regulatory accounting triggers, subject to regulatory forbearance, convert less often than they should. Flannery (2014) also mention the regulatory discretion that the financial system has been assisted for several years, allied with the hidden condition of banks using accounting ratios. He thinks that these situations merit attention because just a small possibility of enhancing supervision activities may bring innumerous benefits. So, a key word for this trigger mechanism is, probably, uncertainty.

[3] The failed five largest financial institutions – Bear Stearns, Washington Mutual, Lehman Brothers, Wachovia and Merrill Lynch – reported capital levels between 50 to 100 per cent above the minimums required and 23 to 61 per cent above the level considered as well capitalized.

3.2.3 Market trigger

Those triggers are considered continuously observable metrics reflecting the bank's conditions such as share and CDS prices. The major advantages related to this type of trigger are the up-to-date information, mirroring market expectations, and the overcoming of the referred regulatory discretion/delay (Flannery and Perotti, 2011; Hart and Zingales, 2010). Disadvantages are excessive conversion errors, increased volatility and multiple or no equilibrium prices prone to manipulation (Martynova and Perotti, 2012; Prescott, 2012; Sundaresan and Wang, 2010). In fact, manipulation is the principal disadvantage pointed out, for instance if there is interest in the CoCos' triggering, and it can arise if the market has not sufficient liquidity. De Spiegeleer and Schoutens (2011) refer the extreme case where CoCo investors, selling shares in order to hedge those positions, can drive the share price down, leading to a death-spiral effect and a trigger activation. With the purpose of preventing manipulation, Calomiris and Herring (2013) argued the use of a moving-average of prices and propose a "quasi-market-value-of-equity-ratio" moving-average. And to smooth the death-spiral effect, De Spiegeleer and Schoutens (2012) defend a series of different CoCos' issuances with different trigger levels and Corcuera et al. (2014) mention Coupon Cancellable CoCos "CoCa CoCos".

3.2.4 Multi-variate trigger

Lastly this trigger is related with the use of multiple triggers instead of a single one. The Squam Lake Working Group (2009) and McDonald (2013) consider a dual-trigger CoCo linked to the bank's share price and a bank's index dropping below a certain level. So the product are subject to a micro and macro trigger, declaring a systemic crunch. Pennacchi (2010) also ponders a dual-trigger. If the first and second trigger mechanisms presented are added, they are an example of a multi-variate trigger.

3.3 Market

To set an idea of the evolution and characteristics of CoCos' market it was collected a sample of 166 securities from 17 countries with a market size of 134.3 billion Euros. It was considered products issued until the start of May of 2015 by European Financial Institutions. And the sample was taken from Bloomberg, using the respective exchange rate and removing securities issued by special purpose entities. The data is from Figure A.1 to Figure A.3 in Appendix. It is possible to observe that the top three issuers' countries are UK (€ 43.4 bn), Switzerland (€ 26.1 bn) and France (€ 16.8 bn) and the currency breakdown is led by US dollars (€ 76.4 bn), followed by Euros (€ 37.6 bn). Regarding the historical semi-annual supply, since December of 2009, it was very timid between June of 2010 to 2013, due to some uncertainty regarding its regulatory treatment, place in the capital structure and little support from credit rating agencies (Avdjiev et al., 2013), recovering after that. Write-down CoCos represent the majority of the sample (€ 76 bn), being an available structure from investors that cannot invest in CoCos with equity conversion and the CET1 ratio is the primary trigger mechanism used (€ 106.9 bn). Moreover, most of the issued securities are AT1 (€ 93.3 bn), what can be explained by the no obligation to fill Tier 2 capital with CoCos hence, the banks issued basic subordinated debt, which is cheaper (ESMA, 2014). As observed, this class has been increasing since its appearance but it is important to build a solid investor base to obtain broad acceptance and to fulfill its purpose. Also the liquidity and market depth is dependent of sectorial and geographical holdings' diversification. Initially, private banks and retail investors, from Europe and Asia, retained most of the products but currently there is stronger investor base than what the market assumes[4]. According to Avdjiev et al. (2013) regulators can to discourage CoCo holdings from banks. In fact, this may lead to a reduction in the interconnectedness and subsequently in systemic risks. There is no idea about the effects if a possible triggering of CoCos in one institution can create a domino effect in the financial system. It is important a robust investor base in order to trying to avoid these threats, with participation of pension funds, asset managers and insurance companies (Avdjiev et al., 2013), for instance.

4. Methodology

This section addresses the main pricing approaches related with the Contingent Convertibles' valuation. One of them, the equity derivatives approach, is explained in

[4] In a survey, Ineke et al. (2015) captured a minimum of € 37 bn AT1 holdings and 72% was held by asset managers ("real money" investors) and 19% by hedge funds (that were thought as principal investors). A broader geographic investor base was shown by distribution statistics.

detail for equity conversion products and extended for the write-down ones. The purpose is to price, in the following Section, a fictive product (our benchmark case), performing a sensitivity analysis and also pricing a set of seven outstanding products in the market, under a Black-Scholes world.

4.1 Pricing Approaches

In order to price CoCos there are different valuation approaches that can be used. Maes and Schoutens (2012) believe that the pricing of CoCos is crucial to get an investor base. Nonetheless, up to the moment, there is no single model that is broadly accepted. The hybrid character of the product requires models from both equity and debt sides and therefore we find three, the Structural, Credit Derivatives and Equity Derivatives approaches, in the literature (Wilkens and Bethke, 2014).

4.1.1 Structural Approach

It has its origin in the model of Merton (1974) and it is intended to model the balance sheet, which is constituted by assets, equity and debt. Assets follow a stochastic process and the point of default is hit when the assets are lower than the liabilities. As CoCos have capital ratio triggers, this model is logically related and impose the moment of conversion when the corresponding capital-to-assets threshold is triggered. Numerous models have been proposed but with different extensions and applications like risk-taking incentives, optimal capital structures, default probabilities, manipulation concerns, among others (see Albul et al. (2010); Buergi (2012) ; Glasserman and Nouri (20109; Hilscher and Raviv (2014); Maes and Schoutens (2012); Pennacchi (2010); Sundaresan and Wang (2010)).

4.1.2 Credit Derivatives Approach

This approach takes the fixed-income investors side. Its objective it is to find the extra yield (spread) required, above the risk-free rate, for the probability of incurring in loss, once the trigger materializes. This is achieved through the reduced form approach (or intensity credit modeling) by taking into consideration the probability of default and the loss given default linked to credit instruments existing in the market. See De Spiegeleer and Schoutens (2011) and references therein.

4.1.3 Equity Derivatives Approach

It is the extension of the credit derivatives, treated as the “rule of thumb” (De Spiegeleer and Schoutens (2011), as it gives the CoCo spread as the probability of hitting the trigger and the consequent loss incurred upon this event happens. Since the credit model does not account for the risk of losing coupons when the trigger is reached, the equity model surpasses it. The main assumption is that the accounting trigger is equivalent to a market trigger, the share price dropping to a certain level $S*$ that determines the point of conversion or write-down.

4.2 Our Approach

In this subsection it is developed, in detail, the approach initially presented by De Spiegeleer and Schoutens (2011). Using the same reasoning, it is extended the pricing structure from the equity conversion CoCos to the write-down CoCos. This is the novelty of this study, and the objective is to evaluate the sensitivity of both structures and compare its behavior. Then, it is explored the fitting between the theoretical implementation in real products towards its market prices.

4.2.1 Equity Conversion

Concerning the products that convert into equity since the trigger is achieved, the loss is realized by the conversion ratio $\left(C_r\right)$, which is aN divided by C_p. So, considering a coupon bearing contingent convertible, two possible scenarios may happen. In one hand, the product does not touch the trigger and his behavior is like a bond, pays each coupon $\left(c_i\right)$ in the corresponding coupon date and the face value at maturity. In the other hand, the trigger is breached and the investor ends with the initial invested amount (or a portion of that, α) converted in shares, applying the respective conversion ratio, minus the remaining coupons lost (after the trigger moment, t*). It is assumed a share price at the moment of conversion $\left(S^*{}_T\right)$ equal to S^*. These final payoffs $\left(P_T\right)$ can be summed up in the following Equation 2:

$$\begin{cases} P_T = N + \sum_{i=t}^{T} c_i & \text{If not triggered} \\ P_T = N(1-\alpha) + C_r\, S_T^* - \sum_{i=t^*}^{T} c_i & \text{If triggered} \end{cases} \quad (2)$$

It is added two binary variables for the conversion and coupon payments. $1_{\{t \leq T\}}$, with the value of one if the trigger occurs and zero otherwise, and $1_{\{t \leq T\ -ci\}}$ with the value of one if the trigger does not occur and zero otherwise. Therefore, the Equation above can be rewritten in the following way:

$$\begin{aligned} P_T &= \left[N + \sum_{i=t}^{T} c_i \right] 1_{\{t \leq T - ci\}} + \left[N(1-\alpha) + \frac{\alpha N}{C_p} S_T^* - \sum_{i=t^*}^{T} c_i \right] 1_{\{t \leq T\}} \\ &= \left[N + \sum_{i=t}^{T} c_i \right] 1_{\{t \leq T - ci\}} + \left[N - \alpha N + C_r S_T^* - \sum_{i=t^*}^{T} c_i \right] 1_{\{t \leq T\}} \\ &= \left[N + \sum_{i=t}^{T} c_i \right] 1_{\{t \leq T - ci\}} + \left[N + C_r (S_T^* - \frac{\alpha N}{C_r}) - \sum_{i=t^*}^{T} c_i \right] 1_{\{t \leq T\}} \\ &= \left[N + \sum_{i=t}^{T} c_i \right] 1_{\{t \leq T - ci\}} + \left[N + C_r (S_T^* - C_p) - \sum_{i=t^*}^{T} c_i \right] 1_{\{t \leq T\}} \end{aligned} \quad (3)$$

From the Equation 3 above it is possible to divide the CoCo final payoff in two components in line with the two possible scenarios previously referred. These two components can be described as: a corporate bond (CB), down-and-in forward(s) (DIF) and a sum of binary down and in options (BDI).

As long as the trigger event does not materialize, the product pays each coupon c_i and the face value N at the maturity. So, it can be valued as a long position in a corporate bond with the coupon rate equal to the product coupon's, discounted at the risk free rate R_f. Using a classic pricing bond theory, the value on the valuation date $\left(V_t^B\right)$ can be obtained through (Martellini et. all, 2005):

$$V_t^{(B)} = Ne^{(-R_f T)} + \sum_{i=t}^{T} c_i e^{(-R_f t_i)} \quad (4)$$

In the condition of a trigger occurrence, it is necessary to replicate the conversion in shares. This can be achieved through a combination of a long position in a down-and-in call (DIC) and a short position in a down-and-in put (DIP). Both options having the same underlying asset (S), strike price (K) and maturity (T). And creating a synthetic forward contract, a synthetic position built up without buying, effectively, the forward (Bouzoubaa and Osseiran, 2010). This forward models the purchase of C_r shares at maturity T but, given the fact that this only takes place if the share price hits the trigger price $S*$ (barrier H), the contract is no longer constructed with vanilla options, but with barrier options. Barrier options are path-dependent options conditional on the crossing of a certain threshold during the life of the option, American style, or at the maturity, European style (Bouzoubaa and Osseiran, 2010). In this specific case, it is required down-and-in options that come into existence (*knocked in*) if the share price drops until $S*$, as it is expected that in the moment of the trigger event the share price is lower than the initial price. On the contrary, up and out options cease to exist if the share price rises until the barrier. These types of derivatives are very susceptible to changes in price as they approach the barrier. Fact that deserves attention and it is discussed later on in the sensitivity analysis. The possible conversion in shares offers to the investor a position in C_rF and not C_rS, because the investor ends up with a forward contract to buy shares at T and not in the moment of conversion. It is important to stress out that this position is not equivalent and may be accentuated if the conversion happens a long time before maturity, as the investor is prevented from receiving dividends, for instance. This causes a shortcoming in the model, however, De Spiegeleer and Schoutens (2011) argue that as is predictable a very depressed share price at the trigger moment, is it possible a cut on the dividends from a pre-recapitalized bank and the assumption can be acceptable in the model application. The down-and-in call and put prices, and the forward, can be obtained throughout the Equations 5, 6 and 7 below (Hull, 2009):

$$DIC_t = S_t e^{(-qT)} \left(\frac{S^*}{S_t} \right)^{2\lambda} N(y) - C_p e^{(-R_f T)} \left(\frac{S_t}{S^*} \right)^{(2\lambda - 2)} N\left(y - \sigma\sqrt{T} \right) \quad (5)$$

$$\begin{aligned} DIP_t = & -S_t N(x_1) e^{(-qT)} + C_p e^{(-R_f T)} N\left(-x_1 + \sigma\sqrt{T} \right) \\ & + S_t e^{(-qT)} \left(\frac{S^*}{S_t} \right)^{2\lambda} \left[N(y) - N(y_1) \right] \\ & - C_p e^{(-R_f T)} \left(\frac{S^*}{S_t} \right)^{(2\lambda - 2)} \left[N\left(y - \sigma\sqrt{T} \right) - N\left(y_1 - \sigma\sqrt{T} \right) \right] \end{aligned} \quad (6)$$

$$DIF_t = C_r\left[S_t e^{(-qT)}\left(\frac{S^*}{S_t}\right)^{2\lambda} N(y_1) - C_p e^{(-R_f T)}\left(\frac{S^*}{S_t}\right)^{(2\lambda-2)} N\left(y_1-\sigma\sqrt{T}\right) - C_p e^{(-R_f T)} N\left(-x_1+\sigma\sqrt{T}\right) + S_t e^{(-qT)} N(-x_1)\right] \tag{7}$$

