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BPI Consulting Project - "Structured Products"

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Abstract

This paper studies the best approach to valuing complex financial instruments, namely structured products. As part of a Consulting Project for Banco BPI, we aimed to develop an accurate and broad valuation model for this type of products, enabling the calculation of their Fair Value. To achieve this, we resorted to the Monte Carlo simulation model with appropriate Cholesky decomposition to predict price paths, which allowed for the computation of product cash flows and, consequently, respective fair value. These cash flows were segmented into repayment and return, which were then discounted to present value, resulting in the fair value at the valuation date. We started by benchmarking the current BPI portfolio of products and later enlarged the pool including other product characteristics present in major banks' offering assortment. It is believed that, even though the model as is includes all major characteristics present in current financial instruments offered by the industry, given the dynamism of financial markets and constant evolution of complex products, this model may need recurring adjustments and adaptations.

Keywords: Structured Products; Fair Value; Valuation

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1. Introduction

Grupo BPI (BPI) is an institution in the Portuguese banking scene. It comprises both *Banco BPI*, the commercial branch, and *Banco Português de Investimento* (BPI – Investimentos), the investment banking division. Its core business ranges from commercial and retail banking to investment banking, asset management and insurance and is spread across Portugal, France, Spain, Angola and Mozambique. As of now, it is the fifth largest financial group in Portugal.

Having BPI as a Corporate Partner of the Nova Finance Center (NFC) encompasses several initiatives such as training for BPI employees, annual conferences and consulting projects for Nova students. Every year, a group of students is selected to carry out a real-life problem, faced by BPI, as part of the Master in Finance's Work Project. Besides being an opportunity to apply the skills learnt during the curricular program, the students are given the opportunity to work alongside experts in the industry, with valuable insights and knowledge, whilst connecting to the business world early on.

This year the proposed challenge consisted of valuing structured products within the bank's offering. Mainly, these include structured products obtained from third parties and, thus, the main purpose is attaining their Fair Value. In doing such, one needs to question the base assumptions made by third party brokers which may be highly impactful in pricing complex financial products. By using the Monte Carlo simulation method to forecast price paths, it is essential to consider the influencers such as volatility, expected return and dividend yield. Regarding the products' payoffs, one needs to correctly understand the mechanics and how the effective return is distributed.

After the project kick-off in September, the initial phase consisted of analysing the prospectus and technical forms of active offerings as well as matured products within the

BPI portfolio. With this, we were able to categorize each product by common characteristics and start developing the payoff structures. In parallel, we studied the Monte Carlo simulation method and Cholesky decomposition in order to accurately preview the underlying assets' behaviour for the future. Later, we benchmarked the big banks worldwide (Goldman Sachs, JPMorgan Chase, Morgan Stanley, Société Générale, Citigroup, HSBC, Deutsche Bank, BNP Paribas) to collect further common characteristics of traded structured products in order to broaden the model. The final phase of the project included testing and calibrating the model as well as designing a holistic user manual.

The proposed deliverables are an excel valuation model accompanied by a user manual, in order to guarantee the usefulness and sustainability of the work at hand. The goal is to accomplish the challenge promoted by BPI: to create a generic model that can be used to price any structured product. The manual intends to provide to the user a rounded explanation about the proposed valuation model and is organized by sectors, following a similar distribution as the model itself. This guide will exhibit tips and best usage practices enabling any user to fully understand the model set-up and functionalities.

2. Theoretical Review

2.1 Structured Products

Structured products are over-the-counter (OTC) financial instruments which comprise different individual securities, derivatives, commodities, debt obligations or issuances assembled to allow investors to take exposure to an underlying investment of their risk-adjusted choice. In short, these investment vehicles take a traditional set or basket of securities and replace their usual individual payment components with a non-conventional payoff. Furthermore, these allow illiquid assets to be transformed into liquid assets and help investors to hedge against adverse market outcomes. Given that these instruments are often bespoke to suit the investors' needs, its pricing methodology is of extreme importance since a plethora of complex variables factor into the calculation of their price and thus only a fair analysis thereof can lead to sell the right product, at the right price, to the right investors.

The development, growth, and technological improvements within capital markets during the 80's decade together with the investment banks' obligations to satisfy the increasingly specialized investors' needs allowed market forces to intensify structuring activities within product designing activities. Physicist engineers, mathematicians and computer scientists started joining the financial services industry and started to develop a whole new investment trend, deepening financial engineering and securitization. Structured investments ascended from the companies' needs to issue debt more cheaply. This need led financial engineers to start creating convertible bonds and then they decided to add certain characteristics to the basic convertible debt securities such as an increased participation rates and income in exchange for limits on the stock's convertibility. The additional features in these types of securities were aimed at replicating strategies investors could perform themselves using individual derivative investments. The main objective when including these features within the structures was to lead investors to accept a lower interest rate on debt in exchange for future upside expectations. Thus, the Structured Finance market was created.

Structured Finance markets help companies to raise capital by creating or structuring these types of securities and then selling them to investors. The difference between the Structured Finance (SF) market and Debt Capital Markets (DCM) is that the latter deals with more "plain-vanilla" debt standard issuances while SF tools such as credit enhancement and bankruptcy remoteness are used to bridge the gap between a company corporate rating and an investment grade rating, making these securities less risky. The developments within the derivatives market and, consequently, the structuring technology improvements led to an increasing demand for this type of products in the final decade of the 20^{th} century.

In the last 20 years, Exchange-Traded Funds (ETF's) have been increasing its importance within the financial markets for both institutional and individual investors. These are often presented as a lower-cost option when compared to mutual funds, allow investors to diversify their portfolio and sometimes these instruments offer trading and arbitrage opportunities for investors. ETF's usually track the performance of a given Index, a basket of those, a commodity price, bond price, or a basket of asset such as an index fund. Thus, ETF payoff characteristics are similar to those in Structured Products, which consists of a challenge to the Structured Product market.

The developments of the Structured Finance market during the last two decades of the 20^{th} century came along with the improvements within the securitization market. Securitization is a financing technique by which a set of assets is sold by the originator of those assets to a Special Purpose Vehicle (SPV), which will finance the acquisition of the assets by issuing Asset-Backed Securities (ABS), which will be described in further detail in the following section. Usually, banks securitize some loans within its balance sheets for reasons that include risk management, balance sheet related issues, greater level of capital and to profit from the origination fees. Also, securitization promotes liquidity in the market place since it gives investors the possibility to invest in multiple assets which would not be accessible otherwise, such as student or car loans. The SPV issues different levels of debt, which are known as debt tranches that are then sold to investors. These tranches are gathered together by different factors including the level of risk for the tranche, the seniority of the debt investments or the maturity of the payments due for the tranche.

Due to the effects the Structured Finance market had in the Subprime Mortgage Crisis, nowadays, a greater legal assistance is needed to guarantee compliance with all the new regulations the issuers are obligated to comply with.

Market Participants

The structured products are usually bought, held and traded by institutional investors. These may include pension funds, insurance companies, banks and other financial institutions, non-profit institutions, asset managers, hedge and mutual funds. Institutional investors usually perceive structured products as an investment vehicle when other securities are not able to fit their investment needs. For instance, when a pension fund has a future liability stream whose payoff depends on different underlying assets in different markets, namely an equity instrument and a money market rate, it can never be matched by classical assets like single bonds. It requires a specific structure bespoke to suit the pension fund needs. Structured products will match the liability stream more accurately than other single investments, which is often the primary reason for institutional investors to acquire structured products. Draper and Shimko (1993) show that structured products are natural investment vehicles for institutional investors, who have particularly strong preference for non-linear payoffs due to the non-liner nature of the liability constraints they face. The results described in Goltz, Martellini and Simsek (2008) show that structured products are attractive for risk-averse investors, with a focus on downside protection, such as Pension funds.

Additionally, these may decide to invest in structured product to replicate investment strategies that would be impossible or too costly to perform with plain securities. On the other hand, private investors also have an ignited interest for structured products, however with simpler needs and targets. The rationale behind a structured product acquisition may be the expectation of achieving a higher yield than those offered in term deposits, or participating in the performance of an underlying asset while protecting their notional conditionally or unconditionally.

The sellers of a structured product belong to different types of institutions. The increasing volume of structured products in the market from the early 2000's allowed structured product sellers to flourish during the decade. Almost every financial institution participant in the banking sector was building and commercializing structured products for internal and external clients. The issuers are usually investment banks, although there are some independent structuring houses such as TFS Structured Products. Wholesale banks, retail and private banks, state-owned banks, brokers and finance boutiques were often in charge of commercializing these instruments. The increasing interest producing and commercializing Structured Finance products was the profit margin the issuer was able to achieve. Usually, a mathematical model (just like the one this project designed) determines the "fair value" of the product at the issuance and then the issuer applies a spread to the final price. The spread is not only the issuer's profit for manufacturing the product and structure but also the payment for the service the issuer has to deliver for the lifetime of the product, such as providing secondary market prices, listing costs, term-sheet production, settlement, and hedging, among others. Hedging, in this case means the trading activities the issuer must perform during the lifetime of the product to match the Cash-Flows during the lifetime of the product. Product issuers try to hedge as much risk as they can. In more complex structures issuers cannot hedge all the structured product risk and therefore the profit can only be determined at maturity. Nevertheless, under usual market conditions, the spread the issuer determines at issuance is sufficient to cover the hedging risks, but under a market crash, losing all the margin seems inevitable if the bank uses Delta Hedging to cover its positions. Under a continuous time-frame, if a given event triggers an instant increase (or decrease) in the price of a security therefore producing a price gap, Delta Hedging metrics are not able to avoid or to detect this gap in a security's price. In order to offset some of the structuring's risks, the issuer is interested in having the largest possible trading book to attain cross-hedging risks. Some of the products might cancel out in terms of risk. For instance, if a financial institution issues a call warrant and a discount certificate on the same company, with the same maturity and strike price, the risks are reduced due to the short volatility position of the warrant is offset by the long volatility position in the discount certificate. This happens since the issuer sells the warrant's embedded call and thus is short volatility and the discount certificate has a payoff profile similar to a put which is the reverse in terms of volatility exposure for the issuer.

Although there will always be differences in the structured payment of each product, one is able to identify different types of structured products, depending on the nature of underlying asset:

- **Equity-linked:** linked to the return verified in a single share, basket of shares or equity indexes, such as the EuroStoxx 50 or the S&P500 Index;

- **Bond-linked:** tied to the return of a single bond, basket of bonds, bond index or a basket of those, such as the Merrill Lynch Global Bond Index or the Barclays Capital Aggregate Bond Index;

- **Interest rate-linked:** designed to be connected to a specified floating interest rate, such as LIBOR. These investments are presented as an alternative to traditional fixed or floating rate bonds. These structures allow investors to bet on the performance of a benchmark interest rate potentially achieving abnormal returns. Benchmark interest rates are the lowest rate investors will accept for a non-sovereign debt investment. It can be described is a money market interest rate plus a premium.

- **Currency-linked (FX):** track the performance of a single currency, a basket of those or an index that already tracks the performance of that currency, such as the Dollar Index;

- **Commodity-linked:** track the performance of commodity prices such as oil, gold, sugar or orange juice

- **Credit-linked:** related to the credit quality of a specified entity or group of those. In the case of a triggering event where the entity becomes insolvent or defaults on its loans, the return to the investor may be impacted. Usually, these securities have an embedded Credit Default Swap (CDS) and are issued under an Special Purpose Vehicle (SPV) and allow the issuer to transfer the credit risk to institutional investors, which are paid off with a fixed or floating coupon rate during the life of the note. More complex structured involved within this category are Asset

Backed Securities (ABS), and Collateralized Debt Obligations (CDO), whose value is derived from and backed by a pool of underlying assets, such as auto loans, student loans, credit card receivables and mortgages and investors are compensated with the debt interest payments. The SPV issues different tranches of debt with different features, namely its credit rating and yield. The most common tranches within the structures are: senior, mezzanine and junior or equity tranches. Technological improvements and creativity within the structurers' activity allowed the creation of synthetic CDO's, whose tranches receive payments from cash-flows in Credit Default Swaps. Issuers are expected to receive a form of payment in the event that the debt holder defaults on its loan.

- **Hybrid-linked:** the underlying assets are based on different asset classes. For instance, the product's payoff may depend not only on the performance of a given equity index but also on gold prices, foreign exchange rates or debt. These securities are often issued to provide investors with wider diversification possibilities, protection against inflation and arbitrage among distinct asset classes. The structures within hybrid products can be designed to set a strategy to take a long-position on a given undervalued asset class and a short position in another one. For instance, a Reverse Convertible payoff, which will be explained in further detail in section 3, can be replicated by taking a long position in one Zero Coupon Bond (ZCB) with reverse exchangeable, a long position in ZCB's that have the same face values and maturity dates the reverse exchangeable coupon payments and a short position in one put option with a given exercise price equal to the exchangeable, with the same maturity as the other two positions.

In terms of payoff and notional investment structure, structured products may be further divided in three main categories: Structured Deposits, Capital Protected Products, and Structured Capital-at-Risk Products (SCARP's).

Structured Deposits

This group of structured products comprises fixed-term deposits combined with investment products. Structured Deposits often include the protection of the capital initially invested and couple a return on the deposit which depends on the performance of an underlying asset such as market indices, shares, commodities, interest and FX rates or a combination of these. If the product has a principal protection feature embedded it can be replicated as an investment in a Zero Coupon Bond for pricing purposes. The potential payoff may further depend on the "participation rate", which defines how much of the gain in the underlying asset, index or benchmark will be credited to the deposit, and a "cap" (or limit) on the gains earned based on the performance of the underlying assets.

Structured Deposits allow investors to achieve higher potential returns compared to fixed-term deposits in a low-yield environment by determining the payoff by assessing the price fluctuations verified in a different security. These can be particularly appealing in a low-yield environment. Structured Deposits may also be suitable for investors who want somewhat protected exposure to assets that are not easily accessible for retail investors.

Capital-Protected Products

Structured Capital-Protected products are similar to Structured Deposits to the extent that these are designed to at least return the original capital at maturity. Capital-Protected instruments should not be confused with Structured Deposits or other conservative investments that may also have a capital protection or guarantees. The main difference between Capital-Protected products and Structured Deposits is that the former is often structured as a loan to a financial institution, which is the issuer of the structured product. Additionally, Structured Deposits are usually subject to a Government's deposit guarantee, depending, of course, on both the amount deposited and the specific country's regulation, meaning that in the event that the issuer goes bankrupt or defaults on its loans, the investor will be receiving his deposit amount entirely. In a Capital-Protected product the initial invested capital is not completely secure (no guarantee associated because it does not use a deposit structure). Therefore, in certain extreme conditions, the issuer may be declared insolvent leading to losses on the investment. Capital-Protected products, again given the nature of the underlying assets, are nonetheless more liquid investments than Structured Deposits.

Structured Capital-at-Risk Products

Structured Capital-at-Risk products (SCARP's) are instruments that provide an initially agreed amount of income or growth as well as an exposure to a series of market outcomes in relation to the return on the initial capital. Typically, these products combine a "safe" and a "risky" asset into a single structure and the level of capital returned to the investor depends on the performance of the underlying assets, which may belong to one of the asset classes described before. As in Capital-Protected products, SCARP's are not a deposit and most often take the form of loans to banks or other financial institutions. Generally, these investments yield the highest return-on-investment (ROI), since there is always the possibility to achieve additional returns. As in Capital-Protected products, investors should be expecting to achieve a higher rate of return when compared to the other two subclasses of structured products. In addition, the risk that the capital invested can be lost in adverse market conditions, since many capital at-risk products may return no level of income if there is a large setback in the capital markets. For instance, a product may be designed to protect the initially invested capital if the underlying asset falls by 50%, but if it falls beyond that barrier, the repayment of the notional value will not occur. This feature is usually called the product's "barrier".

Furthermore, an additional characteristic that needs to be pointed out is the redemption level within most types of structured products. The redemption level is the limit or cap to the returns an investor may achieve. This is a clear downside to the investment in these products as growth is capped at a fixed return rate and therefore the upside of these investment products is limited to the amount specified initially.

When investing in a SCARP, an investor should be expecting to receive a premium for taking a greater risk when compared to other subclasses of structured products. Although many SCARP's may protect capital unless there is a huge slump in the financial markets, the capital return is dependent on the fluctuations in the underlying asset.

Risks

Structured investment products across different types and asset classes carry more or less the same risk factors. Although these may differ within its intrinsic features, the uncertainty around the product lies on the same factors.

The first risk factor to consider is the variable pricing factors, namely, changes in the implied volatility of the underlying assets could have an impact on the fair value of the instrument. Also, the value of the investment product is also dependent on variable interest rates, which suggests that the products are subject to interest rate risk. For interest rated linked products, the payment structure may change completely if interest rates have an undesired performance. Additionally, since the risk-neutral framework is applied throughout the pricing process, the fair value of the products is subject to changes in interest rates and these may affect the direction of the Cash-Flows within the structured products. An increase in interest rates may depreciate the fair value of these investments since these may be unattractive when compared to other investments offering higher yields. Also, dividend yields comprise an additional risk to equity-linked structured products due to its inclusion in the Geometric Brownian Motion (GBM) procedure, which is described in further detail in the following section. Therefore, the fair value of the security is subject to a wide number of factors, which can vary independently and in opposite directions which will always affect the final price or repayment scheme of the structured product.

The safety barrier within each structured product represents a risk to the investor, since the repayment profile can change completely. The probability that the structure's underlying assets will cross the barrier level increases as the underlying instrument starts to approach the barrier level. Thus, the intrinsic value of a structured product may decline considerably before it even crosses the barrier level. An additional source of risk comes from the inability the investor may face to reinvest his money if the product is redeemed before maturity. In some cases, the investor may not be willing to transfer his money to other products or deposits with less attractive interest rates. Therefore, investors may be subject to a particular type of reinvestment risk if there is no possibility of reinvesting the proceeds initially invested in the product at a higher rate in other asset classes or structured products.

Some structured products, due to their particular features, have a leverage factor embedded in the structure. Therefore, these products may be disproportionately stimulated by changes in the underlying assets. The effect of leverage allows investors to receive more than 100% of the upward or downward movements in the underlying asset price. Additionally, some structured products do not guarantee any interest or dividend payment during the life of the product but only at maturity. This brings an extra source of uncertainty for investors, that need to tie up their capital until the product matures to see if it will yield some return or not.

The durability of a structured products, i.e. its lifespan, is limited. The perks and rights acquired when investing in these products can lose value or cease to exist upon maturity. As the time to maturity decreases, there may be the case that the greater the risk of a loss in value because there is not much time left for the speculation to pay off if the embedded options in the structure are significantly out-of-the-money. If the options are in-the-money, this loss in value may not be enough to trigger the product's barrier future and therefore this risk is reduced as the embedded options are increasing its in-the-money features. In addition, if the structured product is issued in a given foreign currency, investors will bear an additional foreign exchange rate risk due to the exposure to the value of that currency. In other words, even if the local currency instrument yields a positive return, the investor may still bear losses from a potential foreign currency depreciation.

From a legal point of view, the investor is exposed to the credit risk of the structured product's issuer. If the structure's issuer faces difficulties in meeting its payment dates and amounts or becomes insolvent and the invested capital is not protected, the investor will lose not only his notional amount but also the future periodic payments of the structured product. Therefore, the lower the credit quality of the issuer, the higher the level of risk within the product, since governments sometimes do not back up the issuer's liabilities for more complex structures such as Asset Backed Securities or CDO's.

Another embedded risk in these structures is the liquidity risk. Due to its product-specific features, these instruments are far less liquid than plain equity or debt investments. The more complex the structure is, the more difficult it is to sell it and the larger discount should be offered to the current price to realize the product instantly.

2.2 Monte Carlo simulation

Structured products gather basic financial products and derivative instruments together. Consequently, the price fluctuations of the underlying assets derive their final payoff and price. The groundwork of this model lies on trying to derive the products' expected future cash-flows. Since the future behavior of the financial markets is overwhelmed unknown factors, uncertainty plays a key role in pricing these complex instruments.

In order to solve for problems that might be deterministic one needs to randomize the future behavior of the asset prices with the purpose of getting a more complete valuation metric able to simulate different price paths, taking into account the infinite number of uncertain factors that drive the individual asset prices and their correlations. The Monte Carlo simulation method is a stochastic random process that models the probability of different outcomes. It is used in processes that cannot be easily predicted, due to the presence of random variables. In other words, it aims at randomizing the behavior of specific inputs whose future behavior cannot be rationally or quantitatively explained and predicted. In this specific case, the goal is to model the possible behavior of different underlying asset prices, which determines the cash-flows provided by the structured product, and consequently its price. Additionally, Monte Carlo simulation methods assume that asset prices follow a Random Walk (RW). A RW is a mathematical object that describes a path composed of a succession of random steps on some mathematical space. The assumption that asset prices follow a RW allows for the introduction of the Efficient Market Hypothesis (EMH), a financial theory that states asset prices are correct and these fully reflect all available information about the asset. Therefore, in a RW, the best forecast of future performance is today's price.

A crucial assumption needed to be performed for this simulation method is that investors are rational and therefore their decision-making process aims at optimizing the level of their utility or welfare. Consequently, these may also be assumed to be fully characterized in the mean-variance space. Subsequently, returns need to be assumed to follow a probability distribution when attempting to model their future behavior. The underlying product's yields are assumed to follow a normal distribution. Consequently, asset prices follow should follow a log-normal distribution. The Gaussian distribution is often used due to its genuine frequency in real world events. Iconic asset pricing empirical research such as the work performed by Black, Scholes and Merton (1973), the paper written by Fama and French (1993) or the work completed by Deng, Husson and McCann (2012) assume that stock returns follow a standard distribution. Additionally, the Central Limit Theorem (CLT) can also be directly applied, which states that physical quantities that represent the sum of many small independent processes are approximately normally distributed. This allows for other types of probability distributions to be approximated to standard normal distribution, easing the analysis. So, even if a given asset follows a different and unknown probability distribution, it can be approximated to a Gaussian distribution if the number of observations has a considerable size, usually higher than 30 observations. Therefore, the probability distribution of returns is the following:

$$\Pr(a < r < b) = \frac{1}{\sqrt{2\pi}} \int_a^b \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right) \quad (1)$$

where μ is the expected rate of return per time unit and σ^2 is the variance of the respective time frame used. For an infinitesimal standardized time interval, the change in value of the asset may be described as the difference between the different prices, and the return is this difference divided by the initial price. This is equivalent to a random variable q that is Normally distributed with average μdt and variance $\sigma^2 dt$. Therefore:

$$\frac{S_1 - S_0}{S_0} = q(dt) \sim N(\mu dt, \sigma^2 dt) \lll=\ggg z = \frac{q(dt) - \mu dt}{\sigma\sqrt{dt}} \sim N(0,1) \qquad (2)$$

which leads us to:

$$dS = S\mu dt + S\,\sigma z\sqrt{dt} \qquad (3)$$

However, we should find that this approach allows for the possibility of achieving negative future prices:

$$\Pr(r < -1) = \frac{1}{\sqrt{2\pi}}\int -\infty \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right) > 0 \qquad (4)$$

Therefore, it needs to be adjusted, meaning that for infinitesimal returns a simple Taylor expression can be computed such that:

$$\ln(1+r) \approx r - \frac{r^2}{2} \Rightarrow r \approx \ln(1+r) + \frac{r^2}{2} \qquad (5)$$

which is equivalent to:

$$\ln(1+r) + \frac{r^2}{2} = \ln\left(\frac{S_t}{S_0}\right) + \frac{r^2}{2} = q(t) \sim N(\mu t, \sigma^2 t) \qquad (6)$$

This condition allows for the conclusion that returns are log-normally distributed.

In order to derive the future behavior of the stock prices and consequently its returns, a stochastic process needs to be defined to model the future behavior of the stock prices and consequently its returns. A stochastic process is aimed at defining mathematically the probabilistic evolution of a variable throughout time. In the case of asset prices and returns, the stochastic process associated with it is usually a Markov process. Empirical research related to this topic can be assessed in Frohm (2005) and Deng, Husson and McCann (2012). These processes are supported by the Markov property, which is usually categorized as "memorylessness", meaning that the predictions for the variable are based only on current information, being independent from its past behavior.

The stochastic process that will be applied throughout the whole model is a Wiener Process, a particular type of a continuous-time stochastic process. This procedure states that any increment in the variable we are simulating, in this case the stock price, is Gaussian with mean 0 and a positive variance and the values of this increment for any two short intervals of time are independent. The mean change per time frame for a stochastic process is known as the *drift*, which states the expected value of the variable and a variance per unit of time, usually known as the *variance rate*.

The most common Wiener process used to model stock prices in the Monte Carlo simulation methods is the Geometric Brownian Motion (GBM), which is a continuous-time stochastic process. Within this procedure, the logarithm of the random variable follows a Wiener process with a drift. Since the variable being simulated is the assets' prices, which can never be negative, the GBM process is the most widely used model for stock price behavior. Again, due to the limited public research regarding Structured Product pricing, the group based its decision of applying a GBM procedure after research, replicating the work performed Frohm (2005) and Deng, Husson and McCann (2012). The discrete-time version of the model is:

$$\Delta S = \mu\Delta t + \sigma\epsilon\sqrt{\Delta t} \tag{7}$$

The variable ΔS is the change in the stock price in the time interval Δt. The μ is the expected return on the stock associated with the respective period Δt. Sigma is the volatility of the stock price and ϵ is a random variable. The left-hand side of the equation is the approximation of the return on the asset in a period of time equal to Δt. The right-hand side of the equation can be divided in its *drift*, which is $\mu\Delta t$, or the expected value of the asset's return, plus the *variance rate*, or $\sigma\epsilon\sqrt{\Delta t}$, the stochastic component of the return. Since the ultimate purpose of the Monte-Carlo simulation methods is to project future stock prices, the logarithm of the previous equation should be taken to obtain the log-normal distribution the asset prices are assumed to follow [1]. Thus, the stock return is given by:

$$Ln(S_t) - Ln(S_0) = (\mu - \sigma^2)dt + \sigma z\sqrt{t} \quad (8)$$

which leads to:

$$S_t = S_0^{\left(\mu-\delta-\frac{\sigma^2}{2}\right)\Delta t+\sigma\epsilon\sqrt{\Delta t}} \quad (9)$$

where S_t is the future randomized price, S_0 is the current (initial) price, Δt is the time-step, ϵ is the random draw from the standard normal distribution, σ is the underlying asset's implied volatility, μ is the expected risk-free return and δ is the stock's dividend yield.

Monte-Carlo Variables

The most important variables to be analyzed are both the asset's implied volatility and the risk-neutral expected return, since the other inputs are straightforward and do not need to be incurred in a deeper analysis.

Implied Volatility: An asset's implied volatility is the volatility level for the stock implied by the option's price and the market. In other words, it is an option's intrinsic feature and it states the value of the volatility of the underlying asset which, when plugged in as an input in an option pricing model, such as the Black-Scholes model, gives the market price of the option. Implied volatilities are used to track the market's opinion on

[1] *Applying Itô's lemma to compute the process followed by the asset price, it can be shown that a variable has a lognormal distribution if the natural logarithm of the variable is normally distributed. Itô's lemma is a way of computing the stochastic process followed by the variable itself.*

the volatility of a given asset. By appraising considerable disparities in supply and demand, implied volatility represents the expected fluctuations of an underlying asset over a specific period, equal to the maturity of the option being analyzed. This supply and demand shocks can be derived by a variety of factors, which may be either market-wide events or news precisely related to a single asset or company.

Another alternative measure of volatility is the asset's historical volatility. The historical volatility measures past fluctuations in asset prices, while implied volatility gauges expectations for future volatility, which are translated into options premium. Also known as statistical volatility, it is easier to compute. The main disadvantage when compared to forward-looking volatility is that it assumes the future stock prices will fluctuate the same way as its current behavior, which does not seem reasonable to assume. Therefore, if instead the model had historical volatility as an input, market memorylessness would not hold and therefore neither the Random Walk assumption nor the Efficient Market Hypothesis would be in place. In addition, historical volatility requires the assumption that price shocks are constant or continuously have the same sources of risk. Since the goal of simulating asset prices with both Monte-Carlo methods and Wiener processes is to simulate the individual future asset market prices based on current variables, implied volatility seems more accurate than historical volatility when forecasting future prices.

Expected Return: The underlying's expected rate of return is equal to the risk-free rate. Due to the structured products' option structure, the pricing of these instruments also settles into the principle of risk-neutral valuation. The risk-neutral world leads investors to require the same rate of return independently from the amount of risk they take. Therefore, agents do not require a risk premium. One may wonder about the reasonability of investors, since risk tastes may be perceived to affect derivatives' prices. However, risk preferences are revealed to be insignificant when pricing an option in terms of the underlying asset. The reason is that the option is not valued in absolute terms, but it depends on the price of the underlying asset. Thus, the expectations of upcoming gains or losses are already combined with the price of the underlying, and under no arbitrage market opportunities investors should expect to get their return equal to the risk-free rate.

Risk-neutral valuation allows intuitive results to be applied, since the expected return on the asset is the risk-free rate and therefore the discount rate used for the expected payoff of the embedded option is also the risk-free rate. The above stated reasons support the Binomial model, whose replicating portfolio technology is composed of both the number of shares of stock of the underlying asset and the amount invested in risk-free deposits. The same applies to the Black-Scholes model, whose equation does not involve variables affected by risk preferences of investors.

One of the other remaining variables within the Monte-Carlo process are the **time-step**, which defines the drift and it is the time-frame applied to the pricing procedure as a percentage of one year. For instance, if the underlying asset moves daily and the pricing scheme is performed on a daily basis, the time step is equal to 1/365. However, these may not be the case since the denominator depends on one's assumptions regarding the trading years to assume. The group has assumed a total number of 365 trading years, but it can be easily adjusted for other type of assumptions.

An additional variable included in the process is the **dividend yield** of the company's stock. Since it directly affects the stock price – the amount paid in dividend is subtracted from the security's price – one needs to take into account when randomizing the future stock performance.

Lastly, the **random draw** from the normal distribution is also a component within the Geometric Brownian Motion equation. Since stock prices are assumed to follow a log-normal distribution, a random draw from the probability distribution that describes the behavior of the variable is also introduced in the equation. The random draw is replicated into Excel by using the RANDOM() function, which refreshes the value from normal distribution when the model is operating, therefore simulating different possible pricing scenarios.

2.3 Cholesky decomposition

The correlation between two (or more) underlying assets damages the previous assumption of stock returns being normally distributed, since two samples are required to be independent from each other, meaning correlation must be zero. Therefore, a Cholesky decomposition needs to be applied to generate two (or more) uncorrelated Gaussian random variables. Cholesky's factorization allows the assets' correlation matrix to be decomposed, and gives the lower-triangular L of the matrix. For instance, two correlated samples *n1* and *n2* are correlated with each other are required, and therefore two independent univariate normal distribution samples *z1* and *z2* are obtained. The required samples are then calculated as:

$$n1 = z1$$
$$n2 = \rho z1 + z2\sqrt{1-\rho^2} \tag{10}$$

in which ρ is the coefficient of correlation. For *n* correlated samples from normal distributions, the required samples are then defined as:

$$n1 = \alpha_{11} z_1$$
$$n2 = \alpha_{21} z_1 + \alpha_{22} z_2 \tag{11}$$
$$n3 = \alpha_{31} z_1 + \alpha_{32} z_2 + \alpha_{33} z_3$$

where α_{ij} are coefficients chosen so that the correlations and variances are correct. This process starts by setting $\alpha_{11} = 1$, chooses α_{21} so that $\alpha_{11}\alpha_{21} = \rho_{21}$, α_{22} is such so that

$\alpha_{21}^2 + \alpha_{21}^2 = 1$, choose α_{31} so that $\alpha_{11}\alpha_{31} = \rho_{31}$, α_{32} is so that $\alpha_{31}\alpha_{21} + \alpha_{32}\alpha_{22} = \rho_{32}$and chooses α_{33} so that $\alpha_{31}^2 + \alpha_{32}^2 + \alpha_{33}^2 = 1$.

Therefore, the random samples n_i need to be adjusted by the Cholesky correlation matrix coefficients, α_{ij}, thus generating independent and identically distributed random samples.

3. Methodology

In this work project, we constructed a model to price structured products that were, are or can be transacted by BPI. This model is constructed to forecast, on a daily basis, the possible price paths of the underlying assets based on the Monte Carlo simulation, using as inputs current market information. Depending on the inputs inserted, the model sets different mechanisms according to the product's typology, adjusting the information and computing the expected value.

3.1 First step: Data research

To deliver a functional and efficient model, three main questions needed to be addressed in a primary phase: What are the characteristics of the structured products transacted by BPI and by the market in general? How can one properly forecast the price's evolution of the underlying assets? How can one construct the model to incorporate the effect of the correlation between underlying assets?

The data source of the structured products (SP), namely the information sheets (factsheets), were in part provided by the BPI team whilst the remaining were downloaded from the following financial institutions' websites: JP Morgan, BNP Paribas, Morgan Stanley, Goldman Sachs, Société General, CitiGroup and HSBC (see Section "Bibliography" for detailed information). This dataset provided the typology of the product and other characteristics such as asset class of the underlying asset, transaction currency, payoff details as well as the issuer details and legal information. All material was collected between September and October of 2017.

Reflecting the empirical exercise, we opted for the Monte Carlo simulation as a numerical procedure for valuing derivatives. As previously mentioned, this technique involves using random numbers to simulate many different paths that the asset price may follow, in a risk-neutral world. For each path, the payoff was computed and discounted at the risk-free interest rate. The arithmetic average of the discounted payoffs is the expected value of the derivative.

Moreover, the model used an algebraic procedure - the Cholesky decomposition, useful for Monte Carlo simulations. This procedure allows to remove correlations among the variables, in other words, it transforms a set of correlated variables (base scenario assumed in the Monte Carlo without the addition of Cholesky factorization) into independent variables.

3.2 Second step: Data Analysis

Two principals were followed when sorting available data, to ease the construction of the model:

1 – Build a model as generic as possible, allowing BPI to price products that are not currently within their portfolio;

2 – The base information should come with an existing price tag, this is, with a respective price available to subsequently calibrate and refute the model and avoid erroneous results, due to lack of information.

The data collected was grouped and systematized in a table (please refer to appendices 1 and 2 for detailed information). This data was examined and treated, to plan the model's calculus mechanism and truly replicate the payoffs. Many of the characteristics found in the products were used and combined, allowing for a larger set of scenarios.

3.3 Third Step: Modelling

This empirical model attempts to answer the main question: What is the fair price of a specific product?

We started by developing the Monte Carlo simulations, as these would provide the future prices to be used in computing the payoffs. Since simulating prices for past dates when real prices are already available is incorrect, an adaptation was made. Thus, we sourced from Bloomberg the last trading prices for days since issuance until the current day (when the product is being valued) and from there started simulating future prices, until maturity.

Using the values from the previous step, we established performance sheets, computing the performance the underlying assets for the required period. The criteria chosen to evaluate such performance was left at the user's preference (this will be explained in Section 4.2), once more allowing for a broader model.