With,

$$S^* = H\ ; C_p = K\ ; q = dividend\ yield\ ; \Phi(.) = cumulative\ normal\ distribution$$

$$\lambda = \frac{(R_f - q + \frac{\sigma^2}{2})}{\frac{\sigma^2}{2}} ; y = \frac{\ln\left[\frac{S^{*2}}{(S_t C_p)}\right]}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}$$

$$x_1 = \frac{\ln\left(\frac{S_t}{S^*}\right)}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}\ ; y_1 = \frac{\ln\left(\frac{S^*}{S_t}\right)}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T}$$

The last element needed to price CoCos is the possibility of losing coupons, replicated with a sum of binary down-and-in cash-or-nothing options matching each coupon payment date. The purpose of each BDI_{ci} is offset the respective coupon payment (c_i) once the level $S*$ is breached so, it is required a short position. Once more, it is a knock in option since it comes into existence as the barrier is hit. And, it is a binary cash-or-nothing, as it receives a pre-defined fixed amount Q (in this case, the coupon value) if it ends in-the-money, or nothing if it expires out-of-the-money (Hull, 2009). Since it is a binary barrier, the in/out –the-money condition is defined by the crossing of the barrier. Each option is priced in accordance with Rubinstein and Reiner (1991) . The formula is given by:

$$BDI_{ci_t} = c_i e^{(-R_f t_i)}\left[N\left(-x_{1i}+\sigma\sqrt{t_i}\right) + \left(\frac{S^*}{S_t}\right)^{(2\lambda-2)} N\left(y_{1i}-\sigma\sqrt{t_i}\right)\right] \tag{8}$$

With,

$$\boldsymbol{c_i} = fixed\ cash\ amount\ Q;\ \boldsymbol{x}_{1\boldsymbol{i}} = \frac{\ln\left(\frac{S_t}{S^*}\right)}{\sigma\sqrt{t_i}} + \lambda\sigma\sqrt{t_i}\ ;\ \boldsymbol{y}_{1\boldsymbol{i}} = \frac{\ln\left(\frac{S^*}{S_t}\right)}{\sigma\sqrt{t_i}} + \lambda\sigma\sqrt{t_i}$$

Finally, with the aim of obtaining the CoCo final price when the CoCo converts into equity $\left(EC\ CoCo_{price}\right)$, these components may be added. A standard corporate bond replicating the case in which the instrument is not triggered, the down-and-in forwards(s) composed by a long position in a DIC and a short position in a DIP multiplied by the C_r (giving the number of DIF needed to buy) and a short position in k binary down-and-in options. The Equation 9 below demonstrates the final price, in every t moment, that it is used in the benchmark case and in the real case application:

$$EC\,CoCo_{price_t} = V_t^B + DIF_t - \sum_{i=t}^{T} BDI_{ci_t} \tag{9}$$

4.2.2 Write-down

Concerning the products that receive a cut in their face values since the trigger is achieved, the valuation is performed using the same reasoning as in the equity conversion case. The loss is realized by the write-down amount (WD), which is the face value (N) multiplied by the write-down percentage $(WD_{\%})$. As before, two possible situations can arise. The product is not triggered and has the same performance as a corporate bond. Otherwise, the trigger event takes place, the investor obtains a cut that partially or fully reduces the initial invested amount and loses the remaining coupons c_i. Also, it is important to refer that the model proposed is applicable in products that only receive a permanent cut and not a temporary one. The final payoffs P_t are given below:

$$\begin{cases} P_T = N + \sum_{i=t}^{T} c_i & \text{If not triggered} \\ P_T = N\left(1 - WD_{\%}\right) - \sum_{i=t^*}^{T} c_i & \text{If triggered} \end{cases} \tag{10}$$

It can be used the same binary variables as before, $1_{\{t \le T\}}$ and $1_{\{t \le T\ -\ ci\}}$. And the formula above can be rewritten in Equation 11:

$$\begin{aligned} P_t &= \left[N + \sum_{i=t}^{T} c_i\right] 1_{\{t \le T - ci\}} + \left[N\left(1 - WD_{\%}\right) - \sum_{i=t^*}^{T} c_i\right] 1_{\{t \le T\}} \\ &= \left[N + \sum_{i=t}^{T} c_i\right] 1_{\{t \le T - ci\}} + \left[N - WD - \sum_{i=t^*}^{T} c_i\right] 1_{\{t \le T\}} \end{aligned} \tag{11}$$

The Equation can be disaggregated in two parts and combined with a corporate bond (CB), a sum of binary down-and-in options (BDI_{ci}) for the coupons and a binary down-and-in (BDI_N) for the face value.

Regarding the corporate bond and the set of binary down-and-in options that replicate the coupons, the application is equal to the equity conversion case. The corporate bond is priced as in Equation 4, using the same coupon rate as the product and discounted at the risk-free rate with the same maturity. The set of BDI_{ci} cancels out the coupons received once the trigger materializes hence, to capture this effect, a short position is necessary. Again, the valuation of these options can be founded in Equation 8.

About the binary down-and-in for the face value, the purpose, identic to the BDI_{ci}, is to neutralize the face value that is lost in case of trigger. For that reason, it is needed a binary barrier cash-or-nothing that receives the write-down amount WD if the share price falls and the barrier S^* is *knocked in*, or nothing at all. It is only necessary one of these options with maturity T covering the WD and not a set, as it is for the coupons. Adopting Rubinstein and Reiner (1991), the price is given by the subsequent Equation:

$$BDI_{N_t} = WDe^{(-R_f T)}\left[N\left(-x_{1i}+\sigma\sqrt{T}\right)+\left(\frac{S^*}{S_t}\right)^{(2\lambda-2)}N\left(y_{1i}-\sigma\sqrt{T}\right)\right] \quad (12)$$

With**,**

$$WD = \textit{fixed cash amount } Q$$

To end with the write-down product valuation, the CoCo final price $(WD\ CoCo_{price})$ joins the three elements. A corporate bond replicating the case that the product is not triggered, a short position in k binary down-and-in options BDI_{ci} offsetting the coupons and a short position in a BDI_N for the face value. At any moment t or valuation date, the formula below demonstrates the final price:

$$WD\,CoCo_{price_t} = V_t^B - BDI_{N_t} - \sum_{i=t}^{T} BDI_{ci_t} \quad (13)$$

5. Results

The goal of this section is to apply the theoretical equity derivatives approach presented in Section 4 for both equity conversion and write-down CoCos. At a first stage, it is created a benchmark fictitious CoCos in order to understand the pricing mechanics of this approach. Second, it is developed a sensitivity analysis, a parameter analysis and a simulation, evaluating the CoCo price fluctuations towards changes in the models' parameters. Finally, seven real CoCos are priced and compared with the market prices observed, in terms of fitting. The appropriate conclusions are, then, drawn.

5.1 The Benchmark case

The benchmark fictitious CoCo is created with the following characteristics: its issue date is on the fifth of May of 2015 and the share price that triggers the conversion or write-down is half of the initial price. All the variables are used equally for the price examples with the exception of the conversion price, ratio and write-down percentage. The C_p and C_r only applies on the $EC\ CoCo_{price}$ and the $WD_{\%}$ on the $WD\ CoCo_{price}$ .The risk free rate corresponds to the five year German Bund rate on the valuation date. The parameters used for the calculations are presented in the Table 1 below:

Benchmark fictitious CoCo parameters

Parameter	Description	Value
N	Face value	100
R_f	Risk free rate	0.017%
c_i	Annual coupon rate	6%
T	Maturity (in years)	5
S_0	Initial Share price	50
S^*	Share Price at Trigger	25
α	**Conversion Percentage**	100%
C_p	**Conversion Price**	50
C_r	**Conversion Ratio**	2
$WD_{\%}$	**Write-down percentage**	100%
q	Annual dividend yield	0%
σ	Annual std. deviation	30%
ACT/ACT	Day count convention	Actual/Actual

Table 1 – Benchmark fictitious CoCo price parameters. Based on De Spiegeleer et al. (2014).

5.1.1 Pricing Results

Starting with the equity conversion case, as in Equation 9, it is calculated the three components separately. The CoCo final price is nothing but the sum of these components. The long position in the corporate bond is the present value of each coupon value (6% multiplied by 100) paid annually during five years plus the face value received in T, discounted at the risk free rate of 0.017%. The sum of all cash flows gives a price of 129.90 for the bond, as it is observable in the next table:

Corporate Bond Value

t_i (in years)	c_i	N	V_t^B
1	6		
2	6		
3	6		
4	6		
5	6	100	
		Total	129.90

Table 2 – Corporate Bond value.

For the value of the long position in down-and-in forwards it is necessary to compute, first, the number of options that are required in the structure. It is assumed that the entire invested amount is converted in shares if the trigger event occurs $\left(\alpha = 100\%\right)$. Having this, the total number of DIF is 2 (N/ C_p), meaning that for each CoCo with a face value of 100, in case of conversion, the investor obtains two shares. The parameters for valuing the long DIC and short DIP, as in Equations 5 and 6, are: $S_t = S_0 = 50;\ K = C_p = \ 50;\ H = \ S^* = 25;\ T = 5;\ R_f = 0.017\%;\ q = 0\%; \sigma = 30\%$. The final price is shown below:

$$DIF_0 = C_r \left(DIC_0 - DIP_0\right) = 2\left(0.23 - 10.56\right) = -20.66 \qquad (14)$$

The remaining component is the package of binary down-and-in options. Since the product has five coupons and the pricing is made on the issue date, it is required five BDI_{ci}. The value subtracted from the CoCo price, covering the possibility of losing coupons is presented in the following table:

BDI_{ci} options' prices

t_i	BDI_{ci}
1	0.1754
2	0.8546
3	1.5134
4	2.0495
5	2.4802
Total	7.0731

Table 3 – BDI_{ci} options' prices for each coupon period.