Finally, we calculated the expected cash flows and, consequently, the fair price of the product. Generally, the payoff of a structured product may be expressed by the following equation:

$$Payoff = Notional\ Value + Fix\ coupon + Variable\ Coupon \quad (12)$$

This was the foundation for the model's progress. The process was slightly different for products that contain floating interest rates as an underlying asset, as it will be explained in Section 3.5 – Product Scope.

The model was delineated to accommodate characteristics as early redemption, accumulation of coupons and other requisites specific to the typology of each product like barrier(s) or coupon rates. After all the features/conditions of the product are inserted, the model uses the underlying assets projected performance (previous step – Monte Carlo Simulation) to calculate investors cash-flows in each scenario and point in time. The average of those cash-flows should then be discounted to their present value.

In parallel, a manual to navigate the model was created, with all the steps and mechanisms explained. It should serve as an auxiliary document to help the user understand the mechanisms and usability of the model, and how to avoid errors, taking the best use of this tool.

3.4 Calibration and Design

In a development phase, since Monte Carlo simulations are a time-consuming process, the number of trials were often between 100 and 500. This low set of paths were mainly to control and detect errors in the formulas and confirm their output.

At a later stage, the number of trials met the market requirements of 10,000. Here, the price was the focus, where differences lower than 1% to the reference price (prices provided to calibrate the model) can be easily explained by the spread applied by the bank. However, differences larger than 1% raised a red flag and could be explained by errors in the formulas or, assuming that the formulas were correct, by the sensitivity to the assumed inputs such as volatility, correlation and discount rate. The understanding of the source of the gap between results was key to improve and calibrate the model.

Finally, the model's design aimed to be clear and user-friendly as well as provide error protection. The former was attained through clear division of different areas of inputs, consistent formatting and explanation of the inputs area through the cover sheet to guide and help the user. The error protection was achieved through color coding input cells and input messages, to make data insertion more intuitive and minimize wrongful data insertion. Also, validation tools were made available to alert the user in case of such wrongful inputs or lack thereof.

3.5 Products Scope

The data collection and analysis enabled us to gather eighteen different characteristics which will be explained in this section. The explanation of the model itself (inputs, engine and output) is delineated in section 4.

Autocallable

Autocallable is a feature that can be applied to structured products. This characteristic enables early redemption, meaning the issuer may call the product before its set maturity date if pre-established conditions are met during the lifetime of the product. Such pre-established conditions refer to a fixed level within which the underlying asset(s) performance may fluctuate and that, whenever crossed, will trigger the autocall. In case of this happening, the contract will cease, the investor receives full invested amount and a coupon, whose value is also contracted initially. This type of feature is applicable to many different structures and exotic options that can have multiple underlying assets such as stocks, equity indices, and baskets of stocks, funds, ETFs or commodities.

Consider an Autocallable Note with face value of €1,000.00. The underlying asset is a stock and pays an annual coupon of 5%. Finally, consider that there is an Autocall level of 125% and a 2% coupon in case of early redemption. If, on any valuation date, the value of the reference asset (stock) is more than 125% of its initial level, the note will be redeemed and the investor will receive full notional plus 2%, totaling €1,020.00.

Capital Protection

A note with this feature is called a Capital Protected Note and, as the name indicates, the initial investment is guaranteed at maturity, acting as a safeguard to the investor. This still allows for exposure to the reference assets in the form of variable return depending on the underlying performance, surrendering this way some potential income related to the underlying.

Asian

The outstanding feature of Asian products is their unique method of determination of the strike and final prices. In order to smooth away large end-of-period price oscillations, Asian products use the average price over a predetermined period as the final price for coupon determination purposes. Since this averaging reduces the inherent volatility of options, Asian options and products are usually cheaper than their European and American counterparts. The final price can be an average of the spot prices throughout the whole period or just for a predetermined number of days. Similarly, the averaging method can also be applied to the strike reference price. In each coupon payment date, the product will make a payment equal to:

$$Max(Notional * \frac{Final\ Price}{Reference\ Price} * Participation\ rate; 0) \qquad (13)$$

where at least one of the prices is computed as the average price over a certain period. Usually, the Asian feature is only applied to either the final or to the reference price, it is not very common for a product to feature both.

Basket

A Basket is an investment strategy that manages risk while exposing the investor to a mix of markets and underlying assets, such as equity indices, stocks, currencies, interest rates or commodities. The basket performance is the weighted average performance of its individual components and has, at maturity, a final payment that can be made into a combination of calls (positive performance) or puts (negative performance). When calculating its payoff, it is important to know the participation rate and also the barrier for comparing the individual performances of the components. An example of such structure would be, if the weighted value of individual components at a certain determination date is above the barrier, the basket pays 100% of notional plus the participation rate multiplied by the amount by which the basket exceeds the barrier. If the basket performance is below the barrier at the determination date, only part of the notional value will be recovered. For instance, for a barrier of 110%, if the value of the basket at maturity is 120% of its initial value, inserting a participation rate of 150% would result in an additional payoff of 15% (i.e. 150% times the 10% by which the basket exceeded the barrier).At maturity, the payoff of this product is given by:

$$\begin{cases} If\ Basket\ Performance < Barrier: Notional * Basket\ Performance \\ If\ Basket\ Performance > Barrier: \\ Notional * (100\% + Participation\ rate * (Basket\ Performance - Barrier) \end{cases} \quad (14)$$

Best/Worst

This type of product pays the invested return principal plus a percentage of the return of the basket elements, with weights directly linked to the ranking of their returns.

The basket return is the weighted sum of the returns of the underlying assets, where generally the first weight corresponds to the best performing asset and the last weight corresponds to the worst performing asset, with those weights being predefined.

At each moment of observation, the asset with the best performance, the second-best performance and so on, are established and the respective return is multiplied by a corresponding percentage, resulting in a weighted average of the performances, providing this respective payment.

$$Cash\ Flow = \sum_{i=1}^{5} \text{i}th\ best\ performance\ asset\ weight$$
$$* performance\ of\ the\ \text{i}th\ best\ asset\ in\ the\ basket \quad (15)$$
$$* Notional\ Value$$

Booster

A Booster structured product assumes an increased participation in the underlying asset, which is limited by two pre-defined barriers levels. Its main difference from other similar products is that the lower barrier is below the current stock market level. This means that the investor could gain a positive return at maturity if the index is flat or down. Nonetheless, there are a couple of risks associated with this product. For example, if the underlying price rises above the up barrier, there is a chance that this structure underperforms the underlying since there may exist a cap to its returns. Furthermore, the capital could also be at risk if the underlying price falls below the down barrier since all can be lost or only a small part redeemed. Comparing this product to simply owning the underlying, the investor is taking on less risk since he/she benefits from the protection of the underlying price changing between the barriers, but he/she is giving away any potential return above the up barrier.

The payoff of these products is basically defined at each determination date, and it is dependent on the underlying asset's relative position to the barriers. Note that in case of multiple assets, the reference is the worst performer. Therefore, to pay maximum return, all underlying assets need to be above the barrier; to pay out intermediate return, all underlying assets need to be above the Down Barrier whilst the worst performer is below the Up Barrier; and finally, to pay minimum return, it is only required that the worst performer is below the barrier. The payment in each of the branches can be either *performance dependent:*

$$Notional\,Value * Min\ of\ the\ underlying\ assets * Participation\ Rate_{(i)} \qquad (16)$$

where Participation Rate$_{(i)}$ stands for the participation rate in each branch.

Or a *fixed coupon*:

$$Notional\,Value * Coupon\ Rate_{(i)} \qquad (17)$$

where Coupon Rate$_{(i)}$ stands for the coupon rate in each branch.

Cliquet

A Cliquet is a product composed of a series of consecutive forward start options which has a cumulative payoff at maturity date. At issuance, the first forward start option is immediately active, with a settled strike price. At its maturity, a second forward at-the-money start option becomes active, and so on. Thus, this product periodically settles and resets the strike prices, allowing the investors to lock-in profits on the underlying. This means that the payoff comes from the performance of the underlying during the product's life, locking in the gains periodically. More specifically, if at the option's maturity the underlying rose above its original price (=strike price) the investor keeps the gain, and the new strike price is set as the new observed price. On the other hand, if the underlying fell, no profits are locked in, but the accrued profit is kept, since the strike price also reset to that level new level. Cliquet structures may as well provide fixed coupon rates. Given the two payment options, the product's payoffs are given by:

If performance,

$$\begin{cases} Notional * Participation\ rate * \dfrac{Price(t)}{Price(t-1)}, if Price(t) > Barrier * Price(t-1) \\ 0, if\ Price(t) < Barrier * Price(t-1) \end{cases} \qquad (18)$$

If fixed coupon,

$$\begin{cases} Notional * Coupon\ rate, if Price(t) > Barrier * Price(t-1) \\ 0, if\ Price(t) < Barrier * Price(t-1) \end{cases} \quad (19)$$

Defensive Supertracker

Some structured products specify a maximum return than can be paid should the market rise. They are, thus, denominated as capped products, which have limited return even if the underlying asset rises more. An example of this type of product can be one that guarantees the initial investment at maturity, plus any growth in the underlying asset, subject to a maximum return. More specifically, let's assume an initial investment of €1,000.00, 100% participation rate and a cap of 40%. If the performance of the underlying is +150%, the return of the product will be €400.00.

There are several other conditions that may be considered in such category of products. One can include a performance multiplier, which enhances return, and also determine an initial reference level below 100% (one may name it as Lower Bound) based on which performance will be determined. In this case, the investor can be compensated even when there is a small downfall in the underlying asset's behavior. For example, consider a financial instrument that evaluates growth of the underlying from 90% of the initial level, has a performance multiplier of 1.5 and where the underlying ends up falling by 5% at maturity. Its return will be $(95\% - 90\%) * 1.5 = 7.5\%$.

It is important to note that if a product tracks growth and limits returns it is defining a range for performance levels. Therefore, the upper level of the range can be defined as:

$$Upper\ Bound = \frac{Cap}{Performance\ Multiplier} + Lower\ Bound \quad (20)$$

Generically, these products have imbedded growth returns and are subject to evaluating the performance of the underlying assets between initial and end dates. With this information, one can conclude the due return for the investor as defined below:

$$\begin{cases} \text{If Performance} > \text{Lower Bound}: \\ Min([(\text{Performance level} - \text{Lower Bound}) * \text{Performance Multiplier}]; \\ [(\text{Upper Bound} - \text{Lower Bound}) * \text{Performance Multiplier}]) \\ \text{If Performance} < \text{Lower Bound}: 0 \end{cases} \quad (21)$$

Floating Rate

Floating Rate Notes pay coupons based on the performance of an underlying interest rate. The coupons are normally paid quarterly, semi-annually or yearly. These products are very versatile and may be of several different types:

Floored Floaters are structured in such a way that if the underlying rate is lower than the predefined floor, then the value of the coupon is determined by that floor. They protect investors from large decreases in interest rates, by guaranteeing that a minimum amount will be paid.

Capped Floaters are essentially floating-rate notes paying coupons only up until a pre-specified maximum level of the underlying rate. This product is composed of a vanilla note with an embedded cap, which serves as a protection to the issuer in case of large increases in interest rates.

Collared Floaters include both the previous features and can be best described as floating-rate notes whose coupon payments are subject to an embedded collar. Thus, their coupons are capped at a predetermined level, meaning that the buyer sacrifices some upside value, but is also floored, which, on the other side, offers protection from a downturn in the reference interest rate. This product has in its specifications a minimum and a maximum interest rate, maintaining its fluctuations subject to a specific range. It can also be referred to as a mini-max floater.

It can be structured with an initial coupon and include other features such as being callable, having a spread added to the rate or having this rate multiplied by a scaling factor.

In order to price Libor 3m-index structured products, instead of Monte-Carlo simulations, the method used is based on payoff replication and the no-arbitrage principle. By replicating the future payoff of each future coupon with securities whose value is known today, it is possible to know the present value of each of those coupons. The replication of the coupons depends on the type of product: free, floored, capped and collared floaters.

Free floater

$$PV(Coupon_t) = PV(Libor_0) + Call\ option_{K=Libor_0} - Put\ option_{K=Libor_0} \quad (22)$$

In addition to the value of the Libor rate today, the call option guarantees that, at coupon date, the investor will receive any increase the Libor rate, while the put option guarantees the payoff will be reduced by any decreases. Since they have the same strike price, they will never offset each other.

Floored floater

$$PV(Coupon_t) = PV(floor) + Call\ option_{K=floor} \quad (23)$$

The present value of the floor guarantees the investor receives the floor value at the coupon date, while the call option guarantees the investor receives the amount by which the Libor rate exceeds that floor. By the no-arbitrage principle, the cost of these two components must be the same as the present value of the coupon.

Capped floater

$$PV(Coupon_t) = PV(cap) - Put\ option_{K=cap} \quad (24)$$

While the present value of the cap guarantees that the maximum the investor may receive at the coupon date is the value of the cap, the short put option will reduce the payment by the amount by which the Libor is below that level. The maximum the investor may receive is the value of the cap, which happens when the Libor rises above that level and the put option expires worthless.

Collared floater

$$PV(Coupon_t) = PV(floor) + Call\ option_{K=floor} - Call\ option_{K=cap} \quad (25)$$

Up to the level of the cap, the intuition is the same of that behind the floored floater. The present value of the floor and the long call option with the same strike guarantee that the investor receives, at the coupon date, an amount equal to the floor value, plus the amount by which the Libor exceeds that floor. If the Libor rate reaches the cap, the short call option will offset any Libor increases beyond that value, effectively triggering the cap.

Given the inexistence and/or illiquidity of call and put options for the desired strikes and maturities, the value of the call options is computed using the Black-Scholes model for Eurodollar futures, a Libor based derivative contract, whose price is expressed as 100 minus the 3 months U.S. Dollar Libor interest rate. Puts are consequently found through the Put-Call forward parity.

Income Accumulator

This product makes periodic payments depending on the closing level of the underlying asset on weekly observation dates. The observations are usually recorded on the same week day the payment is due (for example, every Friday if the coupon payment is due on a Friday). It exhibits this nomenclature because the periodic coupon payment will depend on the portion of weekly observations in which the underlying asset finishes within a certain range (say between 95% and 105% of the initial price). This product is then appropriate for an investor that expects the underlying asset to be stable over the product's life. Each coupon is computed as:

$$Coupon = \frac{Number\ of\ weekly\ observations\ within\ range}{Total\ weeks} * Periodic\ Coupon\ rate \quad (26)$$

For example, assuming quarterly coupon payments, a periodic coupon rate of 6% and Friday as the weekly observation day, if the underlying asset finishes within the pre-defined range in 8 out of the 12 Fridays, the coupon will be equal to $\frac{8}{12} * 6\% = 4\%$.

Knock-Out

A Knock-Out is a kind of barrier option, as it terminates when the underlying asset's price surpasses some predetermined barrier level, automatically expiring the instrument even before maturity. Regarding return, it sets a cap to which level the option can reach, limiting the profit potential for the investor. As with plain vanilla options, Knock-Out options can be of European or American type. There is also the possibility of boosting/limiting leverage through the use of a payoff multiplier, which will enhance/limit the standard payoff of the option. The daily expected payoffs of the options are the same regardless of their type, and are simply calculated as:

$$Call = (Spot\ Price - Strike) * Multiplier \quad (27)$$

$$Put = (Strike - Spot\ Price) * Multiplier \quad (28)$$

Multi-Barriers

There are structured products that during its lifetime change the value of some characteristics such as the barrier. To describe this type of products, we used the expression Multi-Barriers given the fact that, at different periods of the financial instrument's life, the barrier is different.

The main idea behind the payment is the following: at each determination date, it checks if all of the underlying assets values are above the correspondent barrier level for the specific date. If this happens, the coupon payment is:

$$Notional\ Value * \ Coupon\ Rate_{Above\ Barrier} \tag{29}$$

Otherwise, if at least one of the assets is below the barrier level, the coupon payment is:

$$Notional\ Value * \ Coupon\ Rate_{Below\ Barrier} \tag{30}$$

Note that the barrier level can change yearly, semester, quarterly or even monthly.

Multi-Rates

Multi-Rates is a designation chosen by us to define a type of structure that pays a certain coupon, regularly or at maturity, based on how many underlying assets have fluctuated above or below a certain level. For example, consider a €1,000.00 notional value European instrument, with three underlying assets and a barrier level of 90% of the initial level. If at maturity none trade above the barrier, the coupon is 0; if only one trades above the barrier, the coupon is 1%; if two trade above the barrier the coupon is 2%; and, if all trade above barrier level, the return is 5%. Let's suppose that at maturity, two out of the three underlying assets are trading above the barrier. The coupon paid is 2% and hence the total return for the investor is €20.00.

Outperformance

This product can be seen as a two-factor option that provides the investor the right to receive the outperformance of one (main) underlying asset over another. The adequate investor is the one that expects prices to diverge. For example, if an investor considers that an index will outperform another, he could buy this product since it pays a coupon equal to a participation rate times the outperformance of the main index over the other. For example, with a participation rate of 50% and a difference in performances of 10%, the resulting coupon is 5% of the notional value. At each determination date, the value of the coupon will be determined by:

$$Max(Participation\ rate * Performance\ Difference; 0) \quad (31)$$

where

$$\begin{aligned} &Performance\ Difference \\ &\quad = Performance\ of\ Asset(1) \\ &\quad - Performance\ of\ Asset(2) \end{aligned} \quad (32)$$

And stands for the difference in performances of the main and the other underlying asset. In case the main underlying fails to outperform the other, there is no coupon being paid.

Phoenix

Phoenix Notes pay either monthly, quarterly or semi-annually coupons if the underlying assets do not fall below a predetermined barrier. Furthermore, they offer the possibility to pay or lock-in a fixed return as long as the underlying stays above the aforementioned level. In terms of its payoff, for each observation date, it observes the worst performing underlying. If it is above the barrier, the investor receives the due coupon, otherwise it pays a different coupon rate.

These products normally have an autocallable feature as well as an accumulator option for when coupons are not paid at a given payment date but can be paid on the following. For example, imagine a Phoenix option that pays 2% if above barrier or 0% if below. At T=1, the investor got a coupon of 2% because the underlying crossed the barrier, but in T=2, given that the underlying asset didn't pass the barrier, the compensation was 0%. If the accumulator option is embedded, then in T=3, this investor has the possibility to recover the coupon that was not paid in T=2. If the underlying asset passes the barrier, investor receives 2% plus the coupons that were not paid before, thus, the investor would receive a total of 4%. When compared to the Autocallable Notes, they offer a lower yield since they are designed to pay cash-flows on a more regular basis

The representation of such product is fairly simple. When all the underlying assets surpass the barrier then, the coupon will be:

$$Notional\ Value * \ Coupon\ Rate_{Above\ Barrier} \tag{33}$$

Otherwise, the payoff will be:

$$Notional\ Value * \ Coupon\ Rate_{Below\ Barrier} \tag{34}$$

Reverse Convertible

A reverse convertible note is a product which comes with downside exposure to a specific underlying security, while also providing a coupon. Typically, a reverse convertible note consists of a principal component linked to a performance component, which normally is a stock. Its primary feature is its enhanced yield. The note pays a coupon that is usually higher compared with fixed income securities of comparable maturities. It is also important to mention that in exchange for a higher coupon, the investor must be prepared to accept the risk of losing some or all of the principal amount at maturity and, unlike investing in the reference asset itself, this structured product appreciation potential is limited to the coupon amount. In addition to the fixed coupons, the note pays, at maturity, the principal amount or something less depending on the performance path of the underlying asset throughout its life. More specifically, the principal amount will be reduced by the percentage decrease in the underlying asset (and will either be paid in cash or shares of the underlying asset, at the issuer's discretion). There are two critical features for determining the principal value received at maturity: the strike price and the protection level, which is slightly below the first. In case the protection level is never breached during the life of the note, the investor will receive the full principal amount. If the underlying asset happens to fall below the protection level during the life of the note, but manages to finish above the strike price, the investor will still receive the full principal amount. The only case in which the investor will not receive the full principal amount is the case in which the protection level is breached during the note's life and the underlying asset is below the strike price at maturity. The final payment may be then summarized as:

$$\begin{cases} \text{If Protection Level is never breached OR Underlying asset} > \text{Strike Price: Full principal amount} \\ \text{If Protection level is breached AND Underlying asset} < \text{Strike Price:} \\ \dfrac{\text{Final share price}}{\text{Initial share price}} * \text{Principal amount} \end{cases} \quad (35)$$

Stellar

A stellar structure pays the investor a coupon on each determined date with the particularity that this coupon is variable and dependent on the performance of the underlying asset(s). It is, thus, the arithmetic average of the performance for all underlying at the determination date. In case all underlying assets lost value and the average is negative, the coupon rate is null and the investor receives nothing.

Furthermore, this type of product usually has a coupon cap which means that there is a maximum level of return. Accordingly, if the arithmetic average of performances is higher than the cap, the return is capped at the predetermined level. Following, all possible outcomes are exposed:

$$\begin{cases} \text{Arithmetic Average} > \text{Cap}, & \text{Coupon} = \text{Cap} * \text{Notional} \\ \text{Cap} > \text{Arithmetic Average} > 0, & \text{Coupon} = \text{Arithmetic Average} * \text{Notional} \\ \text{Arithmetic Average} < 0, & \text{Coupon} = 0 \end{cases} \quad (36)$$

Twin Win

This instrument has a potential to have, at maturity, a payout that is based on by how much the underlying rise or fall over the period. As a participation product, it has 100% participation on either the upside or the downside, in absolute terms. To illustrate, consider a Twin Win product tracking a stock. If the stock, at maturity, has risen by 10% the investor will receive 10% return. If at maturity it represents 90% of initial value (10% decrease), the investor will still receive 10% return.

However, this gain is limited to a pre-determined barrier called Protection Level. This is, if the value of the underlying falls below this level at any point during the product life, Twin Win structure will alter into a certificate tracking the underlying asset and, thus, putting the investor's capital at risk. Consider again the Twin Win product tracking a stock. Assume that it has a protection level of 25% below spot. If, during the life of the instrument, the stock falls 30%, the Twin Win structure transforms and, if at maturity the stock has dropped by 10% the investor will incur in a 10% loss.

There are, again, several restrictions available to alter a classic Twin Win instrument. For example, one can place a cap to the upside participation, calling it a Capped Twin Win. Additionally, one can consider the variant Worst-Of Twin Win. Here, with more than one underlying asset, the lowest performing asset is considered the defining asset for calculating returns.

Below, one can understand, in a more schematic way, this product's payoff structure:

$$\begin{cases} If\ Lowest\ Performance > Cap{:}\ Cap * Notional\ Value \\ If\ 0 < Lowest\ Performance\ < Cap{:}\ Asset\ Performance * Notional\ Value \\ If Protection\ Level < Lowest\ Performance < 0{:}\ |Lowest\ Performance| * Notional\ Value \\ If\ Lowest\ Performance < Protection\ Level{:}\ Lowest\ Performance * Notional\ Value \end{cases} \quad (37)$$

Adjusted Performance

Structured products with the adjusted performance feature have a particular way of calculating its payment features. As in any other structured product, a notional amount needs to be invested and there are two main payment features: fixed guaranteed remuneration and variable non-guaranteed remuneration. The payments are only performed at maturity and the fixed guaranteed payment is usually a small percentage of the product's notional amount. Additionally, the notional amount is guaranteed at maturity and the variable non-guaranteed return is calculated according to the following formula:

$$\begin{aligned} &Var.Payment \\ &\qquad = Notional * Participation\ Rate \\ &\qquad * Max[0\%, Adjusted\ Performance] \end{aligned} \quad (38)$$

where

$$Adjusted\ Performance = \frac{Performance}{Adjustment\ Factor} - 1 \quad (39)$$

where

$$Adjustment\ Factor = Higher\ Level\ 1 * Higher\ Level\ 2 \quad (40)$$

where the higher level equals the highest observed level on a given interval of observation dates. The level at a given date is equal to today's price divided by the initial price. The underlying instrument is usually an equity index, however the structure may also be subject to different kinds of assets such as commodities or foreign exchange rates. Therefore, if the Adjustment Factor is higher than the performance of the underlying asset during the lifespan of the structured product, there will be no variable remuneration and investors will only be compensated with a small coupon rate at maturity.

The table below, which shows the performance for the S&P500 during two years, provides an easier understanding about the mechanics of this product. The product comprises two observation date intervals: from month 1 to 12 and from 13 to 24:

Month	Price	Change (%)	Level	Month	Price	Change (%)	Level
1	1549.00	3.51%	1.0351	**13**	1635.00	-0.53%	0.9947
2	1510.00	-2.52%	0.9748	**14**	1604.00	-1.90%	0.9810
3	1679.00	11.19%	1.1119	**15**	1610.00	0.37%	1.0037
4	1895.00	12.86%	1.1286	**16**	1697.00	5.40%	1.0540
5	1638.00	-13.56%	0.8644	**17**	1791.75	5.58%	1.0558
6	1749.00	6.78%	1.0678	**18**	1683.50	-6.04%	0.9396
7	1744.00	-0.29%	0.9971	**19**	1697.75	0.85%	1.0085
8	1613.00	-7.51%	0.9249	**20**	1648.00	-2.93%	0.9707
9	1719.00	6.57%	1.0657	**21**	1666.00	1.09%	1.0109
10	1705.00	-0.81%	0.9919	**22**	1574.25	-5.51%	0.9449
11	1621.00	-4.93%	0.9507	**23**	1546.50	-1.76%	0.9824
12	1643.75	1.40%	1.0140	**24**	1444.25	-6.61%	0.9339

Exercise Price	1496.5	**Final Price**	1444.25
Fixed Coupon (per notional value)	4%	**Performance**	0.9651
Multiplier	50%	**Adjusment Factor**	1.1917
Max Level [1,12]	1.13	**Adjusted Performance**	-19.01%
Max Level [13,24]	1.06	**Variable Coupon Payment?**	NO

Table 1 – Adjusted Performance example

Since the product's Adjusted Performance was lower than zero (-19.1%), the variable coupon payment feature was not triggered. So, an investor that has invested 1000€ would only receive the notional value plus the fixed coupon component of 40€. However, if the Adjustment Performance component was higher than zero the investor would receive the additional variable payment described in the above formula.

Factor x Performance

This denomination was created with the purpose of characterizing all products whose coupon is variable and computed by multiplying a predefined multiplier factor (participation rate) and the underlying assets' performance, over a specific period. Although this is a common type of payment scheme for structured products that are transacted by the major financial institutions, it is normally conjugated with an early redemption feature, the reason why they are often simply called Autocallable.

The coupon payoff is defined at each determination date and dependent on how many underlying assets are above the barrier. There are several available scenarios such as:

If all assets are above the barrier, then the payment will be:

$$Notional\ Value * Participation\ Rate * (Lower\ performance\ underlying\ asset - 1) \quad (41)$$

If a maximum return (Cap option) is applicable, and surpassed, the payoff is:

$$Notional\ Value * (Maximum\ Return - 1) \quad (42)$$

Lastly, if one of the underlying assets falls short of the barrier level, then the payment will be:

$$Notional\ Value * Max\ (0, (Lower\ performance\ underlying\ asset - 1)) \quad (43)$$

The principal's value will depend of the product's nature. It may be full protected or have a downside exposure leading to losses if the performance is below the barrier level.

4. User Manual

The model has been built for and is intended to be used by BPI staff and management. It is assumed that its users know how to operate Microsoft Excel, understand its functions and are familiar with the base assumptions used in pricing structured products. For its perfect functioning, it is required that the Microsoft Excel has active add-ins such as Analysis ToolPak – VBA and Bloomberg Office Tools.

The model, due to intricate calculations and consequent large size, was split into various different excel files. The "0. Model Core" file is the only one that needs to be open. It is recommended that the user opens this document, provides the required inputs (explained in section 4.1), triggers the Monte Carlo simulation macro (explained in section 4.3), calculates the price using the button "Price", extracts an Output sheet (explained in section 4.2) and closes the document by pressing the button "Close Model", thus avoiding saving all price paths which will increase the document's size. The excel files included in the model are explained below.

- *0. Model Core* – This excel file is the model's principal file. It is the only one intended to be opened by the user and contains the IO sheet and the main engine sheets required for valuation, for example, Monte Carlos Simulation computation sheets (MC_Asset1, MC_Asset2…) and performance computation sheets (CF_Asset1, CF_Asset2…).

- *1. Asian; 2. Basket; (…); 17. Adjusted Performance; 18. Factor x Performance* – These excel files perform the computation of the selected type of product. They contain Fixed Coupon, Notional Value, specific coupons, Sum Up and Price sheets. These files are not meant to be open as an excel Macro is set to use them solely when required for computations.

4.1 Inputs

The IO sheet is the only sheet intended to be changed by the user. It is wherethe user defines all aspects of the structured product in order to calculate its fair value. As such, we divided into segments. All the changeable cells are highlighted in grey.

Time steps

Time steps	
Issue Date	
Today	
Maturity Date	
Last Determination/Observation Date	

User Input Table 1

Firstly, the user must define *Issue Date* and *Maturity Date* (as seen above). *Today* is automatically defined using the excel formula "=TODAY()" and influences other formulas within the same as well as other sheets. *Last Determination/Observation Date* is, likewise, automatically defined using the formula "=MAX(DeterminationDates)" (it will be used for structuring the payoffs of some of the products).

Underlying assets

	Name/Ticker	Initial Price	Actual Price	Volatility	Dividend	Country	Expected Return
Underlying 1							
Underlying 2							
Underlying 3							
Underlying 4							
Underlying 5							
Discount Rate							

User Input Table 2

The second stage of the input sheet consists of defining the underlying assets for the product. As displayed above, the model is adjusted to include five, in which the only required inputs are the Bloomberg *Ticker* and the country in which they are registered. For example, if the underlying is the S&P 500 index, one must choose 'SPX Index' as the ticker and 'USA' as the country.

The remaining columns are defined using Bloomberg appropriate functions or linked to other sheets. The *Initial Price* automatically retrieves the last trading price of the underlying at the product's issue date using the formula '=BDH(Underlying_1;"PX_LAST";Issue_Date;Issue_Date)'. The *Actual Price* is, likewise, pre-defined using the Bloomberg Function '=BDH(Underlying_1;"PX_LAST";Today_Date;Today_Date)' which presents the last trading price of the current day. *Volatility* is calculated using '=BDH(Underlying_1;"VOLATILITY_30D";Today_Date;Today_Date)%' and *Dividend* using '=BDP(C22;"BDVD_PROJ_12M_DIV_INDX_PTS")/ActPrice_1' if the underlying is an index and '=BDP(C22;"BDVD_PROJ_12M_YLD")/100' if it is a stock. Finally, the *Expected Return* is assumed to be equal to the risk-free rate of the country in which the underlying is based. As such, these values are linked to the Govt Yields sheet, which will be explained in section 4.2, depending on the choice of country of the user.

Notional Value

Principal/Notional Value	
Guaranteed at maturity?	
If it isn't guaranteed, level to receive full notional	
Early Redemption option?	

User Input Table 3

Here, the user must define all components as they change according to the structure of the financial instrument. The *Principal/Notional Value* respects the nominal amount which is the base for all return calculations. There are characteristics that must be defined for instance, if the principal is totally guaranteed at maturity or if there is a possibility of an early redemption. Inputs are limited to 'Yes' or 'No' (Data Validation Criteria – List: see appendix 3) and in case of a 'Yes' further information will be later required. If there is no capital protection feature, the user must define the performance barrier above which it will receive total notional amount. This input should be a percentage – for example, a product that pays total notional if the performance of the underlying asset, at maturity, is 60% or above its initial value.

Underlying Performance

Performance	
Criteria	
# Days to be considered	

User Input Table 4

This segment determines the scope of the underlying asset(s) behavior throughout the life of the product, and there are three options: Single day; Mean price (X days); Minimum (in the last X days). These inputs are defined by Data Validation Criteria: List (see appendix 4). Summarily, these allow for different considerations of what information to compare with the initial price: price observed on validation date only, the mean price over the X prior days including the validation date or the minimum price observed over the X days before validation date, inclusive. The number of days in question is defined in the second cell, after the heading *# Days to be considered* (see above User Input Table 4).

Payment Dates

Payment Dates

Determination date	Payment date

User Input Table 5

Following, the user must insert *Determination Date*(s) which correspond to the day in which the product must be valued and, consequently, when it is determined if the coupon shall be paid or if the instrument will be early redeemed. The *Payment Date*(s) is usually seven days after the determination event. However, as there are special cases regarding the time frame, these too are left to be introduced by the user. Please note that the format must correspond to DD/MM/YYYY.

The table shown above (User Input Table 5) will have two additional columns if in the Notional Value segment (User Input Table 3) there is a possibility for Early Redemption. As such, the new columns will respect the *Redemption Date* and *Redemption Level* (see table below). Commonly, the redemption dates coincide with determination dates thus the user input is limited to 'Yes' or '-' using Data Validation Criteria: List (see appendix 5). The level is usually determined by the issuer of the note and normally is set as a percentage (ex.: 95%).

Payment Dates

Determination date	Payment date	Redemption date	Redemption level

User Input Table 6

Finally, the user must define the return of the instrument. There are two categories: the Fixed Coupon and the Variable Coupon.

Fixed coupon

Fixed component	
Rate	

User Input Table 7

The user must define whether the product under valuation pays a certain coupon by inserting the rate. In case it does, the user should insert a percentage (ex.: 1%) or, otherwise, insert 0% or leave blank.

Variable Coupon

Variable component	
Type of Product	

User Input Table 8

There are several available types of products. This cell will determine the structure of the instrument's payoff, as it is what most differentiates the products within the available spectrum. There are eighteen available (for more information, please refer to the "Product Scope" section:

- Asian
- Basket
- Best/worst
- Booster
- Cliquet
- Defensive Supertracker
- Floating Rate
- Knock-Out
- Multi-Barriers
- Multi-Rates
- Outperformance
- Phoenix
- Reverse Convertible
- Stellar
- Twin Win
- Adjusted
- Factor x Performance
- Performance

These will be explained below as will the required inputs for each.

Asian

Variable component	
Type of Product	Asian
Average days	
Type of Asian Option	
Participation rate	

User Input Table 9

The inputs for this product are the *Average Days*, *Type of Asian option* and *Participation rate*. *Average Days* refers to the period considered for the average price computation. Here, the user is requested to type in "*All period"* if the price is the average during the whole coupon period, or "*# Days*", which allows the user to insert a specific number of days to be used in the calculation. *Type of Asian Option* allows the user to specify whether the Asian feature is to be applied to the final price, by typing in "Average Price", or to the reference price, by typing in "Average Strike*"*. Finally, *Participation Rate* allows the user to insert the rate to be used in the determination of the periodic payment, following the formula (13). It must be inserted as a percentage or a number (ex. 120% or 1.2).

Please note that, in this model, Average Strike and Average Price are mutually exclusive features, since these features were never found coexisting in the products analyzed.

Basket

Variable component	
Type of Product	Basket
Barrier	
Weights	
Weight of Asset 1	
Weight of Asset 2	
Weight of Asset 3	
Weight of Asset 4	
Weight of Asset 5	
Participation Rate	

User Input Table 10

The required inputs are the *Barrier*, the *Weights* attributed to each asset on the calculation of the overall basket performance and the *Participation Rate*. The first is the level above which the full notional will be recovered and the enhanced payoff will be triggered and should be inserted as a percentage (ex. 100%). *Participation Rate* allows the user to customize the product's return by multiplying the basket performance by a fixed amount and should be inserted as a percentage or a number (ex. 120% or 1.2). The *Weights* allow the user to customize the constitution of the basket and are required to sum up to 100%. These should be inserted as a percentage.