Lastly, the theoretical contingent convertible value is 102.17. Putting the individual values in percentage, it is possible to point out the contribution of each element in the final price. As expected the corporate bond counts with the highest value, 129.90%, the remaining contributions replicate the probability of conversion and losing coupons. The aggregate price is as follows:

$$EC\,CoCo_{price_0} = V_0^B + DIF_0 - \sum_{i=t}^{T} BDI_{ci_{t0}} = 129.90 - 20.66 - 7.07 = 102.17 \qquad (15)$$

Using the building blocks from the equity conversion, with the exception of the binary down-and-in for the face value, it can be easily obtained the final price for the write-down CoCo. As before, the corporate bond is the biggest component but the binary-down-and-in covering the possibility of losing the face value has a higher value than the down-and-in forwards in the equity conversion case. This difference makes sense since it was considered a full write-down amount for the instrument and this corresponds to a recovery rate of zero. Although, in the moment of the trigger event it is probable a very low share price, in the equity conversion scenario, the investor ends up as shareholder. There is some scope for recovery. This greater amount of risk embedded in a full write-down CoCo is greater than in the equity conversion and it decreases as the write-down percentage reduces. The equation below, showing the final price for the write-down CoCo, demonstrates the difference mentioned:

$$WD\,CoCo_{price_0} = V_0^B - BDI_{N_0} - \sum_{i=t}^{T} BDI_{ci_0} = 129.90 - 41.34 - 7.07 = 81.84 \quad (16)$$

The BDI_N has a value of 41.34 and the DIF values 20.66. This discrepancy has a difference of 20.33 in the final price comparing the models. As the coupon rate (6%) and yield (risk-free rate), for the two pricing examples are the same, the investor in the write-down CoCo pays substantially less, as it invests in a riskier product that values nothing if the product gets triggered.

5.2 Sensitivity Analysis

In Section 4 the main pricing approaches, focusing on the equity derivatives, were presented and in the beginning of this Section the pricing examples for the equity conversion and write-down cases were provided. Before applying the models in real products, it is essential to perform a sensitivity analysis. First, a parameter analysis and then, a simulation.

5.2.1 Parameters' sensitivity

For this analysis a single input parameter is altered, *ceteris paribus*, and the impact in the final price is explored. The changing variables are the underlying share price, share price volatility, conversion price (EC), write-down percentage (WD), risk-free and coupon rates, trigger level S^* and maturity. The Figures 2 and 3 correspond to the equity conversion model and the Figures 4 and 5 to the write-down model.

In the left-hand plot of Figure 2, it is possible to observe a positive relation between the CoCo price and the underlying share price. For different levels of volatility, as long as the share price increases, the price of the product approaches the value of the standard corporate bond. This is related to the higher distance to the trigger $S^* = 25$ and it has a lower increasing speed as lower it is the volatility. With a growing share price, the barrier for the DIF and BDI_{ci} is becoming further away and these options become out-of-the-money and reach the value of zero. This is the point where the CoCo costs the same as the risk-free bond. Inversely, the product final price, delta and vega may have an accentuated change near the barrier. The delta, that gives the change in the option price relatively to changes in the underlying, is negative for the DIF and BDI_{ci}. As the underlying price goes down, the options' prices go up. For instance, in an intermediate level of volatility $(\sigma = 30\%)$, with a share price of 26 the CoCo price decreases almost 50% to 52.99. Even with a low level of volatility, as 10%, the price decreases to 61.62 (around 47% less). The vega, sensitivity parameter for variations in the options' prices to movements in the underlying's volatility, is higher than in comparable vanilla options. With high levels of volatility, the probability of touching the barrier increases (Bouzoubaa and Osseiran, 2010). In the right-hand diagram it is possible to draw some ideas about the behavior of the conversion price. The C_p affects the value of the forward built with the DIC and the DIP, giving the price at which the product invested amount is converted at the trigger event. The difference between C_p and S* gives the loss incurred by the investor. So, the investor wants, as much as possible, a low C_p minimizing this loss. Acting as strike price K, as C_p approaches S* the DIC becomes more in-the-money and the DIP more out-of-the-money, lowering the value of the DIF and the negative weight in the total CoCo price. This situation reverts if the conversion price is inferior than the barrier. The long DIC will be higher than the short DIP and the contribution of the forward to the final price will be positive. There is a point where this positive contribution compensates the negative value of the k BDI_{ci} and the total price will be greater than the risk-free bond price. However, this situation does not meet the purpose of the bank, when creating the product. It is not expected that the investor ends up with an amount superior than the initially invested. Finally, it is also observable the multiple price equilibrium problem discussed in Sundaresan and Wang (2010). For two different trigger prices, it is obtained the same CoCo price.

In what concerns Figure 3, it is presented the relation between the product price and the maturity for some levels of risk-free and coupon rates, respectively. The sensitivity parameter that gives the rate at the options' price alters over the time is Theta. This Greek assumes always a negative value, as the time passes by, the options are worth less. Noticing the left side panel, for different levels of risk-free rate it can be discussed the respective change in the final price. Considering again the options' sensitivity variables, the relation between the prices and the interest rates is given by Rho. Rho is positive for calls and negative for puts, always. The relationship may be not obvious but has to do with delta hedging. For a short position in a call, as the underlying's price rises, it is necessary buying delta shares. If the interest rates go up, the borrowed money for the purchase will be more costly, increasing the delta hedging and subsequently the call's value (Bouzoubaa and Osseiran, 2010). The whole CoCo price decreases as the interest rate increases, but for longer maturities this price tends to increase as the number of cash-flows for the corporate bond also increases. In the graph, it only verifies for Rf of 1% and lower. For higher rates, the options' negative contributions surpass the bond value. On the right panel, the coupon rate affects the bond and the k BDI_{ci}. The bond price is positively related with the coupon rate and maturity, as the cash-flows increase in number and in value. For the BDI_{ci}, with increasing maturities and coupon rates the price also rises and it causes a negative rebate in the final price. Despite this, as the corporate bond has the major weight in the final price, the price growth exceeds the negative contribution of each BDI_{ci}, increasing the overall CoCo price.

EC CoCo price as a function of share and trigger prices

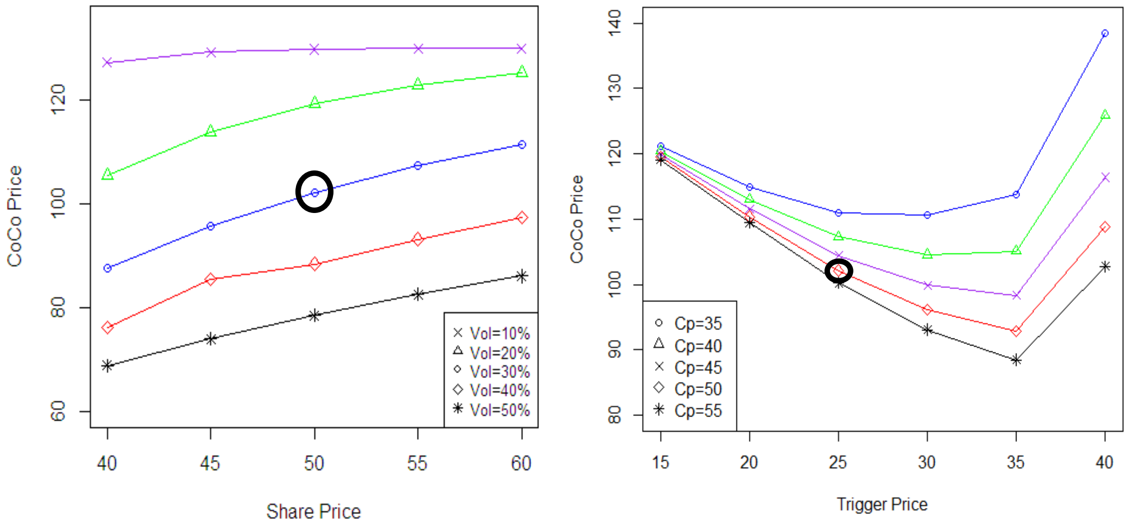

Figure 2 – EC CoCo price as a function of share price and trigger price for different values of volatility and conversion price, respectively.

EC CoCo price as a function of maturity

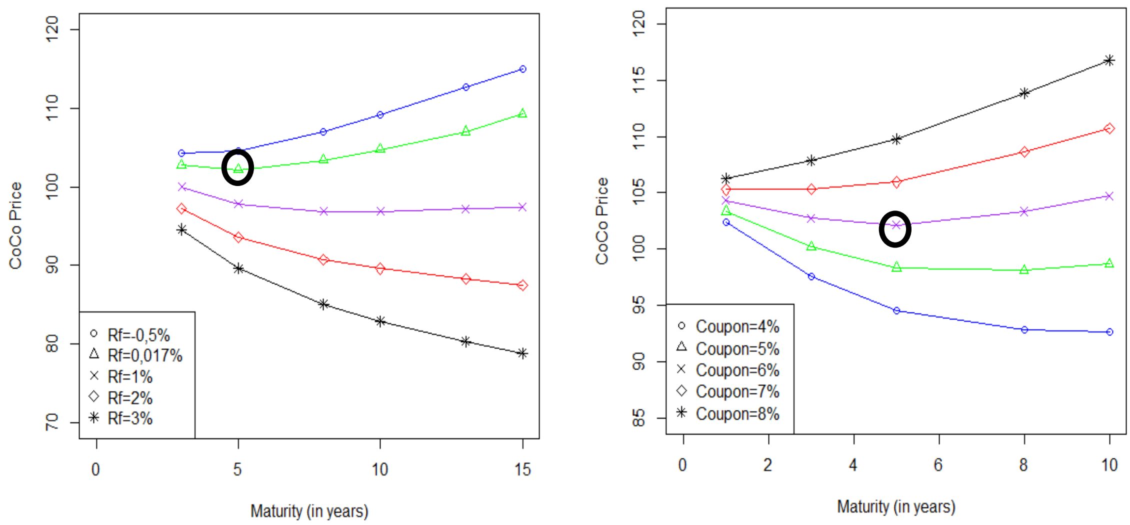

Figure 3 - EC CoCo price as a function of maturity for multiple risk-free and coupon rates.

Observing the left-hand plot of Figure 4, it is clearer the relation between the product and share price for different values of volatility than in the equity conversion model. As both the k binary down-and-in for the coupons and the face value are rebates on the final price, as the volatility decreases and the share price increases, the CoCo price is reaching the value of the corporate bond. This connected movement occurs since, with the share price rise, the barrier options become out-of-the-money, fact that it is intensified with lower levels of volatility. The probability of touching the barrier S* is eventually less likely with a higher share price and lower volatility. As before, it is important to refer, on contrary, the extreme values assumed by delta and vega near the barrier. With a base case price of 81.84 (σ=30% and S=50), if there are considered negative shocks of 10% for volatility and 24 for share price, the final CoCo price is 7.82. This demonstrates that, even if the volatility share price level assumes a very reasonable value of 20%, the proximity of the barrier makes the final price deepens in value. Recalling the example given in the Equity Conversion case, this shock made the final price falls 47% and in this case the decrease is 90.44%. Such a huge difference is explained by the loss amount embedded in each structure. If the trigger is reached, in the Equity Conversion CoCo, the investor receives two shares worth a total of 50 with the chance of increase. In the Write-down CoCo, the investor gets nothing, permanently. The final positions are obviously not equivalent. On the right-hand plot, different write-down percentages give different amounts of loss if a trigger event happens. With an invested amount of 100, once the trigger occurs, if the CoCo has a $WD_{\%}$ of 25%, the investor ends up with 75. But, as referred previously, this cut is permanent and with no possibility of recovery. Having this, the relation between the final price, trigger price and $WD_{\%}$ seems evident. For lower $WD_{\%}$ the BDI_N also has inferior price, incrementing the product final price. More, this lower cut percentages allied with decreasing trigger share prices corresponds to a smaller probability of touching the barrier and activate the knock-in options (BDI_N and k BDI_{ci}). So, the CoCo price rises until reach the corporate bond value.

Lastly, in Figure 5, it is plotted the CoCo price against the maturity for various risk-free and coupon rates. Initiating with the risk-free rate changes, on the left diagram, for higher maturities the corporate bond and the binary barrier options increase. Since the binary barriers are deducted from the corporate bond, as the maturity rises, these options create more downward pressure on the final price. Also, in the base case, it is considered a maturity of five years with five binary down-and-in options. In a case where the product has 10 years of maturity, the number of coupons is 10, with a corresponding ten BDI_{ci}, increasing the negative rebate in the final price. Concerning the risk-free rate, the inverse relation between yields and prices gives lower bond prices for higher yields. The same occurs with the options. Looking at the right diagram, the relation between the final price and maturity for some coupon rates are presented. The corporate bond increases with higher maturities and coupon rates. But the total value decreases because, in one hand, the negative rebate of the BDI_{ci} increases with higher coupons and maturity and, on the other hand, the BDI_N also increases with maturity.