Best/Worst

Variable component	
Type of Product	Best/Worst
Weight of the best performance	
Weight of the 2nd best performance	
Weight of the 3rd best performance	
Weight of the 4th best performance	
Weight of the worst performance	

User Input Table 11

The inputs required to compute the cash flows according to the performance are the *Weight* of each asset until a total maximum of 5 underlying assets. For instance, it is possible to attribute any weight to the best performance - a lower one if the goal is to limit the payments or a larger one to increase the potential of high returns in each period and, consequently, its attractiveness. The only feature that we know upfront is the weight and that it should be attributed in percentage, as the following example: 10% of the best performance; 15% of the 2nd best performance; 20% of the 3rd best performance; 25% of the 4th best performance; 30% of the worst performance. This product requires the sum of weight to result in a total of 100%, but it does not need to have five underlying, as it works with a lower number of underlying assets.

Booster

Variable component	
Type of Product	Booster
Up Barrier	
Down Barrier	
If above Up Barrier:	
Performance Driven or Fixed?	
Participation Rate/Coupon Rate	
If between Barriers:	
Performance Driven or Fixed?	
Participation Rate/Coupon Rate	
If below down barrier:	
Performance Driven or Fixed?	
Participation Rate/Coupon Rate	

User Input Table 12

To be able to compute its fair value, the model requires four different types of inputs: *Up Barrier*, *Down Barrier*, *Type of Coupon* and *Participation Rates/Coupon Rates*. The first one is the *Up Barrier* followed by the *Down Barrier*, both of which should be expressed as a percentage (ex. 120% and 80%). Furthermore, the user must specify whether the coupon payment type is *performance dependent or fixed* for each scenario. If it is the former, payment depends on the performance of the worst performing underlying asset and the participation rate, if it is the latter, it only depends on the specific coupon rate. Finally, the model also requires the respective *Participation Rate/Coupon Rate* for each available scenario: Above Up Barrier, Between Barriers or Below Down Barrier and should be presented as a percentage or a number (ex.: 120% or 1.2).

Cliquet

Variable component	
Type of Product	Cliquet
Barrier	
Performance Driven or Fixed coupon?	
Participation Rate/Coupon rate	

User Input Table 13

The required inputs for this product are *Barrier*, *Type of Coupon* and *Participation/Coupon rate*. *Barrier* stands for the percentage of the price at the previous determination date that must be reached in order to pay a coupon. For example, for a traditional Cliquet, in which the strike price is re-established every period, this barrier would be 100% and only an increase in price would result in a coupon being paid. *Type of Coupon* allows the user to select whether the payment is a fixed coupon or a variable coupon based on performance. Please insert "Fixed" or "Performance", respectively, depending on the situation. Again, for a traditional Cliquet, the user would type in "Performance", and any price increase above the previous determination price would result in a higher coupon. Finally, *Participation/Coupon rate* allows the user to insert the due return and should be inserted as a percentage or number (ex. 120% or 1.2).

Defensive Supertracker

Variable component	
Type of Product	Defensive Supertracker
Participation Rate	
Lower Bound	
Cap	

User Input Table 14

To value such product, the model requires three different types of inputs: *Participation Rate*, *Lower Bound* and *Cap*. The latter defines the maximum return the product will pay, and should be inserted as a percentage (ex.: 40%). The *Participation Rate* allows a higher payout than solely performance and should be filled as either a percentage or a number (ex.: 120% or 1.2). If not applicable, the value to be inserted should be 100% or 1. Finally, the *Lower Bound* defines the reference level from which growth is tracked and can be lower than 100%. Therefore, the input must be a percentage (ex.: 95%).

Floating Rate

Variable component	
Type of Product	Floating rate
Floor	
Cap	

User Input Table 15

The required inputs for this product are the *Floor* and the *Cap*. The *Floor* stands for a minimum guaranteed coupon rate. For example, if there is a floor of 1%, the note will always pay a coupon of at least 1%, regardless of the Libor 3m being below that level. On the other hand, the *Cap* refers to a maximum coupon rate the note may pay. If there is a cap of 4%, this is the maximum coupon the note will pay, even if the Libor 3m rises above that level. If any of these inputs is not applicable, the corresponding input cell should be left empty.

Income Accumulator

Variable component	
Type of Product	Income Accumulator
Period	
Coupon rate	
Range:	
Up Barrier	
Down Barrier	

User Input Table 16

The required inputs for this kind of product are the *Period*, the *Coupon Rate* and the *Up* and *Down Barriers*. *Period* requires the user to insert the number of days between coupon payment dates (for instance, insert "90" if coupon payment frequency is quarterly). The C*oupon Rate* should be the annual coupon rate, as the model automatically adjusts for the considered period. Finally, the *Up* and *Down Barriers* define the range within which the weekly observation must fall in order to accumulate for the coupon payment and should be inserted as a percentage of the initial underlying asset value.

Knock-Out

Variable component	
Type of Product	Knock-Out
Type	
Strike	
Multiplier	
Knock-Out Barrier	

User Input Table 17

The required inputs for this product are the option *Type*, *Strike*, *Multiplier*, and the *Knock-Out barrier*. *Type* refers to the option type: Call or Put. *Strike* is the exercise price of the option and should be inserted as an integer. *Multiplier* allows the user to increase/decrease investor's exposure to the option payoff and should be presented as a percentage or number. For example, at maturity, a multiplier of 50%, or 0.5, would reduce the standard payoff of a call option to 0.5*(Spot price-Strike price). *Knock-out barrier* is simply the barrier at which the option will cease and should be inserted in percentage of the initial value of the underlying asset. Please note that the model is built for an upper barrier (ex.: 120%), according to the example found in the products studied. Also, it only allows for the computation of European type Knock-Out products.

Multi-Barriers

Variable component	
Type of Product	Multi-Barriers
Dates/Barrier	
Rate (if above barrier)	
Rate (if below barrier)	

User Input Table 18

The model requires two different types of inputs, the first one being the different *Barrier levels* for each determination date, which should be expressed as a percentage of the initial value. Please note that the dates in the first column will be automatically defined with the determination date set on User Input Table 5. The second input required is the *Coupon Rate* if the underlying assets performed better than the barrier level and the rate if they end below the barrier. It should, also, be defined as a percentage (ex. 5%).

Multi-Rates

Variable component	
Type of Product	Multi-Rates
Barrier	
Coupon Rate when:	
None above barrier	
1 above barrier	
2 above barrier	
3 above barrier	
4 above barrier	
All above barrier level	

User Input Table 19

To compute this type of structured product the model requires two different inputs: *Barrier* and *Coupon Rate*(s). The first one is a percentage of the initial price(s), and will be used to measure the performance. Furthermore, the model requires six different *Coupon Rate(s)* for the different cases: when none of the underlying assets are above the barrier level, when either one, two, three or four of them are above the barrier or all of them are above the barrier. These rates should be inserted as a percentage (ex.: 5%). The model will also function with less than five underlying assets.

Outperformance

Variable component	
Type of Product	Outperformance
Barrier	
Participation Rate	
Position of Asset 1	
Position of Asset 2	

User Input Table 20

The inputs for this product are the *Barrier*, *Participation Rate* and the *Relative Positions* of the Stock/Indexes in the computation of the difference. The *Barrier* is simply the level above which the notional value is fully received and should be inserted as a percentage. The *Participation Rate* allows the user to boost, or to limit, the effect of the performance difference in the calculation of the payoff. Please note that this product is specifically modelled to pay when the first asset (Position 1) outperforms the second (Position 2). If the first asset underperforms the second, the coupon has a lower bound of zero.

Phoenix

Variable component	
Type of Product	Phoenix
Barrier	
Coupon Rate (if above barrier)	
Coupon Rate (if below barrier)	
Accumulation Option?	

User Input Table 21

The model requires four inputs: *Barrier*, *Coupon Rate (if above barrier)*, *Coupon Rate (if below barrier)* and *Accumulation Option*. The *Barrier* level, expressed as percentage of the initial value or reference value, will be an orientation to measure the performance. The *Coupon Rate* when the barrier is exceeded and a different rate when the performance falls short. These should be inserted as a percentage (ex.: 5%). Note that the latter does not need to be zero. The final input is the *Accumulation Option* that allows the user to define if the product under scrutiny allows for accumulation of coupon for the next period, in a scenario when it was not paid in the current observation date. Here, insert "Yes" or "No". Please note that this option is only possible if the user inserts a coupon rate of 0% when the barrier is not reached, otherwise the accumulation feature will not work.

Reverse Convertible

Variable component	
Type of Product	Reverse Convertible
Strike Price	
Coupon Rate p.a.	
Coupon Frequency	
Is there any Protection Level?	

User Input Table 22

The required inputs for this product are the *Strike, Coupon rate per annum, Coupon frequency* and *Protection level*. The *Strike Price* should be inserted as a percentage of the initial price as should the *Protection Level*, if applicable. *Coupon Rate p.a.* is the annual coupon rate (ex. 6%). *Coupon Frequency* requires the user to type in "monthly", "quarterly", "semi-annually", or "annual" according to the frequency of coupon payments per year. The model automatically computes the periodic payment (ex. 6% annual coupon with monthly frequency is equivalent to twelve coupons of 0.5% each). The field *Is there any Protection Level?* should be answered with "Yes" or "No".

Stellar

Variable component	
Type of Product	Stellar
Cap	

User Input Table 23

To allow the model price this type of asset, only one input is necessary: the *Cap*, which works as a limit for the coupon rate. This should be a percentage (ex.: 5%). If this is not applicable, the user should leave the cell blank.

Twin Win

Variable component	
Type of Product	Twin Win
Cap	
Protection Level	

User Input Table 24

The required information to correctly compute the return are the *Cap*, which limits upside participation, and the *Protection level*, which sets the level above which the investor is protected from downfalls. However, any performance below this barrier will constitute a loss for the investor. Both inputs may be inserted as percentage or a number (ex.: 120% and 80%, or 1.2 and 0.8 respectively). If the former is not applicable, the user should leave the cell blank.

Adjusted Performance

Variable component	
Type of Product	Adjusted Performance
Participation Rate	
Period Date	
Position First Observation Date for Level 1	
Position Last Observation Date for Level 1	
Position First Observation Date for Level 2	
Position Last Observation Date for Level 2	

User Input Table 25

The required inputs consist of *Participation Rate*, *Period Date*, *Position of the First Observation Date for Level 1*, *Position of the Last Observation Date for Level 1*, *Position* *of the First Observation Date for Level 2, Position of the Last Observation Date for Level 2*.

The *Participation Rate*, being a multiplier, should be indicated as a percentage or a number (ex. 120% or 1.2). Regarding the *Period Date*, it should indicate the number of days examined previous to each observation date. For instance, if it is supposed to check the days of a month, the observation date indicated should be the last day of the month and the period day equal to 30. On the other hand, if the goal is to observe the days of a quarter then, the observation date should be the last day of that quarter and the period date equal to 180.

The final inputs are the *position of the observation dates*. The user should put the number that corresponds to the date in the respective period. For instance, if the total period of the product is 24 months and the level 1 is within the first 12 months and the level two in the next ones, the user should write: 1 to the First Observation Date for Level 1; 12 to the Last Observation Date for Level 1; 13 to the First Observation Date for Level 2; and 24 to the Last Observation Date for Level 2.

It is important that the user inserts in the observation dates the respective final day of each period of observation.

Factor x Performance

Variable component	
Type of Product	Factor x Performance
Barrier	
Participation Rate	
Cap	

User Input Table 26

The three required inputs to value this product consist of the *Barrier, Participation Rate* and the *Cap*. The first should be inserted as a percentage of the initial price and represents the point at which the product alternates payment scenarios (pay if above barrier or no payment if below). The *Participation Rate*, a multiplier feature that enables a higher return (if above barrier) than solely the performance of the underlying asset, should be inserted as a percentage (ex: 120%) or as a number (ex: 1.2). If there is no multiplier within the product's structure, the user must insert 100%. Finally, the *Cap* works as a barrier to limit the performance range and, consequently, the return. Above the Maximum Return level, the payment becomes constant independently of the performance (Maximum Return x Notional Value). If it is not applicable, the cell should be left blank.

4.2 Outputs

Besides displaying the results on the IO Sheet, the model provides to the user the option to create a word document with all the information used to simulate the price of a determined structured product as well as the assumptions for all the process. The document produced is divided into 3 parts:

A. Product Characteristics – In this segment, the report will present the type of product selected, the reference dates (issue date and maturity date) and the specific inputs required that were introduced to price the financial instrument.

B. Assumptions – Here, a summary of the assumptions and the respective values assumed. Information as the number of simulations, the underlying asset characteristics (volatility, dividend yield and expected return) and the discount rate for the cash flows are displayed.

C. Results – The last section verbalizes the major results of the valuation. It has three components: the date of the valuation, the price, and the IRR estimated for the product.

The output document is displayed in appendix 7.

To create this document, a VBA Excel Macro was developed which is triggered by pressing the 'Final Valuation Report' button on the IO Sheet. Please note that if this button is pressed before the Monte Carlo Simulation takes place or without all the inputs, certain zones of the document will appear blank due to the absence of information.

4.3 Engine Sheets

The Engine sheets are intended to support all the calculations needed for correct functioning of the model. They are not supposed to be altered by the user since that may destabilize the proper functioning of the model.

Layout

This sheet has the sole purpose of aiding user experience. For example, when choosing the variable component of the product's return, the required input table changes. It is on the Layout Sheet that all the tables are stored, and thus, the IO sheet is linked to it. Moreover, the error's validation is set up here but only visible in the IO sheet whenever needed.

MC_Index1, (…), MC_Index5

These sheets are set up with the Monte Carlo Simulations (MCS). Its inputs, as seen below highlighted in blue, are automatically defined by the choices in the IO sheet and, thus, there is no required insertion in these sheets.

μ	
σ	
d	
S_{01}	
Δt	
um-ff	

Dates	ε	ε_ajustado	S

# paths			
1	2	3	4

Engine Table 1

The column *Dates* starts with the issue date and ends at maturity. The *ε* is defined by the formula '=NORMSINV(RAND())' which, as explained previously, is a required condition for the effectiveness of the MCS. The *ε_ajusted* column aims to apply the Cholesky decomposition using the formulas earlier exposed (section 2.3, page 26). Furthermore, the S stands for stock price and is defined by either the last trading price, sourced from Bloomberg, if the date is between issue and current day, or the MCS projection, calculated with the formula (9) (page 22) . Lastly, the numbered columns are filled with the number of MCS that the user chooses when triggering the VBA Excel Macro (please refer to appendix 6).

CF_Index1, (…), CF_Index5

Redemption Level	Dates	#Paths Position	1	2

Engine Table 2

Here, one calculates the performance of the stocks which will allow for the correct evaluation of the payment, or of a coupon. As such, the column *Dates* retrieves the user input in the Determination Dates' column. The previous column, *Redemption Level*, states the redemption level in case of early redemption, or 1000% which is an implausible value and thus replicates a no cap alternative. The *#Paths Position* identifies the row number in which the respective date is placed in the MCS sheet. This will help find the MCS price of that day, in order to calculate the performance. The numbered columns are filled with the performance in each path of the MCS and range from 1 to the number of simulations chosen by the user. This is subject to the preferences of the user, that is, the choice made in the Underlying Performance section in the IO Sheet. Thus,

$$\begin{cases} Single\ day: {}^{MCS\ of\ that\ day}/_{Initial\ Price} \\ Mean\ price\ (\#\ days): {}^{Average\ of\ MCS\ in\ last\ \#\ days}/_{Initial\ Price} \\ Minimum\ (in\ the\ last\ \#\ days): {}^{Min(MCS\ of\ the\ last\ \#\ days)}/_{Initial\ Price} \end{cases} \tag{44}$$

Govt Yields

		USA		Germany		Portugal		Spain		France	
Time Step	Time	Ticker	Yield	Ticker	Yield	Ticker	Yield	Ticker	Yield	Ticker	Yield
0.083	1M	GBM Govt		GTDEM1M Govt		GTPTE1M Govt		GTESP1M Govt		GTFRF1M Govt	
0.25	3M	GB3 Govt		GTDEM3M Govt		GTPTE3M Govt		GTESP3M Govt		GTFRF3M Govt	
0.5	6M	GB6 Govt		GTDEM6M Govt		GTPTE6M Govt		GTESP6M Govt		GTFRF6M Govt	
1	1Y	GB1 Govt		GTDEM1Y Govt		GTPTE1Y Govt		GTESP1Y Govt		GTFRF1Y Govt	
2	2Y	GT2 Govt		GTDEM2Y Govt		GTPTE2Y Govt		GTESP2Y Govt		GTFRF2Y Govt	
3	3Y	GT3 Govt		GTDEM3Y Govt		GTPTE3Y Govt		GTESP3Y Govt		GTFRF3Y Govt	
5	5Y	GT5 Govt		GTDEM5Y Govt		GTPTE5Y Govt		GTESP5Y Govt		GTFRF5Y Govt	
7	7Y	GT7 Govt		GTDEM7Y Govt		GTPTE7Y Govt		GTESP7Y Govt		GTFRF7Y Govt	
10	10Y	GT10 Govt		GTDEM10Y Govt		GTPTE10Y Govt		GTESP10Y Govt		GTFRF10Y Govt	

		Italy		United Kingdom		Switzerland		China		Brazil	
Time Step	Time	Ticker	Yield	Ticker	Yield	Ticker	Yield	Ticker	Yield	Ticker	Yield
0.083	1M	GTITL1M Govt		GTGBP1M Govt		GTCHF1M Govt		GTCNY1M Govt		GTBRL1M Govt	
0.25	3M	GTITL3M Govt		GTGBP3M Govt		GTCHF3M Govt		GTCNY3M Govt		GTBRL3M Govt	
0.5	6M	GTITL6M Govt		GTGBP6M Govt		GTCHF6M Govt		GTCNY6M Govt		GTBRL6M Govt	
1	1Y	GTITL1Y Govt		GTGBP1Y Govt		GTCHF1Y Govt		GTCNY1Y Govt		GTBRL1Y Govt	
2	2Y	GTITL2Y Govt		GTGBP2Y Govt		GTCHF2Y Govt		GTCNY2Y Govt		GTBRL2Y Govt	
3	3Y	GTITL3Y Govt		GTGBP3Y Govt		GTCHF3Y Govt		GTCNY3Y Govt		GTBRL3Y Govt	
5	5Y	GTITL5Y Govt		GTGBP5Y Govt		GTCHF5Y Govt		GTCNY5Y Govt		GTBRL5Y Govt	
7	7Y	GTITL7Y Govt		GTGBP7Y Govt		GTCHF7Y Govt		GTCNY7Y Govt		GTBRL7Y Govt	
10	10Y	GTITL10Y Govt		GTGBP10Y Govt		GTCHF10Y Govt		GTCNY10Y Govt		GTBRL10Y Govt	

Engine Table 3

The main table provides the various reference rates for a selection of different countries, namely USA, Germany, Portugal, Spain, France, Italy, United Kingdom, Switzerland, China and Brazil, and for different maturities (1M, 3M, 6M, 1Y, 2Y, 3Y, 5Y, 7Y and 10Y).

As explained previously, the expected return of each stock is assumed to correspond to the risk-free rate of the respective country, chosen by the user. Therefore, this sheet is also organized to provide the respective rate:

Country Asset 1
Column
Row
Rate

Engine Table 4

The first row (*Country Asset 1*) is linked to the choice made by the user in the Underlying assets section of the IO Sheet. The *Column* and *Row* fields match the number of columns in which the chosen country is placed and the number of rows in which the adjusted time gap is placed, to provide the inputs for the '=INDEX(GovtY;Row;Column)' formula inserted in the *Rate* field. This will be the source for the information present in the Expected Return column in the Underlying assets table (see User Inputs – Section 4.1).

Correlation

This sheet solely retrieves last prices from Bloomberg for the chosen assets, for the period of one year. It will enable the calculation of correlations which are essential for the Cholesky decomposition.

Cholesky

Correlation Matrix

Assets' Names	Underlying 1	Underlying 2	Underlying 3	Underlying 4	Underlying 5
Underlying 1	1.000				
Underlying 2	0.000	1.000			
Underlying 3	0.000	0.000	1.000		
Underlying 4	0.000	0.000	0.000	1.000	
Underlying 5	0.000	0.000	0.000	0.000	1.000

Engine Table 5

The correlation is calculated in the white cells using the prices from the Correlation Sheet. The following tables (Matrix decomposition in (L) and (U) and Cholesky Matrix) are auxiliary for computations and result in the Cholesky Values which will be used in the MCS.

Cholesky Values

a11	
a21	
a22	
a31	
a32	
a33	
a41	
a42	
a43	
a44	
a51	
a52	
a53	
a54	
a55	

Engine Table 6

4.4 Validation and Error's Procedure

Validation Tools

Due to the model's complexity, regarding the large set of essential inputs to the good operation, we constructed a set of validation tools to help the user to avoid errors that could result in inefficient and misleading results. These alert for possible errors and appear in the IO Sheet, below the Variable Component table.

The validation tools provide the user a set of messages, each one with a different goal:

- "Invalid – There are inputs missing." – When the user forgets to insert an input, the model will detect and inform that there is a lack of data.

- "Invalid – One input is incorrect." – Every time the user has the need to write down an alphabetic input, the model will check if it is well written. In case of misspelling a term, the model will provide this message as an alert.

- "Invalid – Barrier needs to be at least 100%." – In the Factor x Performance product, there are some constraints to ensure correct computation. When this product is selected, the value to be inserted in Barrier needs to be higher than 100%. Otherwise, this message will appear.

- "Invalid – Lower rate needs to be zero." – This message reflects a constraint that should be considered when the user selects the product Barrier and allows accumulation of coupons, by writing "Yes" as input. The accumulation coupons feature calls for the scenarios where the coupon below the barrier is 0% otherwise the operation will be invalid and the price incorrect. Thus, if the lower rate is above 0%, this message will appear.

- “Invalid – Sum should be 100%.” – When the user is working with weights, the model is calibrated to equal the sum of the introduced weights to 100%. When that is not respected, this message will show.

- “Invalid – One index only.” – Some structured products’ payoff is modelled for one underlying asset, such as Booster and Capped Performance. Whenever the user incorporates more than one underlying assets and then selects one of these types, this message will alert the user.

- “Valid.” – This message confirms that all the inputs cells are fulfilled and the model is ready to work. However, the user must know that this message doesn’t exclude the possibility of incorrect formatting of inputs (for example, 120 instead of 120%).

Error’s Procedure

The complexity and the density of formulas in the model require from the user a special care when dealing with it. To help the user to fix and avoid some errors, this sector provides tips to solve mistakes that may occur.

Before any error in particular, a good practice is to have a backup plan by creating a copy of the original model. Attention for the fact that, as this model contains VBA codes, the user should not change the names of the files and should create a folder with the files inside. Keeping a copy of the original model will help the user in case of wrong alterations that are difficult to source.

As with any other model, this one is prone to errors such as:

I. Deleting formula from cells. – Despite the majority of the model being blocked, the user may change formulas if it inserts the correct password. In case of undue alterations, use the “Undo Typing” button (Ctrl+Z) to try to return to the initial stage. If this is proven unsuccessful, use the copy safety file to start again and see the original formula or even, as the last resource, use the manual to understand the formulas and structure of the model to rebuild it. If the user is in any way uncomfortable with the model, it is recommended that, instead of trying to rebuild it, he/she asks for help.

II. Monte Carlo did not simulate the prices. – This may happen in one of two cases, the first being when inputs are missing. Please make sure that the validation tool appears "Valid" before triggering the MCS VBA Excel Macro. The second case may be that the Excel file has the "Manual Calculations" option on. By changing to automatic (Formulas > Calculation Options > Automatic), the issue should be solved.

III. An error alert came up when the Monte Carlo simulation button was pressed. – This alert is a VBA Functions Break announcement in the code. The most probable reason is Missing References (whose alert message will be: "Compile Error: Can't find project or library"). If that is the case, please pursue the following resolution: 1 - Open your database. 2 - Press ALT+F11 to switch to the Visual Basic Editor. 3 - Open a module in Design view. 4 - On the Tools menu, click References. 5 - Click to clear the check box for the type library or object library marked as MISSING: <referencename>. If that was not the kind of error that appeared, please click in "Help" in the error message, which leads the user to an information web page that explains the error cause and its resolution.

IV. The price does not make any sense. – This situation is the result of wrong inputs. Please read information that the model provides to all input cells or read the manual to understand the kind of inputs that it is expected to have in each space.

V. When the Bloomberg Ticker is inserted, no information appears. – The model is connected to Bloomberg. If the user only connects or opens session on the Bloomberg platform after opening the model, this may cause this kind of error. To fix it, close the model and reopen it after starting the session in Bloomberg. Furthermore, as explained previously, this model requires that Excel has the Bloomberg Add-In. If not available, add it by going to File > Options > Add-ins > COM ins > Bloomberg or, alternatively, File > Options > Customize Ribbon > Bloomberg. Finally, another reason for this error might be an invalid ticker. Please make sure that the ticker is correct and complete. For example, the Facebook ticker is FB US Equity. Both FB Equity and FB US are not enough.

VI. The model does not open (or the model takes significant time to open). – The reason behind this is that a large amount of data was saved in the previous simulation. Keep in mind that if a simulation of 10,000 paths is made for five underlying assets, 50,000 new pieces of information were added to the model. Thus, it leaves the model heavier and leads to a delay in opening the file. We recommend that the user should not save the simulation paths and, instead, use the Output sheet and use the document as a proof. In sum, storing the data is not recommended.

4.5 Final Observations

As with any other model, the one presented has its own limitation that, taking into account the dimension and the time frame of the project, were not addressed. Its user should have them in mind to avoid making miscalculations.

I. The model is only able to price structured products with a maximum of five underlying assets. A few types are even restricted as it only allows for one underlying asset at each time. Please read the previous segments of the manual for more information.

II. The model cannot take more than 10,000 paths. This is a limit based on the dimension of the excel sheets and the need of minimize the file size to process efficiently this large number of paths. If this limit is crossed, the model will alert the user for the incapacity of simulating more paths and will stop the procedure.

III. This model is a time consuming tool. For such a generic model in Excel like this, especially with Monte Carlo Simulations, it will require up to 5 hours of uninterrupted calculations when working at top capacity (10,000 simulation for five underlying assets) and during that time Excel may become inoperative for other tasks. A way to avoid this is to use computers with a powerful processor or doing the simulations overnight as this is an independent step. The use of other mathematics software as MATLAB may be considered in order to gain time.

IV. The typology of the structured products is also limited to the ones present in the model/manual. Although the model contains a large number of characteristics and, in fact, the most commonly observed today, it is possible that the user may be presented with a typology that is not yet incorporated.

V. Finally, the Excel version used was Microsoft Excel 2015. The model uses general formulas to avoid incompatibility among software versions however, in case this happens, the user must follow the program's suggestions.

5. Individual Reports

5.1 Afonso Pinheiro

Introduction

The following section is aimed at summarizing my main motivations, individual contribution, challenges faced and key learnings throughout the whole project. Being already familiarized with some of the concepts and with the pricing procedure brought both advantages and challenges for myself. Although I had already had some understanding about the features to include in the model, in my opinion the BPI field lab also brought some challenges regarding the automated part of the model. My experience with the group was outstanding, and the chemistry and procedure applied during the whole project was key to attain our objects and to deliver the project in time. Undoubtedly, the thoughts and insights I was able to develop throughout this semester will be key in my professional career, not only because of the advance VBA metrics learnt throughout the project, but also due to the complex and particular features embedded in structured products, which comprise different concepts from different fields of Finance. Additionally, the teamworking skills I was able to shape during the project will also be useful in working as a team in a future job opportunity.

Background

The choice of applying to a field lab Work Project came naturally to me when confronted to the different array of Work Project types presented at Nova SBE. It immediately ignited my interest since it allows students to face a real problem-solving work experience in a consulting-like project while applying their analytical, teamwork and finance-related capabilities to achieve a common goal. Also, the further choice of joining BPI's field lab was based on my interest of being continuously deepening my financial markets skills and financial markets related competencies together with a prestigious bank with an impressive background and influence in the Portuguese economy. Therefore, BPI field lab summarized my desire to gain work experience while performing my final Work Project, my interest in having a consultancy work experience while employing analytical and finance related skills and especially my enthusiasm for working in a new group while seeking to learn from the others. In order to complete the required challenges to complete the final work I think I have developed both hard and soft skills that I tried to apply to develop the model and write the paper.

My interest in financial-markets related concepts began when I started my Investments course, which introduced me to basic concepts of asset pricing, such as fixed income securities and derivative contracts. I was first introduced to the Black-Scholes model during the course. Additionally, the Financial Modelling course was essential to develop most Excel and modelling related competences I applied to the model. The course covered topics such as dynamic ranges, Monte Carlo simulations, Geometric Brownian Motion and the basics of VBA. Thus, during the course I developed not only the skillset needed to develop the model but also I was given the tools to deliver a user-friendly program for the client. Moreover, the Fixed Income course in my second semester helped me develop my bond pricing skills and Nova Students Portfolio, which ignited my interest in investment securities. Within the investment committees, I was able to improve my sense of determining the fair value of financial instruments, given that the stock picking process is the key feature of this portfolio management course.

Moreover, this summer I had the opportunity to intern at Banco Invest in the Asset Management and Derivatives department, which allowed me to participate in the option and structured products writing process. During the internship, I was introduced to structured products pricing models, Cholesky adjustments, Implied volatility surfaces and

Monte Carlo. The bank is a structured products issuer and has become a huge player in the Portuguese market for these instruments, thus the insights the bank managers gave me became a crucial part of the skills I applied to develop the model and to understand the theoretical concepts behind the structured products pricing process and industry.

Individual Contribution

The group has initially decided to develop the model, thus there was little division of individual work to attribute. Throughout the whole construction of the model, each member contributed individually with insights, but there were no specific tasks or parts of the work attributed to each one. At the beginning of the project, the group started to conduct some research regarding the structured products BPI commercializes, which were provided by José Nuno Sacadura, BPI's collaborator. Additionally, since there were no limitations regarding the type/range of structured products to include in the model, the group decided to do some further research regarding the type of products that other major structured products issuers commercialize to replicate in our model, which was referred at the beginning of the written paper. In my case, I retrieved information on 11 BPI outstanding products and on more than 90 among Morgan Stanley's and Deutsche Bank's issued products. The next stage of the project was to be completed as a group, namely gathering all the information and discuss what products to include in the model since some products had some particular features that the group decided to exclude from the model. Once the the had summarized the main features to include in the model, we split the modelling procedure of each product. For instance, I was responsible for modeling the construction of the Reverse Convertible, Adjusted Performance and Defensive Supertacker, as well as the Cholesky decomposition. I also contributed to the development of the final VBA macro for the Monte Carlo simulation. Regarding the written paper, I was responsible to build the Theoretical Overview, which comprises topics such as the structured products' market overview, main risks and advantages, Monte Carlo inputs and mechanics. I also gave my contribute in describing the products, such as the Adjusted Performance and completed the limitations of the model with the help of other colleagues. Of course, all the work performed individually needed to be revised by and discussed with the other colleagues. Therefore, each group member was continuously in charge of revising changes in the model performed by the other group members. This collective contribution scheme allowed for a more holistic learning experience for the group as well as solidified the final output.

Main Challenges

The main challenges faced throughout the whole project comprised different areas, such as the Monte Carlo mechanics, Products Scope, meeting the Client demands and expectations and the model Computation requirements.

Regarding the Monte Carlo mechanics, the main challenges I faced were related to the VBA modelling part. Although we managed to write a macro that operated within the workbook, the procedure was too slow. Therefore, the group tried to find a solution together with Professor Afonso Eça, which consisted of writing a more complex code that would run the macro in other workbooks therefore allowing the process to be smoother and faster. Additionally, since there is no standardization among the different countries government yields' ticker, the group was faced with a challenge on how to model it for different countries.

The Products Scope part of the model was definitely a big challenge since the main focus when writing the extensive and complex formulas for the payoffs was to write the simplest code possible to allow the model to operate faster and more efficiently. In addition, one also needed to take into account the different errors or misinterpretations that could arise within the model, such as blank cells in unused pages that resulted into an Excel error that could damage the pricing outcome. Another difficulty the group encountered was when splitting the payoff process into different tranches, such as the derivative component and the notional value across all types of products, always trying to design the model to be as efficient as possible.

A further challenge faced while developing the model was meeting the client expectations and guidelines. On one hand, the client was very clear regarding the scope of the model and the expectations they had on the final outcome. On the other hand, although the client was satisfied about the progress of the work halfway through the project, the guidelines given to the group regarding the types of products and payoff the model should cover were not very clear and the group struggled with the dimension the model could take. However, since a structured product payoff can take almost any structure the issuer wants, the group together with Professor Filipa Castro decided to screen the types based on which products other major European and US banks were issuing. Hence, the team decided to include in the model more products than those BPI commercializes nowadays, trying to cover future structures the bank may sell.

Lastly, the team faced some challenges regarding the computational part of the model. During the first meeting, the client made clear that the model should be entirely performed in Excel or in Microsoft Access and therefore some more advanced and efficient computer programs, such as MATLAB could not be used to optimize the model. The group made an effort to optimize the Monte Carlo procedures by running the simulations in different workbooks, thus splitting the model into different model-parts that are aimed at diminishing the time it takes to perform the pricing procedure.

Key Learnings

Throughout the project I was able to deepen my knowledge in the structured products market and how it has become an increasing product of interest for worldwide investors. Additionally, the field lab challenged myself to always keep client demands in mind, consistently trying to deliver the best possible work. The project has allowed to deepen my knowledge in tools such as advanced Excel, when contributing to the VBA writing process as well as to empower my option pricing skills. The financial modelling skills developed throughout the project will definitely be a key takeaway from this work experience, since the finance world has exponentially increased its dependency on technology and financial models. Additionally, having contact with complex structured option pricing procedures has increased my portfolio management competences, which is crucial for someone who wants to become a successful professional in the financial markets industry.

5.2 Ana Ramos

Introduction

The following report aims to cover my individual participation as well as motivations and challenges while developing the work project "BPI Consulting Project". Thus, it will include an overview of my perspective and reactions to this experience, by describing how I interpreted my role in the team, how we tackled the challenges and what I learned by being a part of it. It will be divided between my experience prior to the project (the background), my contribution, the main challenges and finally the key learnings.

As a whole, I believe this project was a very useful tool, not only for me, but for all of the team members as it allowed for a better consolidation of the concepts learned during our masters and also provided us with a better understanding of the topic of structured products.

Background

When it came to the time of choosing my master thesis topic, I showed from the beginning my deep interest in being a part of a consulting project. In my opinion a consulting project is a real-life learning experience where I would be building skills that would help me throughout my professional path and improve the ones I have been developing during the finance masters. Furthermore, as it was an opportunity to work in a group, I thought it would be very beneficial as it would allow all of us to learn together and from each other, but also would prepare us for the futures challenges that we might face in our future job.