WD CoCo price as a function of share and trigger prices

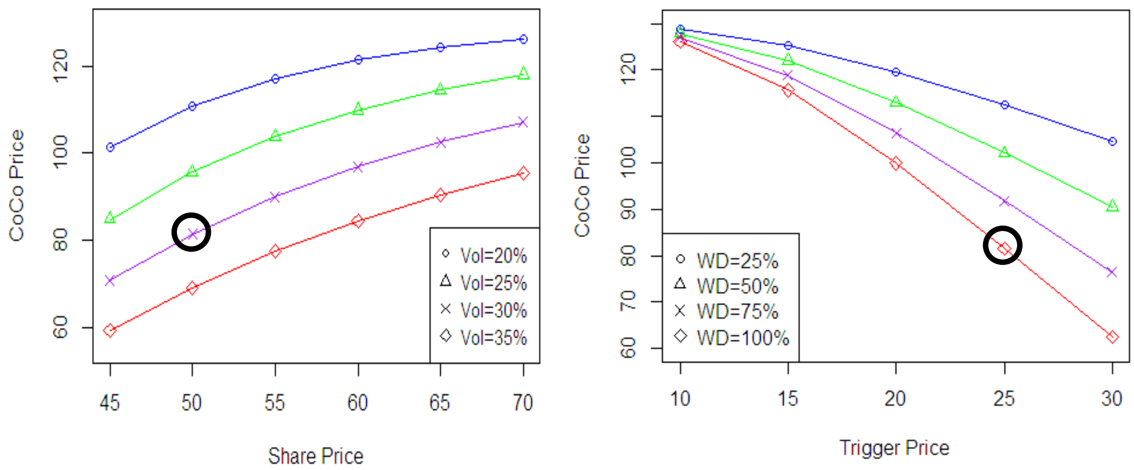

Figure 4 - WD CoCo price as a function of share price and trigger price for different levels of volatility and write-down percentage, respectively.

EC CoCo price as a function of maturity

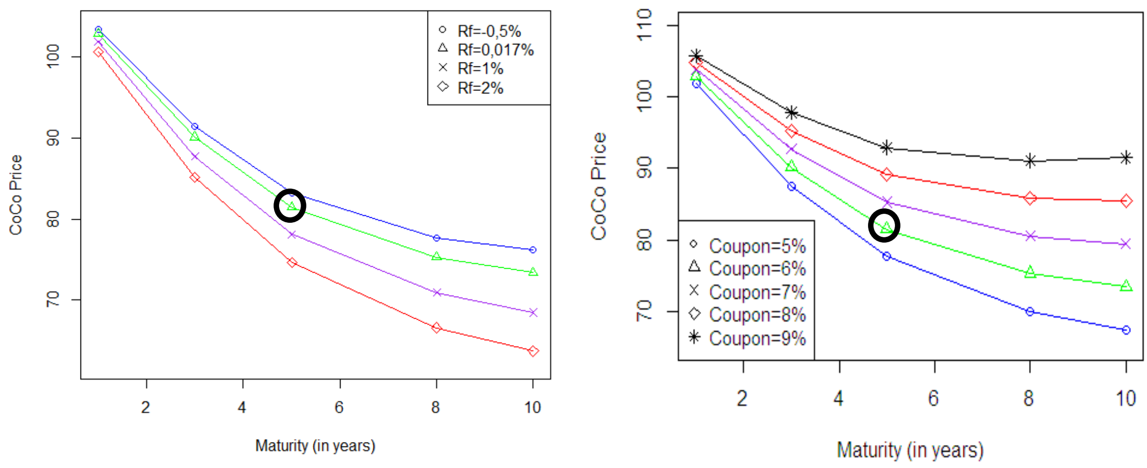

Figure 5 - WD CoCo price as a function of maturity for multiple risk-free and coupon rates.

5.2.2 Simulation

(1) Monte Carlo Simulation Scenarios

	Base Case	Low Volatility (10%)	High Volatility (50%)	Low Rf (2%)	High Rf (4%)
Prob. Hitting the Trigger	11.07%	0.00%	28.29%	9.15%	7.47%
Expected Payoff	-29.78	-	-33.39	-29.63	-29.48
Recovery Rate	40.44%	-	33.22%	40.74%	41.04%

Table 4 – Monte Carlo Simulation Scenarios – probability of hitting the trigger, expected payoff and recovery rate.

(2) Monte Carlo Simulation Scenarios

	Short Maturity (2 Years)	Long Maturity (8 Years)	Low Cp (30)	High Cp (70)	Low S* (15)	High S* (35)
Prob. Hitting the Trigger	2.43%	18.24%	11.07%	11.07%	0.09%	7.64%
Expected Payoff	-27.81	-31.24	-9.78	-49.78	-37.33	-22.95
Recovery Rate	44.38%	37.52%	80.44%	0.44%	25.34%	54.10%

Table 5 - Monte Carlo Simulation Scenarios – probability of hitting the trigger, expected payoff and recovery rate.

In addition to the parameters' sensitivity performed for CoCo prices it is also important to investigate these products in what concerns the probability of hitting the trigger (similar with survival probabilities of autocallable bonds in Albuquerque et al. (2015)), the expected payoff, once the trigger is reached, and the recovery rate associated. In order to come up with some conclusions about the behavior of equity conversion and write-down CoCos it was simulated 10000 share price paths using Monte Carlo Simulation techniques (Hull, 2009). The final results, in Table 4 and 5, are presented for the base case, corresponding to the benchmark fictitious CoCo parameters (Table 1), and for low/short and high/long scenarios, regarding changes in volatility, Rf , maturity, C_p and S^*.

The first line in both tables, Probability of Hitting the Trigger, is applied for the equity conversion and write-down products but, the second and third lines, only apply for the equity conversion ones. In a full write-down CoCo, once the trigger is reached, the expected payoff and recovery rate are zero, since the invested amount is wiped out. On the other hand, in a write-down CoCo with a cut of 50%, for a nominal amount of 100, the expected payoff is 50 and the recovery rate is 50%.

Observing the Tables 4 and 5, the scenarios of low and high volatility show the minimum and maximum probabilities of hitting the trigger, 0.00% and 28.29%, respectively. Concerning the expected payoff, not taking into account the low volatility scenario, the minimum and maximum values are presented in the low and high Conversion Price scenarios, -9.78 and -49.78, respectively. This is related with the distance from the share price at the moment of trigger $(S*)$. In this case, $S*$ is 25 so, a C_p of 70 implies a much higher loss than a C_p of 30. The investor will pay 70 for each share, when those shares value only 25. For the recovery rate, ignoring once more the low volatility scenario, the lower and higher values correspond, again, to the high and low C_p scenarios, 80.44% and 0.44%, respectively. The implied loss referred before is associated with the corresponding recovery rate. For higher losses, the recovery is lower, since the share price needs a great boost in order to reach the price at which the shares were acquired.

Therefore, we can delineate some general conclusions. These products have a low probability of hitting the trigger but with high losses for investors, in line with the analysis of Wilkens and Bethke (2014). Specially, for write-down CoCos. For high levels cut, more extreme are the losses. Consistent with that is the difference between the recovery rates for both type of CoCos. For instance, a full write-down CoCo has 0% of recovery while equity conversion CoCos have scope for that.

5.3 Real life CoCos

In order to apply the theoretical approach to real products, seven active CoCos are used, specifically, three products that convert into shares and the remaining four that fully and permanently are written-down, since the trigger point is reached. These products are from Barclays, Credit Suisse, Lloyds, UBS and KBC. Initially, the data necessary to implement the models and the source where it is available is presented. The aim is to obtain a time series for both model and market prices, beginning on the product's issue date and finishing on the fifth of May of 2015. Then, the main characteristics of each product and how the models are parametrized are outlined. Finally, the results obtained are analyzed and contextualized.

1.2.1 Data Requirements and Calibration

With the purpose of understand how the parameters of each model are used and the respective source, the building blocks of each structure are divided. Since the models use the same parameters, the explanation can be combined, and the division made between the corporate bond and the financial options. To support this, the Table A.1 in Appendix summarizes the required parameters, data source and if the parameter is static or need to be dynamically adjusted (based on Erismann (2015)).

- *Corporate Bond* $\left(V_t^B\right)$

To price the corporate bond embedded in each product, the information necessary such as coupon rates and payment dates are in the prospectus. The missing date is the discounting rate, which in the case is the risk-free. Such a rate is considered as the government bond in the same currency and with the same or approximated maturity of the CoCo (using linear interpolation if necessary).

- *Down-and-in forward* $\left(DIF_t\right)$*), Binary down-and-in options (* BDI_{ci} *and* BDI_N *)*

As the options used in the models have as underlying the share price linked to each product, being the issuer or the reference entity, the necessary parameters are based on that. The share price is incorporated in the model on a daily basis, beginning in the CoCo issue date. The volatility is the annual standard deviation of the respective share price, using as assumption 252 trading days per year, and adjusted every day. The calculation is made with the five year historic daily log-returns. The barrier S^* is obtained through interpolation as on De Spiegeleer et al. (2014), matching the issue price to the model price applied on the issue date. Then, it is maintained constant. As in the Black-Scholes framework the discounting rate is also the Rf, the rate is the same as for the corporate bond valuation. The dividend yield is calculated making an average of the five year historical rate, then it is adjusted. To the forward position, the strike price K is the conversion price C_p, it is available on the prospectus and remains fixed over time. The Q cash amount necessary to price the binary options corresponds to the coupon value for the BDI_{ci} and the write-down amount for the BDI_N. For instance, a product with a coupon rate of 6%, paid annually, has each BDI_{ci} with a Q amount of 6. And if this product gets a cut of 100% on his face value, for a nominal amount of 100, the Q amount for the BDI_N is 100.

1.2.2 Products' Description and Parametrization

The criteria used in the products choice were the type of structure, the longest time period since the issue date and the highest issued amounts. For the Equity Conversion model were preferred products with fixed and pre-defined conversion prices with the aim of reducing the model uncertainty, as the products with variable conversion prices are subject to specific calculation conditions. Regarding the Write-down CoCos, the proposed model, as earlier mentioned, only applies to permanent cuts. This removed the possibility of consider products with temporary cuts. Also, in order to have products with the same structure, were considered the ones with a fully write-down amount. All the securities are traded in minimum denominations of 200.000 but for model purposes, the principal amount is 100. The Table 6 shows the main characteristics of each product, additional characteristics are presented separately and Table 7 shows the main model parameters in terms of minimum and maximum values, over the time series. Also, the maturity date is assumed to be the first call date, for model purposes.

1- Barclays US06738EAA38

As of fifth of May of 2015, Barclays PLC had seven contingent CoCos outstanding. Five of them convert into equity and two are written-down if a trigger event materializes, a Capital Adequacy Trigger Event (CATE), linked to a Barclays Group's capital ratio. For this analysis we use three of them and the first has a time series of 344 trading days until May 5^{th} of 2015. It is converted into ordinary shares if the Group's fully loaded (without transitional provisions) CET 1 ratio is below 7% on any Quarterly Financial Period End Date or Extraordinary Calculation Date. More, independent of the CATE, the relevant U.K. resolution authority can exercise any U.K. Bail-In power by cancelling, or converting, a portion or the total principal amount of the securities. It has first call date on December 12th of 2018 and every five years thereafter, when a resetting of the interest rate takes place (Barclays Bank, 2013).

Products Characteristics

Issuer	Barclays PLC	Barclays Bank PLC	Barclays PLC	UBS AG	Lloyds BG PLC	Credit Suisse Group AG	KBC Bank NV
ISIN	US06738EAA38	US06740L8C27	XS1002801758	CH0214139930	XS1043550307	XS0989394589	BE6248510610
Issue Price	99,993	100	100	100	100	100	100
Issue date	20-11-2013	21-11-2012	10-12-2013	22-05-2013	01-04-2014	11-12-2013	25-01-2013
Maturity	Perpetual	21-11-2022	Perpetual	22-05-2023	Perpetual	Perpetual	25-01-2023
Call Date	15-12-2018	-	15-12-2020	22-05-2018	27-06-2019	11-12-2023	25-01-2018
Issued amount (millions)	2,000	3,000	1,000	1,500	1,480.784	2,250	1,000
Denomination	USD 200,000	USD 200,000	EUR 200,000	USD 200,000	GBP 200,000	USD 200,000	USD 200,000
Coupon	8.25%, quarterly, commencing on 15-03-14	7.625%, semiannually, commencing on 21-05-13	8.00%, quarterly, commencing on 15-03-14	4.75%, annually, commencing on 22-05-14	7.00%, quarterly, commencing on 27-06-14	7.50%, semiannually, commencing on 11-06-14	8.00%, semiannually, commencing on 25-07-14
Day-count convention	30/360	30/360	ISMA-30/360	ISMA-30/360	ACT/ACT	ISMA-30/360	ISMA-30/360
CoCo trigger	CET 1 fully loaded, 7%	CET 1, 7%	CET 1 fully loaded, 7%	CET 1, 5%	CET 1 fully loaded, 7%	CET1 (5.125%) + Higher Trigger Capital Ratio (2.9%)	CET 1, 7%
Basel III Designation	AT1	Tier 2	AT1	Tier 2	AT1	AT1	AT1
Conversion price/write-down	USD 2.64	100%	EUR 1.99	100%	GBP 0.643	100%	100%

Table 6 – Real life products characteristics. Based on products' prospectus.

Main dynamic model parameters

	Share Price	Annual Volatility	Risk-free rate	CET1/ CET1 Fully Loaded	Exchange Rate
	Barclays US06738EAA38				
Minimum	3.34	0.40	0.98	8.4	1.46
Maximum	4.85	0.64	1.74	10.3	1.72
	Barclays XS1002801758				
Minimum	2.61	0.40	-0.15	8.4	0.71
Maximum	3.69	0.63	1.40	10.3	0.85
	Lloyds XS1043550307				
Minimum	21.84	0.38	0.85	12.8	-
Maximum	86.30	0.42	2.10	12.8	-
	Barclays US06740L8C27				
Minimum	3.34	0.40	1.41	9.1	1.46
Maximum	4.85	0.72	2.76	10.6	1.72
	UBS CH0214139930				
Minimum	15.38	0.31	0.83	13.2	0.84
Maximum	21.49	0.52	1.64	19.4	1.02
	Credit Suisse XS0989394589				
Minimum	21.14	0.32	1.61	13.8	0.84
Maximum	33.11	0.34	3.00	15.7	1.02
	KBC BE6248510610				
Minimum	34.23	0.48	0.58	9.7	0.72
Maximum	66.36	0.59	1.63	14.7	0.95

Table 7 – Main dynamic model parameters for the seven CoCos.

2- Barclays XS1002801758

The second product chosen from Barclays has 366 trading days included on the time series. It also has the possibility of any U.K. Bail-In Power exercise and the main characteristics are the same regarding the first product (Barclays Bank, 2013a).

3- Barclays US06740L8C27

The last product was issued by Barclays Bank, a subsidiary of Barclays' Group. It has a time series with 601 trading days. There are two different conditions, if these notes are excluded from the Group's Tier 2 capital relating to any regulation requirements or if there is the occurrence of any Tax Event, the Bank can redeem the total principal amount (Barclays Bank, 2013b).

4- UBS CH0214139930

Until May 5th of 2015, UBS AG had three products outstanding and UBS Group AG had another three products. All of them linked to a Group's capital ratio and with a permanent write-down structure. The security chosen was issued by UBS AG on May 22th of 2013 and it has 322 trading days. It is written-down in 100% of his face value if Group's CET1 ratio falls into 5% and if FINMA (Swiss Financial Market Supervisory Authority) decides to trigger the product in order to prevent the group of being insolvent. The later contingent event, known as Viability Event, it is independent whether the former occurs. Upon the occurrence of a Tax or Regulatory Event, the issuer may redeem earlier the product (UBS AG, 2013).

5- Lloyds XS1043550307

The Lloyds Banking Group (LBG) has a total of 41 equity conversion products in the market. Five of them issued by LBG and the remaining thirty six issued by LBG Capital (corresponding to the Enhanced Capital Notes (ECNs) issued on 2009 from a capital raising exercise). LBG has the right of call these ECNs if there is a Capital Disqualification Event (CDE), which occurs if the products cease to account, as core capital, for any stress tests application purposes. The Bank claimed a CDE after a stress test applied by PRA (Prudential Regulation Authority) but, at June 3rd of 2015, the Court declined the appeal and the redemption cannot be exercised (Lloyds Banking Group, 2015). The product under analysis is part of the exchange offer of some ECNs and was issued on April 1st of 2014, comprising 275 trading days. Earlier redemption may arises if there is a CDE, a Tax Event or at the first call date on June 27th of 2019 (Lloyds Banking Group, 2014).

6- Credit Suisse XS0989394589

Credit Suisse Group (CSG) and Credit Suisse (Group's subsidiary) had five and three CoCos in the market. All the products capital trigger is the Group's CET1 ratio. The security under consideration was issued by CSG and it has 344 trading days. The contingent event is connected to the Group's CET1 plus a High Trigger Capital Ratio (HTCR, 2.9% on the issue date). This HTCR captures the instruments that, at any time, are capable to be converted into shares or written-down/off in order to improve the CET1 ratio against being lower than the threshold ratio (5.125%). The viability event is declared by FINMA as was explained on the UBS product. A capital and tax event and the first optional date at December 11th of 2023 are conditions to redeem earlier the product (Credit Suisse, 2013).

7- KBC BE6248510610

The final product is from KBC Bank NV and it has 578 trading days. Also KBC Group has outstanding one security. On the other side, a contingent write-down to zero exists if the Group's CET1 ratio decreases until 7% or a regulatory event occurs (a CDE as in Lloyd's case but in this case it is relating with Tier 2 Capital) (KBC, 2013).

1.2.3 Results

After applying the equity derivatives approach to the seven real CoCos, we can compare the prices obtained with the prices observed in the market. The Table 8 below shows the 4 write-down CoCos firstly and then, the 3 equity conversion CoCos. Also from the Figure A.4 in Appendix to Figure A.10 the results are presented in terms of time series, obtaining a visual perception for each product. In general, the results are not optimistic since we achieved some very high pricing errors such as 33.99 and 17.09, for the first and the third Barclays' CoCos in the Table 8, respectively. Moreover, from the visual inspection of the Figure A.4 until Figure A.10 in Appendix, there is a tendency of an overestimation of the prices throughout the time. This can be explained by the fixed S*. As the time goes by and the probability of hitting the trigger is becoming less expected, the options embedded in the product price are becoming more out-of-the-money, worth less, and making the CoCo price higher, as its negative rebate is removed.

For the equity conversion CoCos the results are in accordance with Erismann (2015). Concerning the write-down CoCos, there is no way of comparing, since the literature focus has been on the equity conversion type. Nevertheless, the model application is the same and the results are not favorable, as well.

Minimum and maximum values of the model application

	Barclays US06740L8C27			UBS CH0214139930		
	Model Prices	Market Prices	Error	Model Prices	Market Prices	Error
Minimum	100.00	98.00	-1.52	96.83	94.63	1.32
Maximum	141.99	117.25	33.99	113.41	104.00	12.93
Mean of Errors			16.76			8.84
	Credit Suisse XS0989394589			**KBC BE6248510610**		
	Model Prices	Market Prices	Error	Model Prices	Market Prices	Error
Minimum	96.01	100.00	-10.14	100.00	97.50	0.02
Maximum	108.34	111.75	0.90	120.36	115.20	10.91
Mean of Errors			-3.96			6.10
	Barclays US06738EAA38			**Barclays XS1002801758**		
	Model Prices	Market Prices	Error	Model Prices	Market Prices	Error
Minimum	99.99	99.99	-3.30	100.00	100.00	-2.34
Maximum	109.86	107.75	3.86	126.25	112.85	17.09
Mean of Errors			1.03			9.08
	Lloyds XS1043550307					
	Model Prices	Market Prices	Error			
Minimum	100.00	99.63	2.98			
Maximum	111.40	10358	8.87			
Mean of Errors			4.36			

Table 8 – Minimum and maximum values of the model application: model and market prices and error.

6. Conclusion

Contingent Convertible Bonds are a hybrid product that emerged in 2009 with the challenge of truly absorb losses and reinforcing capital requirements of financial institutions. Similar products did not work in the last financial crisis so, there has been an effort in order to fix the damages caused and to create protection against future shocks. CoCos born as a new possibility of recapitalizing financial institutions when they are in trouble thus, facing constraints in raising capital from the markets. This is conceivable since these bonds are automatically converted into shares or its face value is written-down, when some specific condition, the trigger, is reached. At a first glance, its purpose seems promising and welcomed for those who are related with the institutions. For instance, for regulators and supervisory authorities, as we are assisting to the transition from Basel II to Basel III framework with stricter regulations (Basel

Committee (2010) report). However, discussions have surged among academics, practitioners and regulators about the real effects of these products in the capital structures, if they can effectively face losses or create perverse incentives. This uncertainty allied with the fact that any product was yet triggered, creates some contradictions. In fact, there is no standardization regarding the contracts' features and no single valuation model broadly accepted. Concerning CoCos' structure, probably the most contradictory topic is related with the trigger. This trigger can be a market, an accounting, regulatory or multi-variate trigger but all CoCos issued so far are linked with accounting triggers, namely, capital ratios. The objective is to use these products to meet regulatory capital requirements but accounting figures are not readily available in the market and can be easily manipulated (see for instance Kuritzkes and Scott (2009), Gunther (2013), among others).

In what concerns the possible valuation models, in this study is presented in detail the Equity Derivatives Approach, treating CoCos as a structured product and compose it with a corporate bond and financial options, in a Black-Scholes framework, in order to obtain its price. Unlike the majority of the literature, it is given much attention to write-down CoCos. So, the approach is extended from the conversion into shares products to the write-down ones, using the same reasoning. Through the creation of a fictitious benchmark product it was possible to perform a parameter's sensitivity analysis and a Monte Carlo Simulation and draw some ideas. Those prices are highly sensitive through oscillations, even in a Black-Scholes world, with the write-down CoCos showing great variations. Also, these products present a low probability of hitting the trigger but, when this happens, the losses are large and again, write-down CoCos are more penalized. Finally, the model was applied in seven real products, creating a time series possible to compare with market prices. The model prices overestimate market prices (in the case of conversion into shares, the results are comparable with Erismann (2015) but for write-down ones there is no comparable base). Hence, future studies should focus more attention to write-down CoCos, especially in its valuation, like it has been made with the equity conversion ones.

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8. Appendix

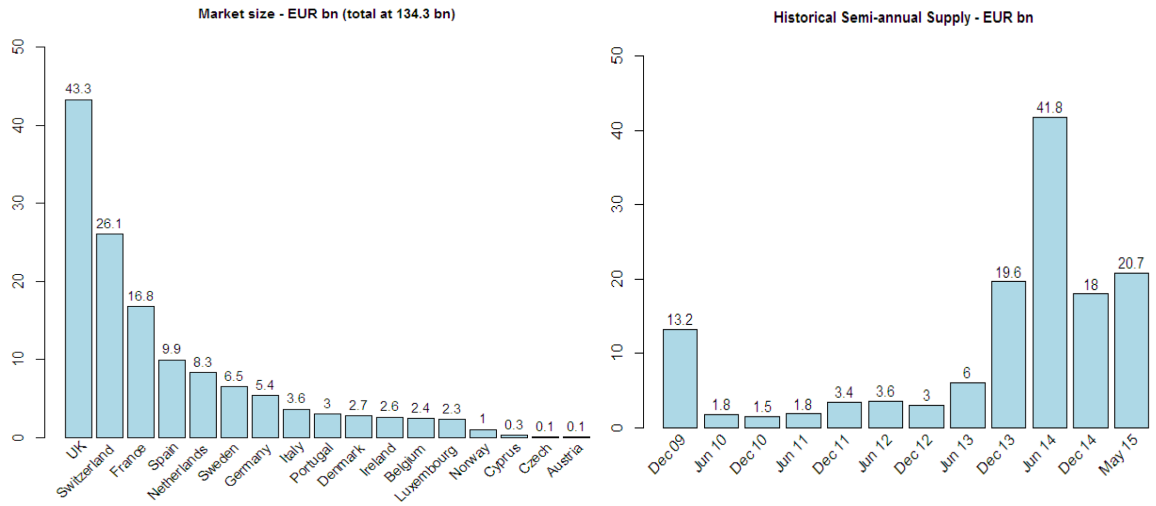


Figure A.1 - Market size and historical semi-annual supply in EUR bn.

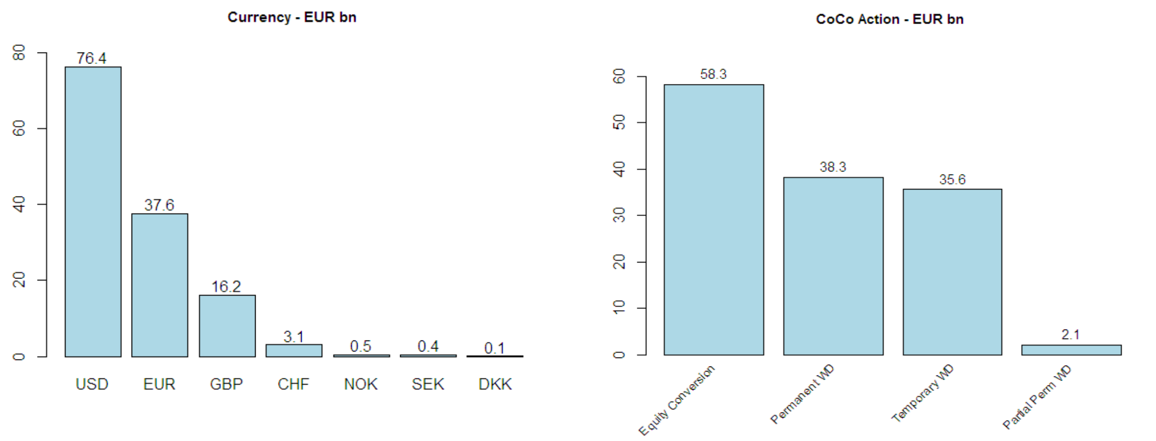


Figure A.2 - Currency and CoCo Action in EUR bn.

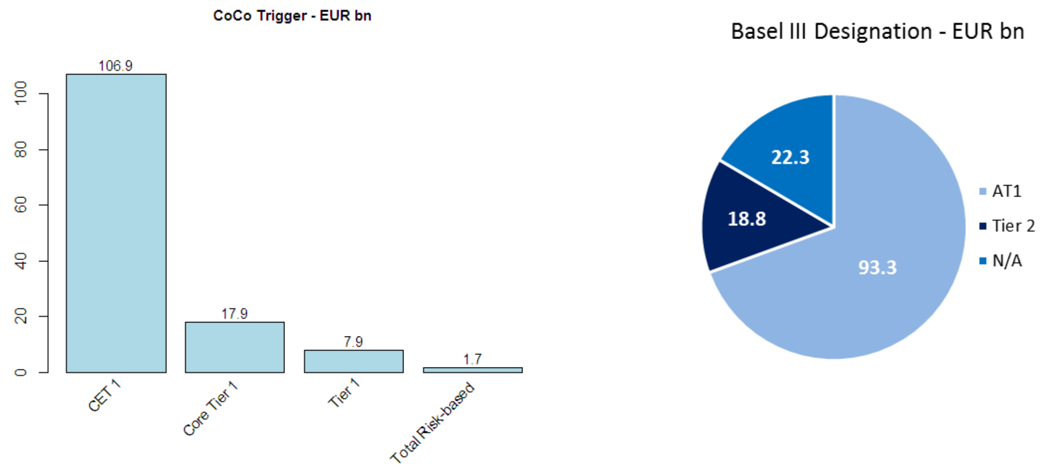


Figure A.3 - CoCo Trigger and Basel III Designation in EUR bn.

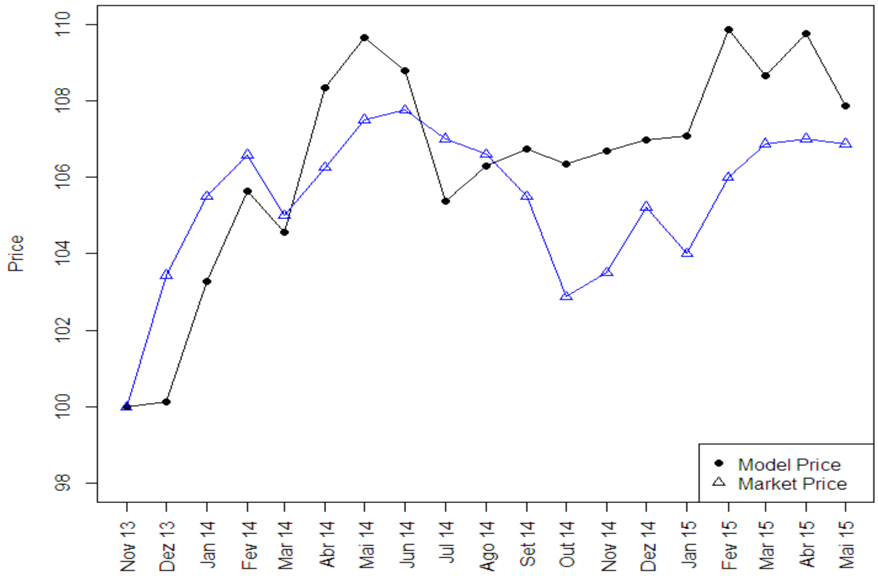
Source and usage of the model parameters

	Source	Usage
Face value	Assumption	Static
Share Price	Market	Dynamic (daily closing prices)
Share Price at Trigger (S*)	Calibrated	Static
Annual std. deviation	Market	Dynamic (five years rolling)
Annual dividend yield	Market	Static (five years average)
Risk Free Rate	Market	Dynamic (Gov. Bond in the same currency)
Business Days (252)	Assumption	Static
Day count convention	Prospectus	Static
Coupon Rate	Prospectus	Static
Conversion Price/Ratio	Prospectus	Static
Write-down amount	Prospectus	Static
CET1/CET1 Fully Loaded	Market	Dynamic
Exchange Rate	Market	Dynamic

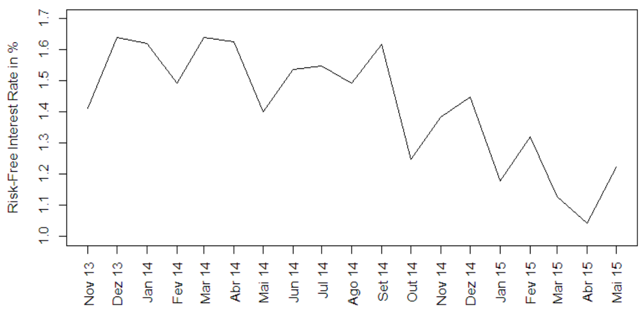
Table A.1 – Source and usage of the model parameters. Based on Erismann (2015).

Barclays US06738EAA38 – Pricing results and model parameters

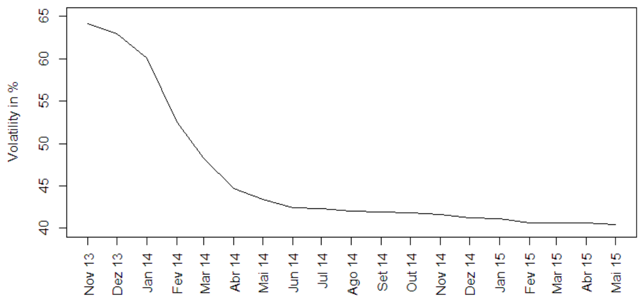
(a) Model vs. Market Prices



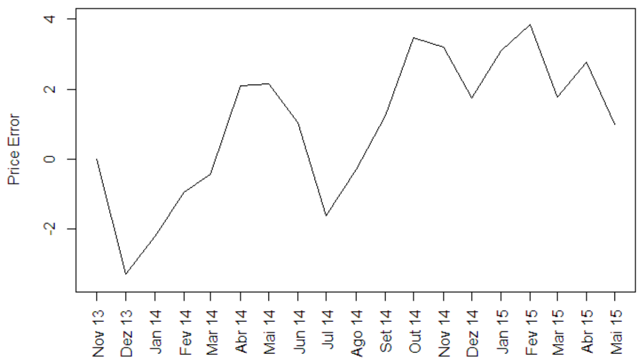
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

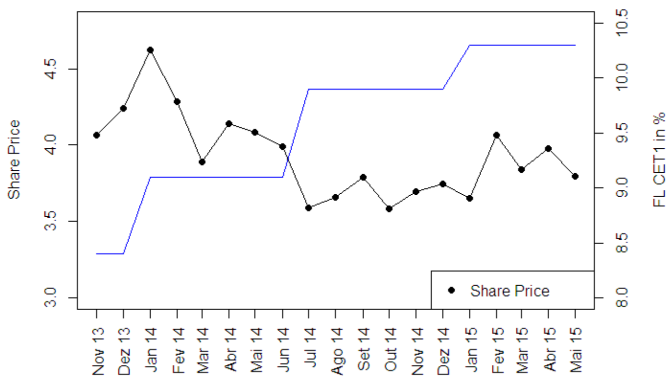
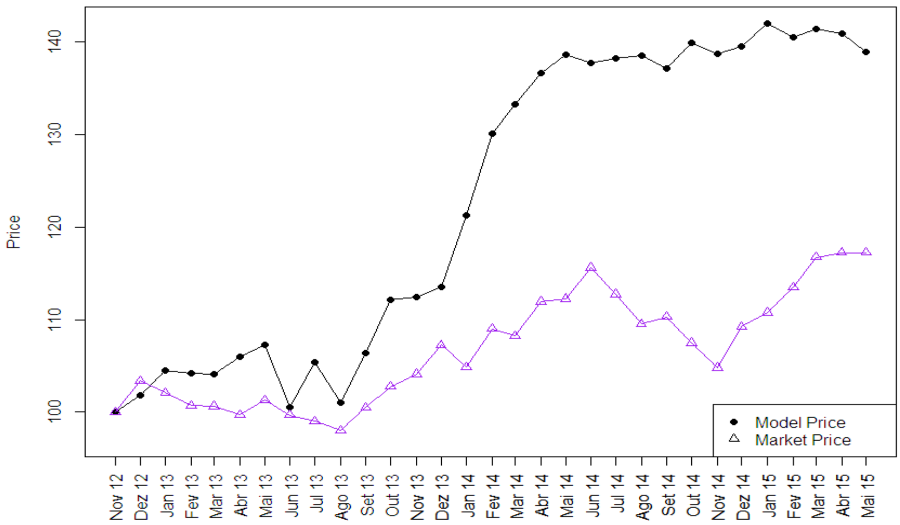


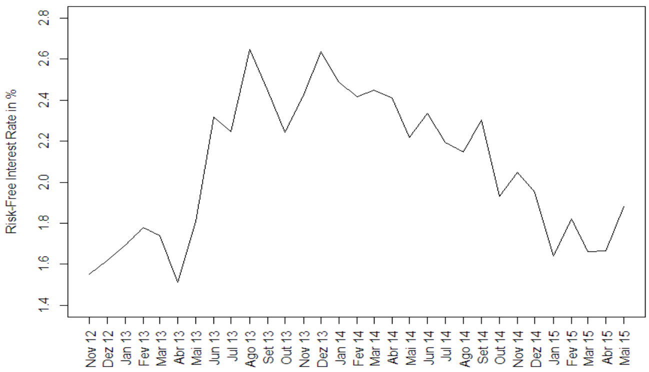
Figure A.4 - Barclays US06738EAA38 – Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.

Barclays US06740L8C27 – Pricing results and model parameters

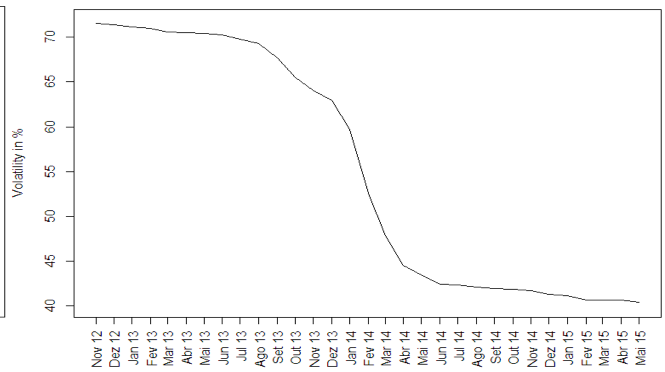
(a) Model vs. Market Prices



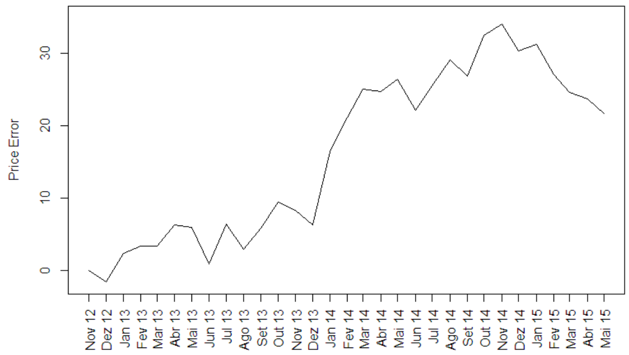
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

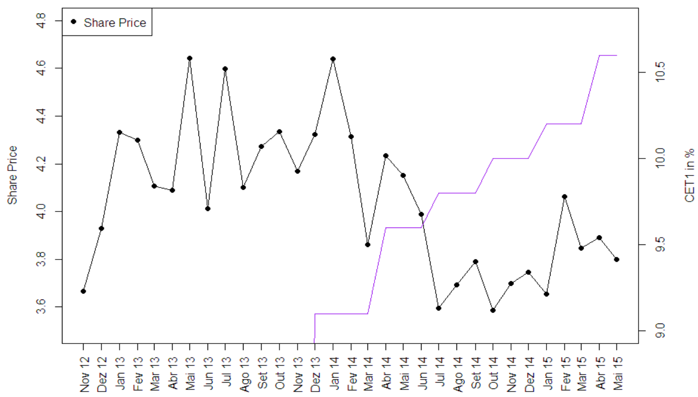
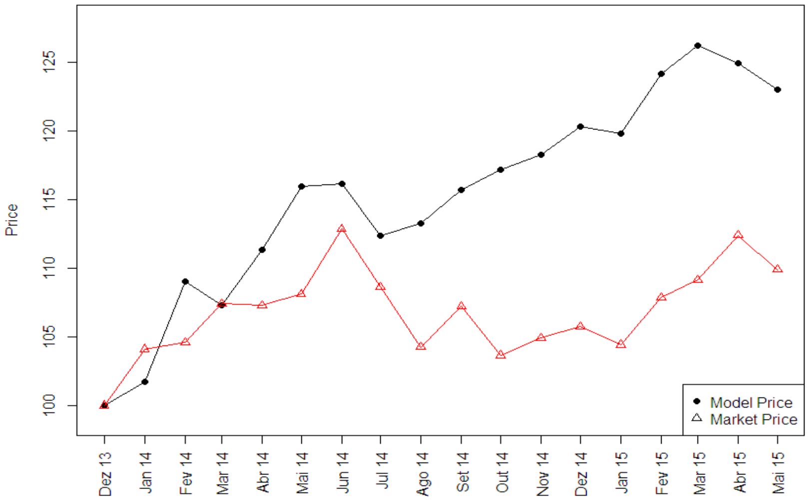


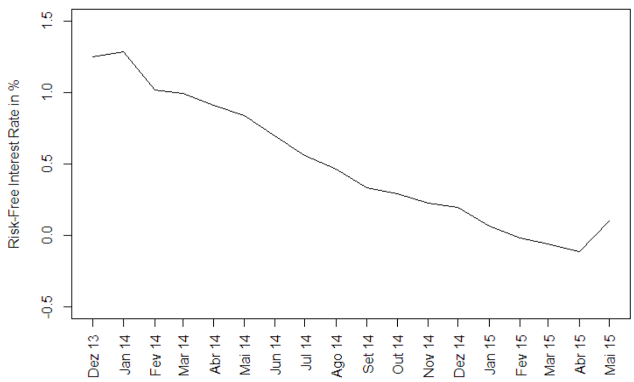
Figure A.5 - Barclays US06740L8C27 – Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.

Barclays XS1002801758 – Pricing results and model parameters

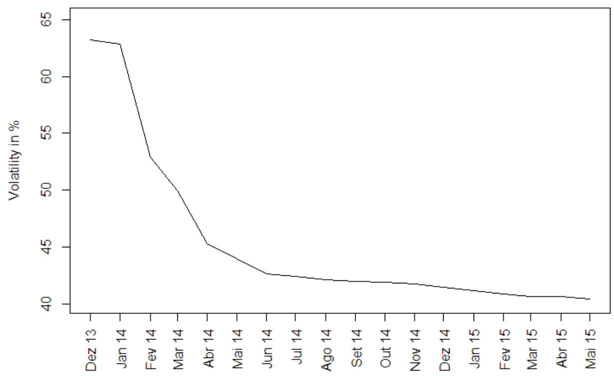
(a) Model vs. Market Prices



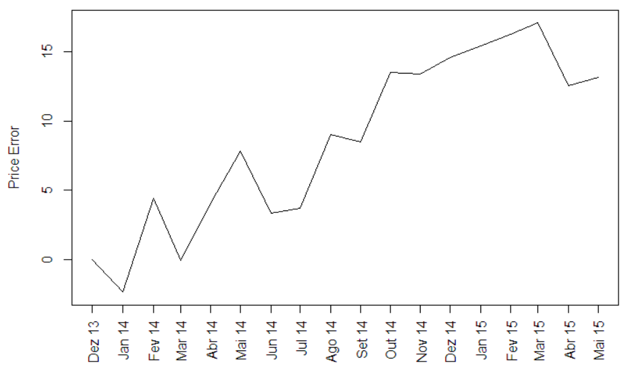
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

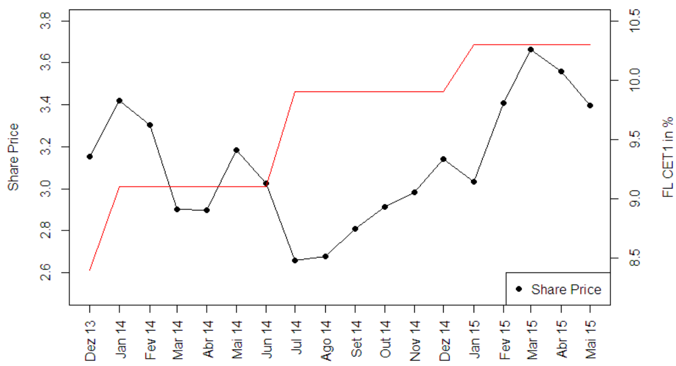
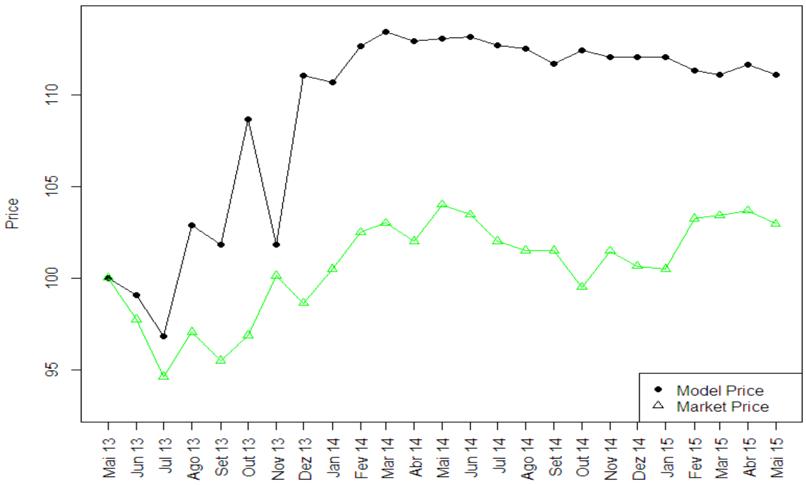


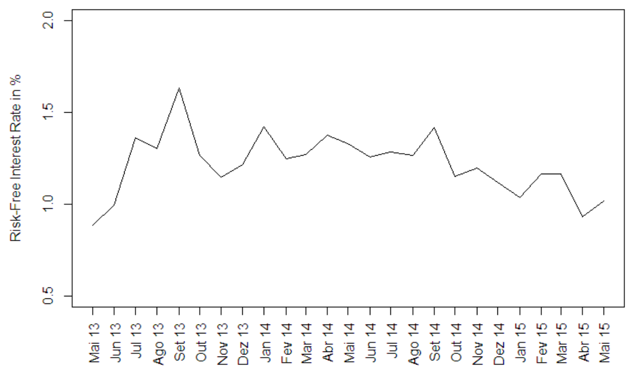
Figure A.6 - Barclays XS1002801758 – Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.

UBS CH0214139930 – Pricing results and model parameters

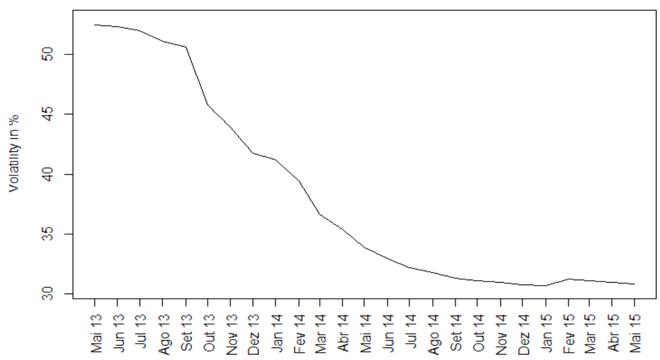
(a) Model vs. Market Prices



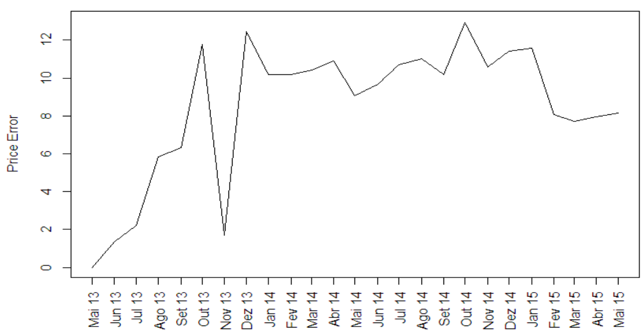
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

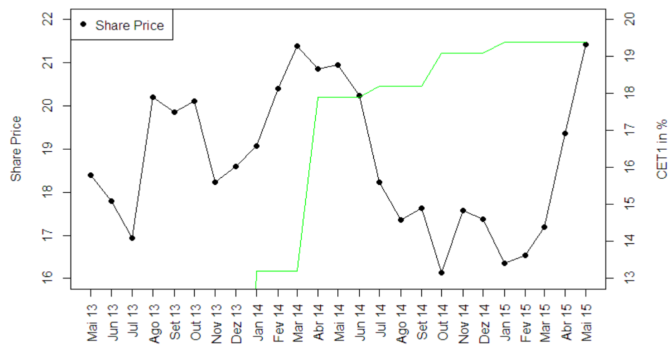
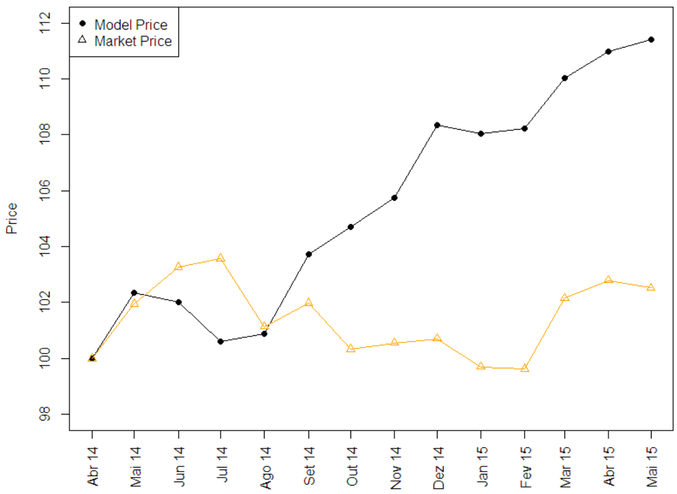


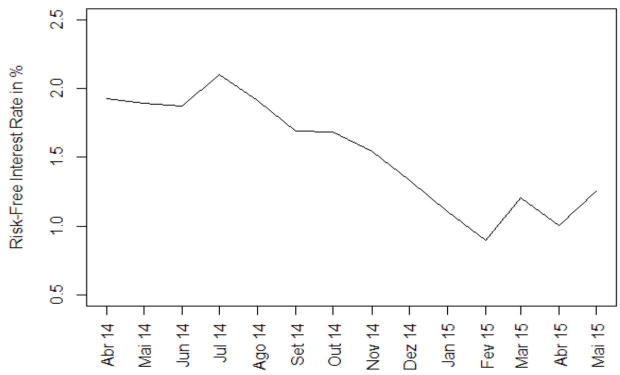
Figure A.7 – UBS CH0214139930 – Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.

Lloyds XS1043550307 – Pricing results and model parameters

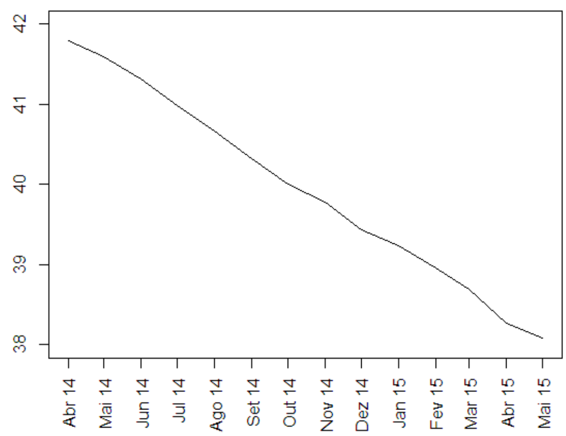
(a) Model vs. Market Prices



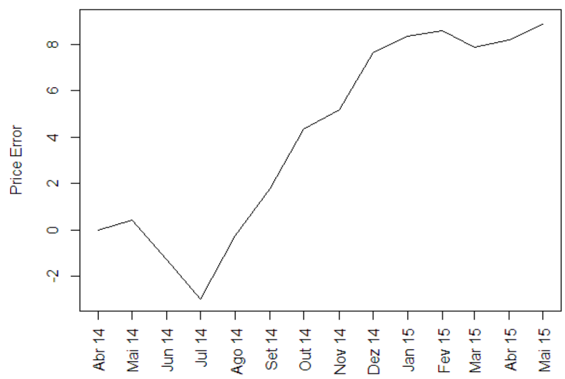
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

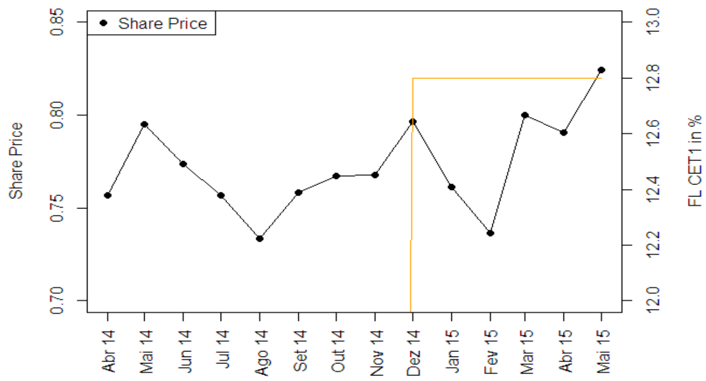
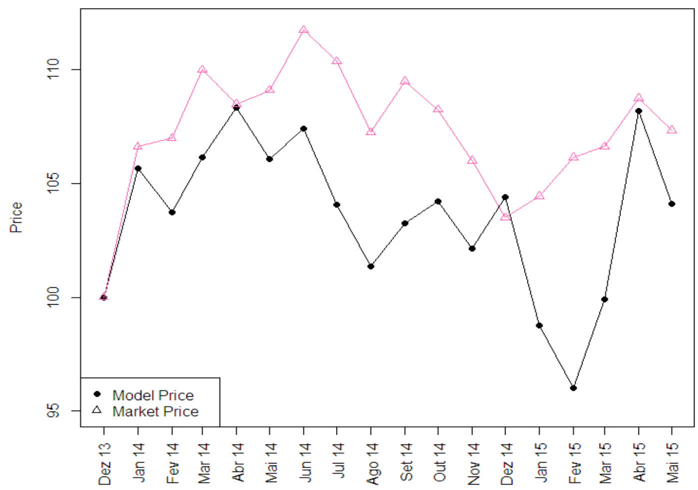


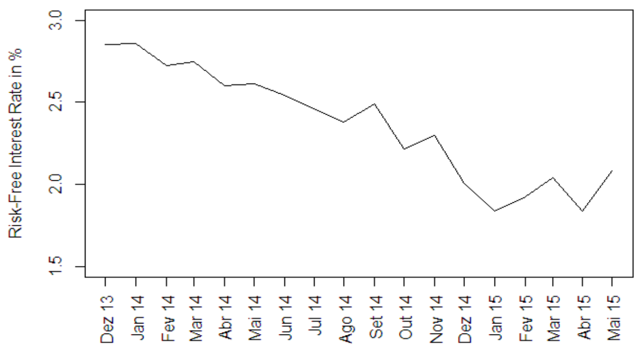
Figure A.8 – Lloyds XS1043550307 – Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.

Credit Suisse XS0989394589 – Pricing results and model parameters

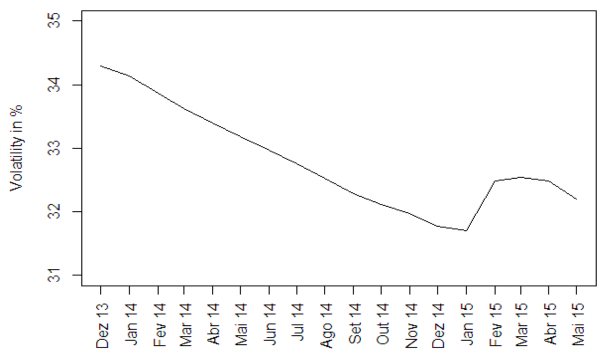
(a) Model vs. Market Prices



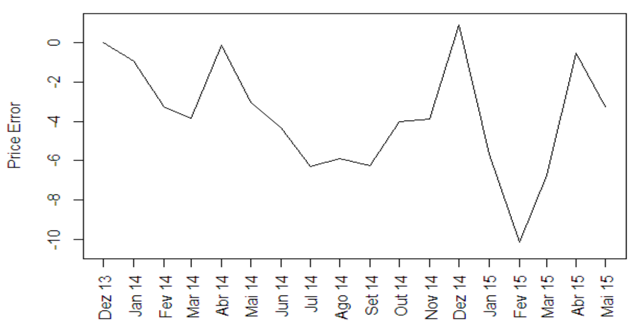
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

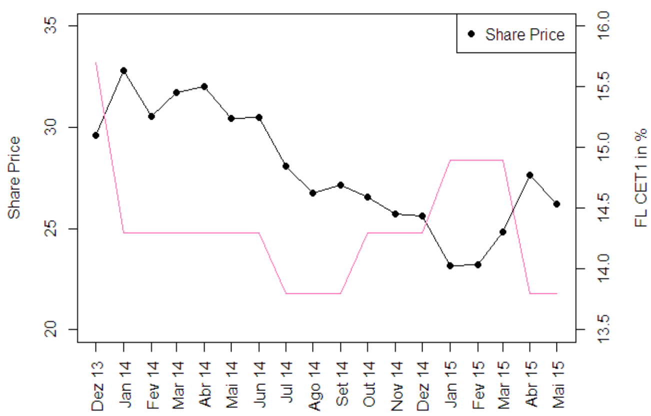
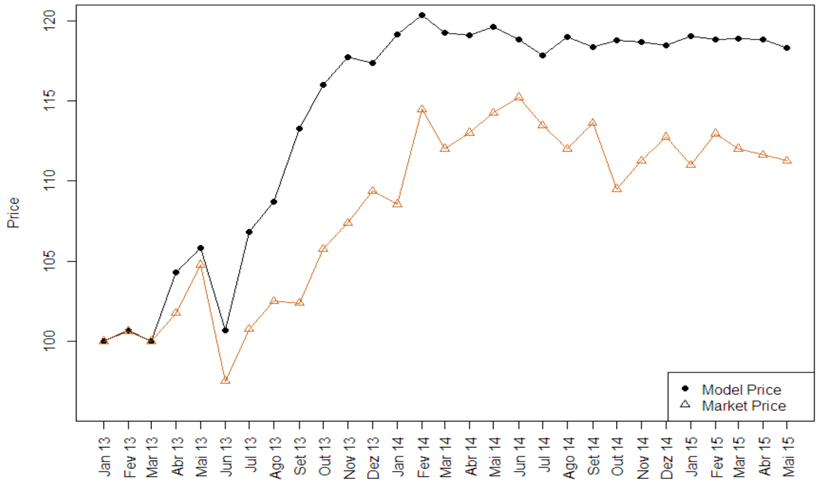


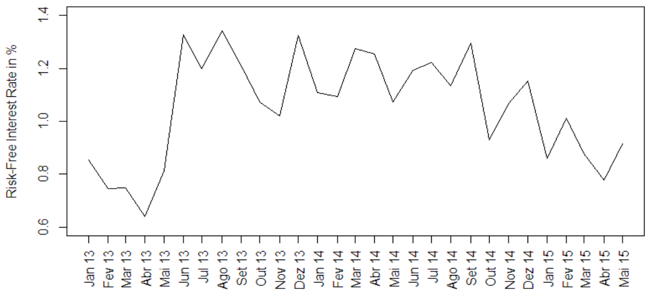
Figure A.9 - Credit Suisse XS0989394589 – Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.

KBC BE6248510610 – Pricing results and model parameters

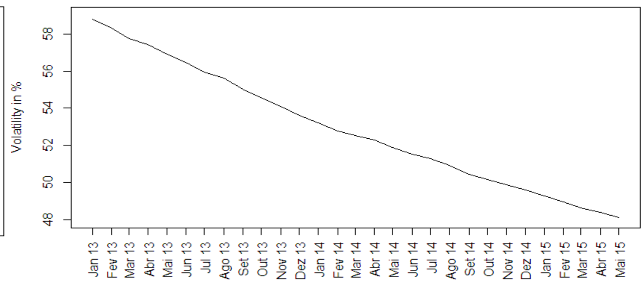
(a) Model vs. Market Prices



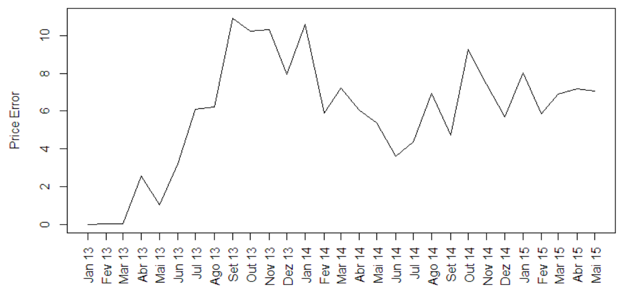
(b) Risk-free interest rates in %



(c) Five Year rolling volatility in %



(d) Price Error



(e) Share price and Capital Ratio Trigger

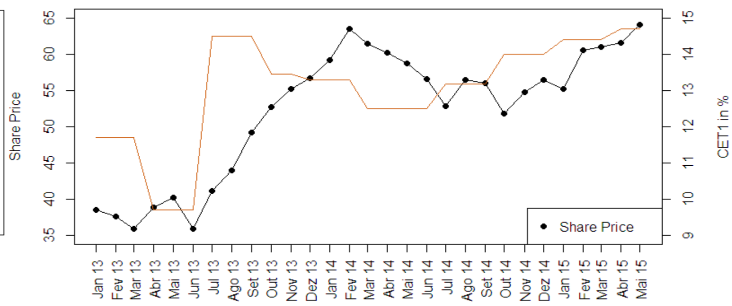


Figure A.10 – KBC BE6248510610 - Pricing results and model parameters: (a) Model v.s Market Prices; (b) Risk-free interest rates in %; (c) Five year rolling volatility in %; (d) Price error; (e) Share price and capital ratio trigger.