Taking into account the previous mentioned aspects and my interest in the banking sector, the "BPI Consulting Project" offered by Nova SBE, seemed to be the perfect fit for my expectations and ambitions. BPI is one of Portugal's top banks and I thought it would be the perfect opportunity to discover more about its business. Furthermore, the topic of structured products always interested me, and the possibility to combine it with the opportunity to help BPI develop its business and contribute to its growth, pushed me to choose this project.

Moreover, during my time spent at Nova, I have developed several skills in different subjects, which I believe were of vast importance for the development of the project.

In my opinion, one of the most remarkable courses we had during our masters was Investments, as it gave us a broad overview of the major topics regarding the subject. By covering topics such as risk and return, asset pricing models and financial derivatives, it provided a strong foundation necessary to developing the model and understanding the theory behind the topic of structured products.

Furthermore, the futures and options course was also highly important to my better understanding of this project as it introduced topics such as derivatives and their pricing principles, with a high focus on the Black-Scholes Model. This allowed me to have a clear view of the mechanics needed to value options which is a crucial part when valuing the structured products.

Individual Contribution

In my perspective, our approach to the project was also to tackle it as a group. This means that, since the very beginning we shared ideas and the individual knowledge we had, in order to build the model in the best way possible. In order to do so, as previously described, firstly we focused on gathering the data and analyzing the structured products provided by BPI. At that stage, we divided the analysis of the products equally, so that we could all take a look at the different types of products and retrieve the most important information that we would need to build the model. Also, as we wanted the model to be adaptable to other types of structured products available in the markets, we decided to do a research analysis on the other types of products offered by different banks. In my case, I described 11 products of BPI and gathered data from BNP and HSBC.

Later, when building the model, we started by trying to price the different structured products and build the engine. This was done as a group, where all contributed and helped each other to achieve our goal of delivering a robust model. In my case I helped more in the beginning of the modelling process, as I tried to divide the existing products into categories, to make the initial pricing process easier. In mid-October, I moved to Frankfurt for an internship, and because of that I had to start contributing remotely to the project. From that moment onwards, I started focusing more on the writing part which was the most effective solution for the group as whole.

Regarding the final report, I was in charge of handling the Products Scope, revising the Methodology and also the User Manual – Inputs.

I want, however, to reinforce the point that, in general, what worked so well in our project was that we tackled every important challenge as a group, making it a better learning experience and easier to deliver a solid final product.

Main Challenges

In the beginning of the project one of the challenges I encountered was the overwhelming skills needed to perform the project. Nevertheless, as our advisor scheduled a meeting early on and described the topics that we should focus on, I was able to deeply study the subjects that I was least comfortable with and properly prepare myself for the what was about to come. Furthermore, as I accepted a job offer in Frankfurt, starting in October, I had to coordinate with my group and advisor to make sure that even though I was in a different city I could still contribute actively to the project. In my opinion that was one of my biggest challenges during the execution of the project, but in the end, I managed with the crucial support from my group.

Moreover, as the project advanced we encountered another set of challenges related with trying to adjust our model to incorporate not only the products BPI offers now, but also future ones they could commercialize. To do so, we had to deal with the large amount of information available regarding structured products. Also, while building this model to match the client's expectations, we had to constantly revise the file in order to prevent the model from being a time-consuming process.

Key Learnings

In my opinion the project was a very interesting experience. It allowed me to get a better understanding of structured products and of how to compute its price. By doing so, it provided an opportunity to apply the topics learned during the masters to a real-life case. Furthermore, one was able to understand better the dynamics of the consultancy projects.

Overall, I feel like I gained a lot from the project. I was able to develop skills that will be useful in the future, like the computation of a valuation model, pricing structured products and the ability to work in teams. Teamwork requires coordination, communication and support, all requirements that I feel our group could achieve and that had a positive impact on delivering the model.

Finally, I think this experience contributed a lot for my professional and personal development. It was the perfect ending to consolidate what was learned during the Master's program, but also as I was working remotely it allowed me to get a set of skills that I will make use of in the future. Since I had to distribute my focus between working and writing my thesis I think it provided me with better time management skills (as I had to juggle between the two important tasks) and also showed me the importance of focusing in what you are doing so you make the best of the limited time. I have to add that this was a demanding task to juggle between the internship and the thesis but is one experience that I am grateful I had the opportunity to have since I believe I grew a lot as a person.

5.3 João Palma

Introduction

This report summarizes my personal perspective on what was developing this work project, a model of fair valuation of structured products for BPI – Banco Português de Investimento. This will include my background and motivations to embrace this project, the role I played and my contributions, the main challenges faced (both at individual and group level), and the key learnings acquired.

It is worth mentioning that I honestly believe this was the best group I have ever worked with. We knew since the first day that the project would be demanding, but I think the whole group agrees we managed to live up to the expectations. The group has always managed to successfully share ideas, knowledge and work, as well as to take the best out of each member's strengths. Everyone was strongly motivated and participated actively, adding helpful opinions and insights at every stage of the project. No lack of effort or motivation was ever noticed from any member of the group.

Background

Throughout my Masters in Finance, my course choice always leaned towards financial markets and securities. I had always heard about structured products, but until very recently, my (mistaken) idea was that they were strange, overly-complex products, beyond the comprehension scope of the average investor and financial markets participant. This idea changed during the last quarter of my Masters with the course of Applied Derivatives, a course that mainly focused on exotic options and pricing of products with embedded options. The course was really captivating and, although it covered many features of structured products supported by real life examples, I always felt that there was more to discover about the topic. Thus, in addition to the solid background in structured products pricing, this course also raised my curiosity for these securities. Another course that turned out to be very helpful during this project was Derivatives, which provided a strong background in plain-vanilla options pricing, as well as familiarization with the Black-Scholes model and Monte-Carlo simulations, all crucial subjects for the development of this project. Last but not least, Fixed Income, provided some important intuition on interest rate-derivatives.

I firstly heard about the Nova Consulting Labs from a friend, one year ago. The concept immediately caught my attention, as it sounded really interesting and dynamic, with much more to offer than the standard, research-focused, concept of Master's Thesis. In addition, the opportunity to work with a bank with a strong national presence and reputation in the structured products market led the BPI Consulting Project to be my first choice for my final project.

Individual Contribution

It all started with a summary of the characteristics featured in BPI's portfolio of structured products. As this task could get quite tedious and time consuming, we decided to split the products equally. What followed was the grouping of these characteristics into product classes and the development of their pricing formulas in Excel, in which I also took part. At this point, the project seemed overwhelmingly advanced. After the second reunion with BPI, we were asked to further develop the model, allowing for other features and other types of products the bank could potentially commercialize in the future. Hence, the next step was to gather information on the most commonly issued products by the main structured product issuers, in which I was in charge of the products issued by Goldman Sachs in Sweden. We proceeded to model the pay-offs for the new selected products. Here, my contribution was the development of the formulas for "Basket", “Outperformance” and the Libor-linked products. During the writing stage, I was responsible for the inputs of some products, as well as for the product scope of a few others. In general, I believe I was able to bring in useful thoughts and insights, as well as to promote enriching discussions. During the last weeks, studying for the CFA exam level 1 consumed more time than I anticipated, which ended up affecting my ability to keep up as much as I would have liked with the final perfecting of the model.

Main Challenges

Developing a model to valuate structured products from scratch was not an easy, nor straightforward task and, inevitably, some challenges arose. I will divide this section into challenges the group (as a whole) encountered and my main personal challenges.

Regarding the first, the group was always able to work every challenge around, either through internal discussion or resorting to the help of professors. In my opinion, our main challenge was to decide which criteria to follow when deciding which products to include in the model after the second reunion with BPI. The structured products universe is huge and, after having developed the model for the fair valuation of the products marketed by BPI, the group was struggling to reach a consensus regarding which products to develop next. Professor Filipa Castro suggested that we should determine the most common type of structured products issued by the major international banks. The group agreed and followed the suggestion, but the truth is that there is not a universally correct answer or solution to the problem. Another big challenge I can name is the constant and continuous concern regarding the model size and consequent Monte-Carlo simulations running time. This concern was present throughout the whole project, affecting the development of formulas, allowable user inputs and ultimately, the format of the model.

Personally, the main challenge I faced was definitely the pure modeling part. In the beginning I felt a bit frightened about the extent and complexity the model could reach, but this changed once the model format was established. VBA could also have been a challenge, had I not had colleagues who felt comfortable working with the program. Professor Afonso Eça, also played a critical role, by helping us with every doubt we had on the topic and suggesting a few valuable improvements.

Key Learnings

Overall, this project has been a very enriching and rewarding experience and has definitely matched my expectations. The key takeaway is undoubtedly the close contact with real life structured products and the application of my theoretical insights to their valuation, which was my main motivation when applying for this project. It is very likely that I will work with structured products during my first job, which only enhances the importance this project will have on the beginning of my professional life. In fact, I can say it has already started paying off, as it helped me prosper on an interview for a structured products related position.

In addition, despite of the ease with which the group got along since day one, this project stimulated team-working skills, which will certainly be a plus throughout my professional life. Among these, it is important to highlight the ongoing group communication and enlightening discussions that were achieved during these months, as well as the group's capacity to efficiently allocate tasks.

Finally, working on such an Excel intensive project with a group that felt comfortable and worked on it naturally and effortlessly, allowed me to sharp and develop financial modeling skills, especially in what regards to presentation.

5.4 Maria João Abreu

Introduction

The present section aims at explaining, summarily, my personal perspective on the development of the work project 'BPI Consulting Project – Structured Products'. Besides the hard skills required to carry out such project, the soft skills played an important role as teamwork and communication were essential for its success. However, challenges are inherent to such ventures and will be highlighted below. All in all, I believe that this project was extremely beneficial to all group members as it proportionated a steep learning experience in all fields.

The first section refers to previous knowledge and motivation for this project; the second refers to individual contribution; the third to main challenges faced; and, lastly, key learnings are described.

Background

A field lab was a novelty and my immediate choice out of all the possibilities within NOVA's offering. Even though all Work Projects had interesting and attractive aspects, my choice was based on three drivers: (1) Desire to gain work experience whilst finishing my master's degree; (2) Ability to explore the consultancy world; and, (3) Possibility to work in a group setting and learn from others.

Furthermore, allying consulting with financial markets at a bank of renowned prestige, the field lab offered by NOVA at BPI came, as an extremely interesting opportunity and one I very much looked forward to. Besides the scope of the project, I desired to learn from the whole group, and the organization itself. The prospect of re-entering a firm and contributing to its growth was a great stimulus to deliver my best self.

During the first year of the master's program, the learning curve was exponential. I believe that the solid set of courses I was exposed to, gave me the skills I needed to be prepared me for this final phase: the work project.

During the first semester, **Investments** covered several topics such as Portfolio Management, Factor Models and Real Options, and allowed for an initial broad understanding of the majors areas of investment. Option pricing and the Black-Scholes Model triggered my interest the most and influenced my elective choices for the following trimester.

The **Derivatives**' course scrutinized this field of finance and all aspects of option pricing, allowing for a true understanding the mechanics behind the value of each option and how each product works.

Finally, I feel that **Financial Modelling** was crucial for the development and conclusion of the project. Being the final output of this project an Excel Model this course became a key tool to understand and learn how to correctly build it, allowing for increased user experience. Furthermore, the course touched upon the use of VBA in Excel which was also an important component of the final valuation model we built. a.

Individual Contribution

Since the beginning, the project was carried out as a group, leaving little space for specific individual work. This is, the individual knowledge of each member contributed to the group as a whole and so we worked together in building the model. However, as previously mentioned, the project started off with data research and gathering of information. Having more than fifty different products within BPI's portfolio, we decided to equally split the products in order to retrieve their characteristics for future modelling. Later, when gathering the market information regarding the major financial institutions' offering, we proceeded similarly and split the banks between the group members. In my case, I retrieved information on 11 BPI products and the offerings from Citigroup in the available countries. The second phase of the project consisted of splitting the characteristics between the group members and modelling them. For instance, I developed the 'Multi-Barriers' and the 'Knock-out' computation sheets. During the whole process of building the model, I also focused on the formatting of the document and the development of VBA Excel Macros for the Monte Carlo Simulations and input messages. However, all team members proactively helped one another in their tasks and so I feel that this phase of the project was, likewise, completed as a group. Finally, regarding the final report, we agreed that it would be more efficient to, again, split tasks and thus each member would be in charge of specific components. Personally, I handled the *Introduction*, *User Manual – Inputs* and *User Manual – Engine Sheets*. Moreover, I was in charge of gathering the several parts and reviewing the whole document, as well as formatting it.

Main Challenges

Before starting the project in September, I had some reservations towards it. Firstly, concerning required hard skills to pursue this challenge. However, during the summer holidays Professor Filipa Castro scheduled a meeting during which she managed expectations and was able to deliver a clear set of requirements. Thus, I was able to study the topics that I was least comfortable with and be, from the start, at ease with the project. Secondly, I was concerned with the group since it was not until the kick-off that I got to meet my colleagues. This concern quickly faded when I realized that I knew most of the elements and I was reassured after the first work session, where we immediately synced and started working together greatly.

During the course of the project, the main challenges concerned (1) Product Scope – There was a large spectrum of information which, at first, did not present itself clearly and, thus, required extra study and mutual aid; (2) Client expectations – Halfway through the project, we met with the client in order to show progress. During this meeting, the client asked to extend the model in order to incorporate new products which could be included in their portfolio. This represented a new set of workload which was not expected at first and posed the challenge as to what products to include given the large variety available; (3) Software requirements – The intricate calculations and the VBA Macros included increased the Excel file's size and, consequently, transformed the model computations into a very time consuming process.

To overcome the first challenge faced, with either sources of information (client and market) we decided to split the available information and, therefore, each one focused on a set of information and then shared with the team. This way, we were able to avoid inefficiencies and quickly get set for modelling.

Regarding client expectations, jointly with our advisor Filipa Castro, we were able to decide a series of criteria for such selection. These were based on the most tradable products available in the market and the probability of them being transacted by BPI. Knowing that the client has already a business relationship with Société Général and Morgan Stanley, these two banks' offerings were the first resource of additional information. We then considered broadening research to other major banks as these are representative of the structured products' market in Europe. Finally, we relied on Bloomberg and its function 'Derivatives Library' to gather further products available in the market.

Finally, software requirements were another issue solved with the help of an Associate Professor at Nova SBE, Prof. Afonso Eça. As our former teacher for Financial Modelling, he was the adequate person to help with this VBA Excel Macro problems. After two meetings, we were able to develop a macro that, from the main Excel document and constrained to the user choice of product, performs the payoff calculations on a separate excel sheet returning final results thereafter to the main document, and thus reducing the calculations performed on a single Excel document.

Key learnings

The BPI Consulting Lab was quite the experience. I believe that it impacted me at a personal as well as professional development level.

On one hand, the project enabled knowledge consolidation on Structured Products and all the components required to value them. More than learning new concepts, one was able to apply 'class-notes' onto a real-life problem thus materializing previous concepts, which is an extremely rewarding feeling. On the other hand, it clearly displayed the demands of the consulting profession. Here, the relationship with the client is of utmost importance since it will allow for the flow of information and constructive feedback, in order to deliver the best project possible that will fulfill client's needs.

I feel that I gained the most from the experience of working with a group of friends. Teamwork requires thorough communication, detailed organization and intragroup support, all of which contribute to the bettering of the final output. I was able to exercise project management, develop my listening and leadership skills, trying simultaneously to be a fair team player. These are truly valuable skills for the future both at personal and professional level, whatever path.

I truly enjoyed this type of work and envision myself as a business consultant. The constant challenges, the dynamism of the projects and the ability to work with a diverse group, developing communication skills and forming new relationships, are all attractive aspects of the consultancy world.

5.5 Pedro Alexandre

Introduction

The next segment contains a brief description and reflection of my participation in a stimulating group consulting project issued by BPI with the one goal: design a model to price structured products transacted by the bank.

The reflection was split into 4 parts: *Background* – where the main focus was the skills pre-developed in order to fulfill and accomplish this task as well as the motivation to participate in this specific project; *Individual Contribution* – a division that contains a few considerations about my evolution and contribution during the project; *Main Challenges* – this section reports the big obstacles and setbacks faced; *Key Learning* – this point sums-up all the thoughts and learning aspects gained.

Background

As a Finance Master's student, I was looking for my final master thesis to be a thought-provoking, practical and attractive project. These were three criteria that made me decide that the BPI's field lab was the right choice. First, it presented an interesting topic to work with, given that structured products, due to its complexity, tend to be marginally referred in finance courses, so there was plenty of room to extend my knowledge in this area. Moreover, it held a strong practical process requiring modeling and coding ability in VBA. Lastly, for a finance student with a strong background in financial market courses, dealing directly with the theoretical topics and mechanisms acquired and, in a widely way, putting that know-how into practice, revealed to be a huge and appealing test. All this complemented by the opportunity to represent NOVA SBE in a consultancy project for a bank of high prestige and excellence as BPI, made it a brilliant initiative to prepare the transaction between the academic and professional world.

In addition, the circumstance of working in a team brought to the equation a different context and the need to upgrade other skills such as communication, organization, and compromise. The chance of working in a group composed by members with different backgrounds and insights in Finance and learn from them, revealed to be a one-time opportunity. Having everyone contributing, fostered the individual development of all members, in a fast-paced, exciting and familiar environment.

The Master in Finance had already provided m amazing foundations, in areas of corporate finance, banking, and financial markets. The courses that I think that helped me the most in this project were Derivatives and Fixed Income.

The first presented me a profound awareness of the options characteristics including exotic options, permitting this way to fit properly the aspects and payoffs of these instruments to the right pricing method.

Then, Fixed Income prepared me and gave me a broad understanding of debt instruments. How to value these products, measure the risk associated with them and how to manage it. Topics such as fixed income securities, interest rate risk management and interest rate derivatives contributed to the comprehension of some of the key aspects of structured products.

Overall, these two courses were crucial to formulate and build correctly the core computations and the steps in the model.

Individual Contribution

As mentioned, this project was a finance consultancy project for BPI. To contextualize, in the kick-off meeting with our client, the goals and the expectations from the point of view of the Bank were established. That meeting in addition to the technical information provided and collected later, regarding the products commercialized guided us by defining a start point, a base idea for our model. Here, the strong organizational skills of the team had a huge impact, with a quick analysis and record of the characteristics of the instruments performed.

When we figured out what type of information we had, the next question was how to proceed. In general, each step of the assignments was developed or had some touch ofall team members due to its data and time intensive requirements. Therefore,, it becomes difficult to point out specific the individual contribution.

Yet, given the set of tasks performed, I consider my first big contribution to the project was to propose a design for displaying the diverse income parts of these products, namely a division of the payoff into 3 segments: Notional Value, Fixed and Variable Component; this adopted organization helped to structure the model in a more efficient way connecting common characteristics among different financial instruments.

Additionally, I had the chance to model and create the formulas for some of the products such as “Factor x performance”, “Cliquet” or “Twin win”, and afterwards the respective description in the manual. From the beginning, the group tried to construct the Excel model in a clean and clear way for two reasons: to avoid confusion and complexity - that could bring problems in the later stages, to repair or check any unexpected issue - and to produce a user-friendly model. At this stage, the interaction and coordination with my colleagues were crucial to effectively build the first version of the model. Once we developed the initial model, we met again with the bank to collect feedback. We evaluated the progress, and understood which features could be added. The main request was to prepare the model to deliver a report of the simulation, and here it was where my second biggest contribution took place. I became responsible for developing a macro to display the report and design the output. The Financial Modelling Professor, Afonso Eça, played a determinant role in the discussion of developing the code.

Wrapping-up, I would like to highlight the constant the contact and communication among group members, a fact only possible because of the good relationship that was created between our team, our supervisor and the bank's representatives. It was always visible the effort that each one made to help, to push and cheer the colleagues, and demonstrate the availability to answer any doubt or request. I hope to have met the expectations of my colleagues that were amazing throughout the entire process.

Main Challenges

This project brought some interesting challenges to the team and to myself. At the top, the initial fear and concern the team had to meet the high standards that Nova SBE and BPI demand. This required a high level of interaction and preparation from the group.

Focusing on the project itself, I would highlight two big challenges: the first one being finding an equilibrium among the client expectations and the effectiveness of the model. The desire to obtain a model as generic as possible able of value as many products as the ones found in the market requires a large set of formulas and links that make the excel model heavy and slower than what should be desirable. So, rearrange everything properly to not compromise the dynamics of the model with the vast amount of formulas was a massive challenge. The solution was to outsource some of the intermediate computations and use other excel workbooks to compute those steps. Finally, everything was connected through a VBA code that opens without the user even realizing.

The second obstacle was to calibrate properly the model. With all the information and data collected, I believe that the main difficulty was not to formulate the payoff but was instead, to make sure that the numbers were correct and final result was accurate and reliable. For most of the products, we got small differences to the reference price. Not all the major financial institutions provide the current price for these assets and when they do it, they don't explain the assumptions, so it was necessary to have an intense examination of the all simulated payments, to be sure they make sense.

Key learnings

Honestly, I believe this was the most exciting and educational field lab. It provided a professional experience on one key topic in the financial markets area. This project permitted to solidify my knowledge and interest in this area, besides the fact that it has the advantage of applying the theory to the common practices in the industry.

Personally, I developed my hard skills, putting into practice the concepts I had been studying during the Masters, which made my task vibrant. The intense research done delivered more detailed information which made me more aware of the characteristics of these products. Also, given the strong technical component, I had the chance to improve my financial modelling skills.

But it was not only the quantitative skills that I had the chance to improve. The soft skills had a very important role in the entire project. Effective teamwork, requires collaboration and the compromise of diverse skills and ideas to promote efficiency, fluency and speed in the whole problem-solving process. Without an assertive and clear communication, it would be difficult to work on this project, given the large quantity of data operated and steps executed.

In conclusion, I think I was useful helping others and myself to achieve our best potential contributing to deliver a high-quality output.

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Appendix

Appendix 1 – BPI's structured products

The data collected is summarized in the following tables. The first one presents the record of the structured products sent by BPI at the beginning of the project. Here, is presented the identification number of the products and the respective typology.

Category	Year	ISIN	Typology
Ceased	**2013**	PTBB4VOM0005	Autocallable
Ceased	**2013**	PTBB5TOM0008	Autocallable
Ceased	**2013**	PTBB5UOM0005	Autocallable
Ceased	**2013**	PTBBBIOM0013	Autocallable
Ceased	**2013**	PTBBBNOM0016	Autocallable
Ceased	**2013**	PTBBPGOM0027	Autocallable
Ceased	**2013**	PTBBQ4OM0023	Autocallable
Ceased	**2013**	PTBBQ7OM0020	Autocallable
Ceased	**2013**	PTBBQDOM0029	Autocallable
Ceased	**2013**	PTBBQIOM0024	Autocallable
Ceased	**2013**	PTBBQXOM0025	Autocallable
Ceased	**2013**	PTBBQZOM0023	Autocallable
Ceased	**2013**	PTBBR5OM0038	Autocallable
Ceased	**2013**	PTBBR7OM0036	Autocallable
Ceased	**2013**	PTBBS3OM0012	Autocallable
Ceased	**2013**	PTBBSLOM0001	Autocallable
Ceased	**2013**	PTBBSWOM0024	Autocallable
Ceased	**2013**	PTBBSYOM0022	Autocallable
Ceased	**2013**	PTBBTAOM0029	Autocallable

Ceased	**2013**	PTBBTGOM0023	Autocallable
Ceased	**2013**	PTBBTHOM0022	Autocallable
Ceased	**2013**	PTBBTKOM0027	Autocallable
Ceased	**2013**	PTBBTLOM0026	Autocallable
Ceased	**2013**	PTBBWFOM0029	Autocallable
Ceased	**2013**	PTBBWROM0017	Autocallable
Ceased	**2013**	XS0637183194	Autocallable
Ceased	**2013**	XS0637183434	Autocallable
Ceased	**2013**	XS0848936927	Autocallable
Ceased	**2013**	XS0849852792	Autocallable
Ceased	**2014**	PTBB33OM0009	Autocallable
Ceased	**2014**	PTBBQJOM0023	Autocallable
Ceased	**2014**	PTBBQKOM0020	Autocallable
Ceased	**2014**	PTBBQLOM0029	Autocallable
Ceased	**2014**	PTBBRVOM0026	Autocallable
Ceased	**2014**	PTBBS2OM0039	Autocallable
Ceased	**2014**	PTBBS8OM0025	Autocallable
Ceased	**2014**	PTBBSGOM0032	Autocallable
Ceased	**2014**	PTBBSXOM0031	Autocallable
Ceased	**2015**	BPI Tecnológicas EUR 2015	Autocallable
Ceased	**2015**	BPI Tecnológicas USD 2015	Autocallable
Ceased	**2015**	PTBB9POM0008	Autocallable
Ceased	**2015**	PTBBBJOM0012	Autocallable
Ceased	**2015**	PTBBQ4OM0031	Autocallable
Ceased	**2015**	PTBBQ7OM0038	Autocallable
Ceased	**2015**	PTBBQPOM0033	Autocallable

Ceased	**2015**	PTBBSQOM0022	Autocallable
Ceased	**2015**	PTBBWPOM0035	Autocallable
Ceased	**2015**	PTBPIROM0019	Autocallable
Ceased	**2015**	PTBPIUOM0014	Autocallable
Ceased	**2016**	ALEMANHA EUR 2016	Autocallable
Ceased	**2016**	CONSUMO EUR 2016	Autocallable
Ceased	**2016**	EMPRESAS LIDERES EUR 2016	Autocallable
Ceased	**2016**	ENERGIA EUR 2016	Autocallable
Ceased	**2016**	HEALTHCARE EUR 2016	Autocallable
Ceased	**2016**	MARCAS DE PRESTIGIO EUR 2016	Autocallable
Ceased	**2016**	TELECOMS 2016	Autocallable
Ceased	**2016**	PTBPMGOM0016	Autocallable
Ceased	**2016**	XS1374813241	Autocallable
Ceased	**2017**	FARMACEUTICAS EUR 2017	Autocallable
Ceased	**2017**	TELECOMUNICACOES EUR 2017	Autocallable
Ceased	**2017**	PTBBQ8OM0029	Autocallable
Ceased	**2017**	XS1212311317	Autocallable
Ceased	**2017**	XS1322383677	Autocallable
Traded	**2015**	XS1138857856	Autocallable
Traded	**2015**	XS1138858078	Autocallable
Traded	**2015**	XS1138860561	Autocallable
Traded	**2017**	XS1574508757	Autocallable
Traded	**2017**	XS1575061962	Autocallable

Traded	**2017**	XS1575062002	Autocallable
Traded	**2017**	XS1575062184	Autocallable
Traded	**2017**	XS1619502203	Autocallable
Traded	**2017**	XS1619503862	Autocallable
Traded	**2017**	XS1622971478	Autocallable

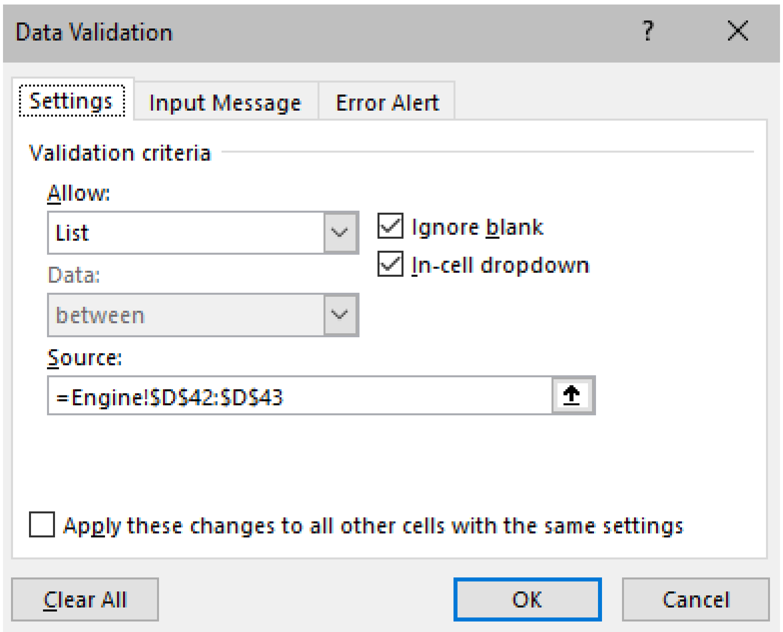
Appendix 2 – Structured Products benchmark

This second table summarizes the typology of products found in the major financial institutions that commercialize and trade this kind of asset.

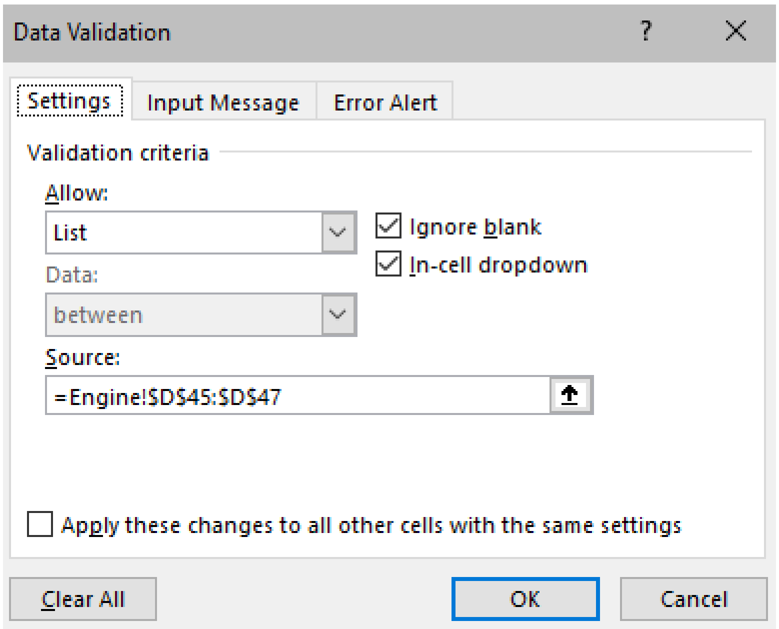
Financial Institution	Country	Type of Product	Special Characteristic
JP Morgan	UK	Autocallable	
	Austria	Reverse Convertible Altiplano	
	Denmark	Certificates	
	Germany	Reverse Convertible Multi assets express Range Accrual	
	Italy	Certificates Twin Win	
	Luxembourg	Certificate	
	Switzerland	Reverse Convertible Phoenix Auto-call Outperformance Capital Protected Note Vanilla (Plain) Knock-In Reverse Convertible Booster Certificate Bull Asian Callable Range Accrual Note	
	Netherlands	Certificates	

Citi-Group	Portugal	Knock-Out	
	Germany	Capped Bonus Reverse Bonus Capped Reverse Bonus Capital Protected Index Tracker Outperformance	
	UK	Plain Vanilla Autocallable	
	Netherlands	Knock out	
	France	Capped Bonus Certificates	
BNP	UK	Phoenix	
HSBC	US	Other	HSBC Market-Linked CDs
Goldman Sachs	Sweden	Auto Callable Phoenix Worst of Autocallable Certificates	
Morgan Stanley	UK	Autocallable Knock out Booster Outperformance Index Tracker	

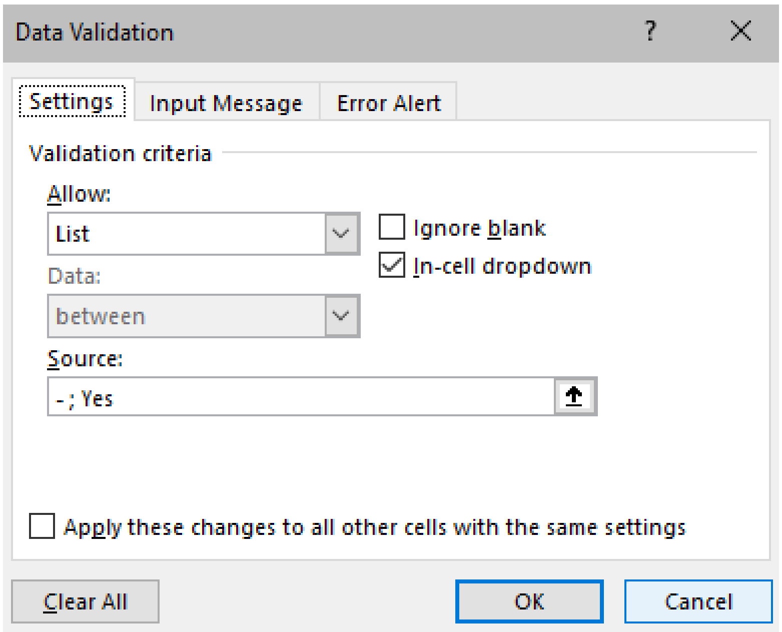
Appendix 3 – Data Validation Criteria (Notional Value)



Appendix 4 – Data Validation Criteria (Underlying Performance)



Appendix 5 – Data Validation Criteria (Payment Dates)



Appendix 6 – Monte Carlo Simulations Macro [2]

Sub Macro1()

Application.ScreenUpdating = False

numbertrials = InputBox("Number of trials")

Worksheets("MC_Index1").Activate

'clear previous trials

Range("G12:XFD3672").Select

Selection.ClearContents

Worksheets("MC_Index2").Activate

[2] Note that this appendix contains solely the first part of the macro. Since computations conditional to the "ActiveCell", there are several blocks and we thought this segment illustrates clearly such computations.

```
'clear previous trials
Range("G12:XFD3672").Select
Selection.ClearContents

Worksheets("MC_Index3").Activate

'clear previous trials
Range("G12:XFD3672").Select
Selection.ClearContents

Worksheets("MC_Index4").Activate

'clear previous trials
Range("G12:XFD3672").Select
Selection.ClearContents

Worksheets("MC_Index5").Activate

'clear previous trials
Range("G12:XFD3672").Select
Selection.ClearContents

Sheets("IO").Activate
ActiveSheet.Cells(27, 3).Select

If ActiveCell = "1" Then
```

```
Worksheets("MC_Index1").Activate

    For ii = 1 To numbertrials

    'copy dynamic price path
    Range("E12:E3672").Select
    Selection.Copy
    'paste special values
    Cells(12, ii + 6).Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

    Next ii



ElseIf ActiveCell = "2" Then

Worksheets("MC_Index1").Activate

    For ii = 1 To numbertrials

    'copy dynamic price path
    Range("E12:E3672").Select
    Selection.Copy
    'paste special values
    Cells(12, ii + 6).Select
```

```
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

    Next ii

Worksheets("MC_Index2").Activate

    For ii = 1 To numbertrials

    'copy dynamic price path
    Range("E12:E3672").Select
    Selection.Copy
    'paste special values
    Cells(12, ii + 6).Select
    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
        :=False, Transpose:=False

    Next ii

(…)
```

Appendix 7 – Output Sheet

Ficha de Avaliação

Características:

Tipo de Produto:

Data de emissão:

Data de maturidade:

Especificidades do produto

Valor nominal:

Valor Nominal garantido à maturidade?

Reembolso antecipado?

Critério De Desempenho:

Barreira(s):

Pressupostos para cálculo:

Nº de simulações (Monte Carlo):

Taxa de desconto:

Underlying assets:

	Volatility	*Expected Return*	*Dividend Yield*

Data de Avaliação: **Fair Value**: