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FTSE 100 Index Linked Structured Financial Product Pricing Analysis

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Abstract: Since facing widespread skepticism after the 2008 economic crisis, nowadays structured products have gradually become the preferred investment choice for individual consumers, driven by the development of technology and economy. This study analyzes the price of the two most recent structured products offered by Lowes, which closely resemble the FTSE 100 index. It focuses on analyzing the differences in predicted returns resulting from modest structural changes and explores the best solutions for different time periods. The variability is determined by combining historical variability with the GARCH model, based on the principle of Risk Neutral Pricing Theory. The final result is acquired by the application of the Monte Carlo simulation method. Based on the trial results, product B has a greater yield rate compared to product A, although being more conditional. This compensates for the shortage and resulting in a much higher yield rate for product B. Furthermore, based on the findings on the projected output of various investment goods over different time periods, it can be observed that as the length increases, the anticipated return also increases. Ultimately, the sensitivity analysis reveals that the primary source of product risk stems from the impact of risk-free yields on this particular product.

Keywords: GARCH, Risk Neutral Pricing Theory, Monte Carlo simulation, sensitivity analysis

1. Introduction

Structured products were introduced in the United States throughout the 1980s.The initial offerings consisted of the Spring 1987 Market Index Deposit CD from JPMorgan Bank and the Stock Index Account from North American Trust Bank[1]. Since 1992, major financial institutions such as banks and securities companies have implemented a range of diverse structured products[2]. During the 1990s, structured products were introduced to the Asian market and experienced significant growth in Japan, Singapore, and South Korea[3]. During the onset of the 2008 sub-credit crisis, which led to a global financial crisis, the financial markets experienced severe instability. This resulted in substantial losses for the creators, issuers, and investors of certain structured products. Additionally, complex structural products came under scrutiny and the markets started to contract[4]. In recent times, due to the progress in economic growth and financial technology, an increasing number of individual customers are becoming interested in structured products.

Andreas Blumke categorizes purchasers of structured products into two groups: Institutional buyers and Private buyers[5]. An institutional investor will choose for structured products as an

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investment instrument when other conventional options are unavailable or unsuitable for meeting their investment requirements[5]. Private investors typically have less complex requirements and objectives. Their motivations for holding structured products include the potential to achieve higher returns compared to a risk-free interest rate, optimizing investment performance, and participating in the performance of an underlying asset while safeguarding their principal either conditionally or unconditionally[5].

Foreign scholars mostly employ financial engineering tools in the analysis of structured product design to break down, merge, or create new structured products. A survey conducted by Wolfgang Drobetz and Hubert Dichtl in 2010 revealed that the overwhelming majority of investors have a preference for insurance strategies, and structured products effectively fulfill their requirements[6]. Foreign scholars primarily employ quantitative analysis as the principal research method in the study of pricing structured products. The Black-Scholes formula, which is a fundamental concept in the realm of options pricing, was initially introduced in a publication authored by Fischer Black and Myron Scholes in 1973[7]. This model provides a solution for the value of the option in a scenario where risk measurement is not considered. Boyle initially employed the Monte Carlo simulation to determine option prices[8]. The underlying premise is that, assuming the law of large numbers, we can estimate the expected value of option prices by extensively modeling the trajectory of asset price fluctuations. Tunaru & Eales were the first to utilize path-dependent pricing in order to value options that are incorporated in structured finance instruments[9]. In their empirical study, Phelim Boyle and Bernard examined the structured products of two linked stocks[10]. The results indicated that an overestimation of the potential for investors to get large returns from these structured products resulted in their being priced too high. A study conducted by Prigent & Bertrand revealed that in the majority of nations, structured products exhibit premium concerns that pose challenges for ordinary investors to identify and increase the likelihood of falling into the high investment trap[11].

This article selects structured items linked to the FTSE 100 from the large range of options available in the market for individual consumers. Structured financial products are favored due to their capacity to offer a tailored combination of risks and returns, which aligns with market demand and trends. FTSE 100 serves as a comprehensive indicator of the overall performance of the UK market. It offers a tangible and useful example for studying structural products, particularly in relation to the influence of market volatility and economic fluctuations.

Hence, the objective of this paper is to assist inexperienced investors in making informed assessments of the worth of investments in structured products tied to the FTSE100 index. Additionally, it aims to encourage the implementation of more effective risk management strategies, enhance the sophistication and integrity of the derivatives market's product structure, and foster alignment in product pricing and risk management practices. This Paper chooses the Monte Carlo simulation and takes two different methods to measure the violation rate. Ultimately, there will be sensitivity analysis from different aspects.

2. Product Description and Pricing Model

2.1. Product Description

Lowes Financial Management has provided independent financial consulting services to individual investors across the UK since 1971. The company is renowned for its specialized knowledge in structured products. The organization possesses extensive knowledge and experience in the area of structured products, encompassing the creation and assessment of the performance of such products. Structured products typically derive their value from the performance of underlying assets, such as a stock index, and offer a degree of capital protection. We have chosen two of Lowes' most recent

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structured products, all of which are tied to the FTSE 100 Index. However, each product has a distinct set of rules governing its structure.

The Product A Walker Crips UK 95% Annual Kick-out Plan (CA080) offers a profit of 7.75% per year if the FTSE 100 index reaches or exceeds 95% of its initial level. This profit can be claimed on any anniversary starting from the second year. And the Product B Walker Crips UK Semi-Annual Kick-out Plan (HS443) offers a potential annual return of 8.50% (4.25% per semester). The payment can be made on any half-day observation date starting in the second year, as long as the FTSE 100 index is at or above its original index level. Here is the specific information for product A, B:

Product A named as Walker Crips UK 95% Annual Kick-out Plan (CA080) is linked with FTSE 100 Index and has 7 years as maximum term. The actual product return rate is calculated as follows: (1) on any half-year observation date starting in the second year, the closing price of the Index is equal to or higher than 95% of the initial index level: planned expiration and receipt of a return of 7.75 %. (2) Plan fails to expire early and the final index level is below 95% of the original Index level: no return of return, full return of investment funds. (3) Plan fails to expire early, and the Final Index level is 35% or more lower than the initial index level: the final Index level will be reduced by 1% each less than the original index level.

Product B named as Walker Crips UK Semi-Annual Kick-out Plan (HS443) is linked with FTSE 100 Index and has 6 years as maximum term. The actual product yields are calculated as follows: (1) on any half-year observation date starting in the second year, the closing price of the index is equal to or higher than the initial index level: planned expiration and receipt of a return of 8.50%. (2) Plan failed to expire early and the final index level is below the initial index level: no returns, full return of investment funds. (3) Plan fails to expire early, and the Final Index level is 40% or more lower than the initial Index level: each end index level falls below the original index level by 1 %, the investment capital will decrease by 1%.

It is noteworthy that we discovered two really comparable goods, labeled as "preferred" and "advised only," on the official website of Lowes Comparison Structured goods: A, B, and B. We want to develop a comprehensive pricing model for structured products that thoroughly evaluates the risks and rewards associated with various return rules, thereby assisting investors in making optimal decisions.

2.2. Pricing Model

First it is necessary to check whether the stock data for the FTSE 100 index is stable, and then calculate the fluctuation under the GARCH model based on the time sequence model determined from the relevant test results. The data is obtained from the London Stock Exchange about the FTSE100 for five years. We have a better adaptive model for equity-price-reduction to reduce the sensitivity of extreme values.

Equivalent rate of return for index price is obtained using formula (1):

$$R_t = log(P_t) - log(P_{t-1})\text{R} \quad (1)$$

Where R_t is the log return at time t, and P_t is the price at time t. Then draw a moving image of the perpendicular yield as shown in Figure 1.

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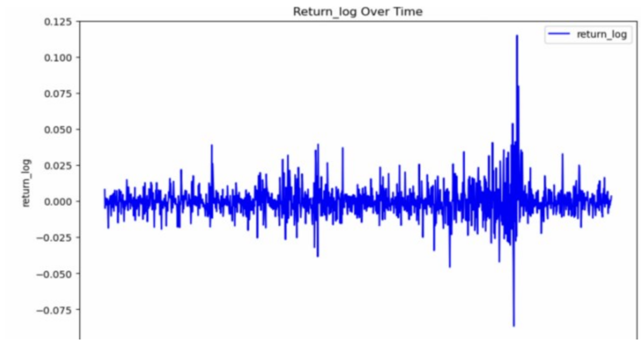
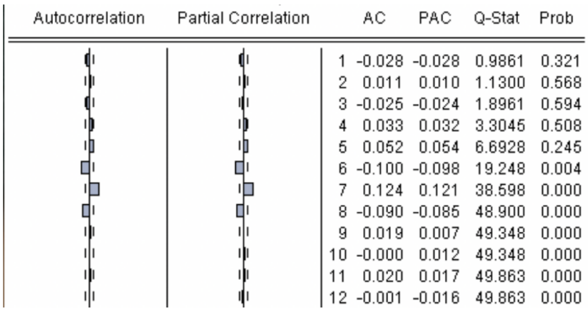


Figure 1: The tendency of R_t.

As shown in figure 1, it is obvious that the FTSE 100 index's counterpart yields fluctuate approximately around a certain horizontal line, and are similar in magnitude, which is preliminarily judged as a smooth time sequence.

The ADF unit root test of R showed that P values are almost zero at the level of 1%,5% and 10%, so it is possible to assume that the R time sequence is flat and no unit root[12]. Afterwards, the peripheral yield sequence is evaluated by autocorrelation test.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.028	-0.028	0.9861	0.321
		2	0.011	0.010	1.1300	0.568
		3	-0.025	-0.024	1.8961	0.594
		4	0.033	0.032	3.3045	0.508
		5	0.052	0.054	6.6928	0.245
		6	-0.100	-0.098	19.248	0.004
		7	0.124	0.121	38.598	0.000
		8	-0.090	-0.085	48.900	0.000
		9	0.019	0.007	49.348	0.000
		10	-0.000	0.012	49.348	0.000
		11	0.020	0.017	49.863	0.000
		12	-0.001	-0.016	49.863	0.000

Figure 2: Autocorrelation test.

Referring to figure 2, since the relevant and bi-related test results showed significant self-relevance at the sixth delay (the corresponding prob value is 0.004). Since the seventh delay, the PAC showed strong self-correlation, and this trend continued during subsequent delays[13]. This also demonstrated that the data could be modeled using an AR model of at least seven layers.

Table 1: AR (7).

	coef	std err	z	P>|z|	[0.025, 0.975]
const	-5.085e-05	0.000	-0.140	0.889	[-0.001, 0.001]
ar.L1	-0.0109	0.016	-0.670	0.503	[-0.043, 0.021]
ar.L2	0.0074	0.020	0.367	0.714	[-0.032, 0.047]
ar.L3	-0.0304	0.012	-2.490	0.013	[-0.054, -0.006]
ar.L4	0.0377	0.015	2.531	0.011	[0.009, 0.067]
ar.L5	-0.0497	0.018	2.694	0.007	[-0.085, -0.014]
ar.L6	0.0956	0.017	-5.576	0.000	[-0.129, -0.062]
ar.L7	0.1208	0.019	6.487	0.000	[0.084, 0.157]
Sigma2	0.0001	2.39e-06	50.356	0.000	[0.000, 0.000]

According to table 1, the regression equation above can be written as:

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$$R_t = -0.00005085 - 0.0109R_{t-1} + 0.0074R_{t-2} - 0.0304R_{t-3} + 0.0377R_{t-4}$$
$$-0.0497R_{t-5} - 0.0956R_{t-6} + 0.1208R_{t-7} \quad (2)$$

This paper uses two methods to calculate the volatility: the historical and the GARCH model[14][15]. First, we calculate the historical volatility. The corresponding counterpart yield R_i (i = 1,2,3......n) has been calculated for the FTSE 100 index closing price sequence P_i (i=1,2,3...n) above, then the mean value R is calculated from the formula (3) and its standard difference s is computed according to the formula (4).

$$\bar{R} = \frac{1}{n}\sum_{i=1}^{n} R_i \quad (3)$$

$$s = \sqrt{\frac{1}{n}\sum_{i=1}^{n} R_i - \bar{R}} \quad (4)$$

Where $\bar{R}$ is the mean R, and s is the day standard difference. By calculating above, the daily standard difference for the FTSE 100 parity yield is s=1.11312%, and the formula (5) converts the day standard difference to the annual standard difference.

$$\sigma = \sqrt{T} \times s \quad (5)$$

Where σ is the annual standard difference, and T is the number of trade days during one year. The general industry recognized stock market has 252 trading days a year, taking T=252 in the formula (5) and obtaining historical volatility of σ=17.67%.

Now get the volatility with the GARCH model. Based on the AR (7) model established in Table 3, this paper uses the GARCH (1,1) model for further analysis of the data.

Table 2: Variance equation of GARCH (1,1).

C	6.54E-06	1.07E-06	6.085376	0.0000
RESID(-1)^2	0.144805	0.017652	8.203412	0.0000
GARCH(-1)	0.792418	0.023705	33.42881	0.0000

As shown in table 2, the ARCH-LM test of the established GARCH (1,1) model residues, both sets of statistics are not significant and cannot refute the original assumption, proving to be good in eliminating the ARCH effect of the residual. The regression equation above can be written as:

$$\sigma_t^2 = 0.00000654 + 0.144806\varepsilon_{t-1}^2 + 0.792418\sigma_{t-1}^2 \quad (6)$$

$Where\ \sigma_t^2\ is\ annual$ variance $at\ time\ t, and \varepsilon_{t-1}^2 is\ residual\ at\ time\ t.$ Based on the adjustment result, α=0.144806, β=0.792418, α+β=0.937224<1 satisfied the constraints. Where α represents the extent of the impact of the current information counterpart on the FTSE100 earnings sequence, β represents that of the past information counter's asset earning sequence fluctuations, the long-term average variance can be found:

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$$V = \frac{C}{1-\alpha-\beta} = \frac{0.00000654}{1-0.144806-0.792418} = 0.00010418 \quad (7)$$

Where V is the long-term average variance. Then the long-term daily fluctuation rate is$\sqrt{V}$ =0.010206858. In other words, the FTSE 100 index has a daily yield volatility of 1.02%, calculated on 252 trading days per year, and the FSTE 100 has an annual volatility of 16.20%. The two methods are not significantly different in terms of value and are mutually validated, so select the estimated annualization rate under the GARCH (1,1) model as a parameter below.

The Monte Carlo simulation model depicts future cash flows based on the principle of risk-based interest rates as yield rates. The risk-free interest rate in this paper is selected as an average of 3.5% of the yield rate of the United Kingdom 10-Year Bond Yield for three years.

Ross and Cox conducted a significant study on the idea of risk neutrality, which established the theoretical basis for the Department of Asset Pricing Research. In an efficient capital market without any exchange of assets, the valuation of derivative instruments is primarily influenced by the value of the underlying asset. Consequently, the pricing equation for derivatives should not incorporate variables that reflect the investor's risk preference, such as projected returns[16].

Investors can be categorized into three groups based on their risk preferences: risk-preferent, risk-averse, and risk-neutral. The risk-neutral individual does not demand compensation for assuming risk, meaning that the expected rate of return is equivalent to a risk-free interest rate. Ross illustrates that in actual markets, the existence of a token leads to distinct risk preferences resulting in various token behaviors, ultimately restoring market equilibrium. Consequently, the concept of risk-neutral pricing is equally applicable to real-world capital markets.

The Monte Carlo simulation[17] is derived from mathematical theory, namely the central limit theorem and the law of large numbers. It involves generating sample averages and observing their convergence to the expected values. According to economic theory and the risk-neutral principle, we assume that the asset yield is a risk-free interest rate. By calculating the yield of options under different scenarios, we can then add the non-risk interest rate to the expected value, ultimately determining the approximate value of the option.

Structural product A, B is inherently influenced by the specific path it takes, making it suitable for Monte-Carlo simulation. By repeatedly simulating the asset's path using specialized software, we can assess the product's performance under various path alterations.

Monte Carlo describes a decentralized trajectory of stock price changes. From the formula (8) it is known that if the initial price S_0 is known, the next moment asset price $S_{0-\Delta t}$ could be observed. And then we can find the price of the asset at each moment.

$$S_{t+\Delta t} = S_t e^{((r-\frac{\sigma^2}{2})\Delta t+\sigma \mathcal{E}\sqrt{\Delta t})}, \quad \mathcal{E} \sim N(0,1) \quad (8)$$

of which S is the price of the asset, r is the risk-free interest rate, σ^2 is the rate of asset volatility, ε is the standard normal distribution.

The specific pricing methodology steps are as follows:

(1) simulation of the asset price of the appropriate model counterpart, deriving the price path.

(2) calculation of earnings under various possible circumstances in the year of purchase.

(3) probabilities corresponding to each scenario by frequency approximation.

(4) assignment of the earnings of the option at a risk-free interest rate to the expected earnings.

(5) repeat the steps of 2, 3, 4 to calculate the anticipated earnings that correspond to all the lengths of the optional term.

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3. The Result of Pricing

3.1. Pricing results

First, model product A. Assume that the investment amount is £10,000 and set the variable parameter: Current level of FTSE 100 S_0 = 7911.16; Time horizon of 7 years T = 7; Assume some risk-free rate r=0.035; Assume some volatility sigma =16.19%; Number of simulations: simulations =100000. After bringing the variables and parameters into the upper form (8) and using simulation in Python to simulate the FTSE 100 index change path, and increasing the number of simulations, we found that when the number increased to 100,000, the probability of the first hit in the 2nd year was stable at about 66%, with no upward and downward fluctuations exceeding 0.5%. For example, Figure 3 simulates 10 million total simulated pathways.

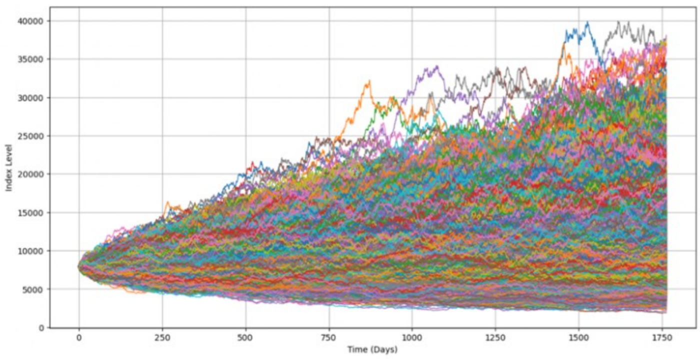

Figure 3: Simulated FTSE 100 Index paths.

Based on the figure 3, this study examines various scenarios and corresponding returns of Product A under different durations ranging from 2 to 7 years. The following figure 4 is an example of a three-year period:

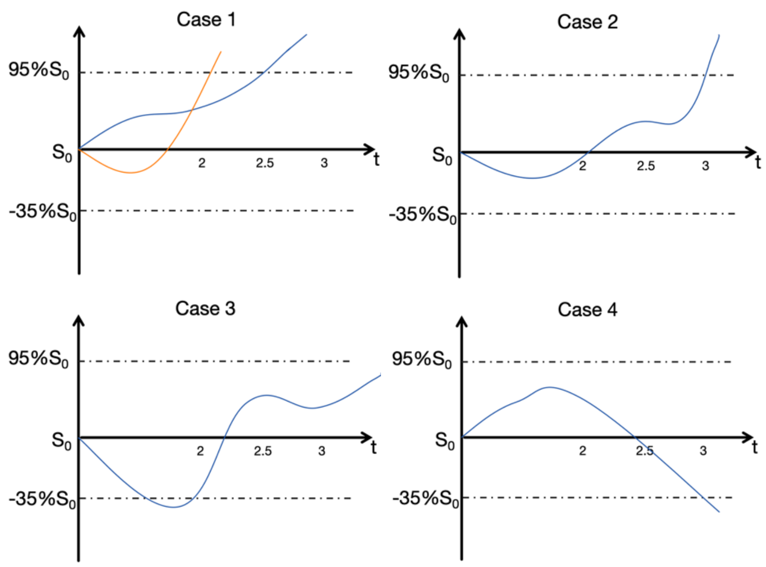

Figure 4: Cases of three-year period.

According to its rule, we analyze 4 cases for three-year period. Case1: Knock out in advance. The probability of the second year is 65.95%, and the corresponding return is $10000 \times (1 + 7.75\% \times 2) = 11550$. The second fails, but the probability of the second-and-half-year hits is 6.77%,

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and the corresponding return is$10000 \times (1 + 7.75\% \times 2.5) = 11937.5$. Case2: End-of-date knock-out. The probability of only until the third-year hits is 3.93%, and the corresponding return is $10000 \times (1 + 7.75\% \times 3) = 12325$. Case3: Only refundable at the end of the period. The probability of not being kicked out in advance, and not even kicked off at the end of the third year, is19.51%, and the corresponding return is 10000. Case4: At the end of the period, the index fell by 35% or more.

The probability of not being kicked out in advance, and falling at the end of the third period is 3.84%, and the corresponding return is 10000× r_t. r_t is the average percentage of breakdown, which is calculated as $r_t = \sum \frac{S_t}{S_0}$. S_t is the end value of all eligible. Based on the corresponding probability of the above four circumstances and the depreciation of profits, using the formula (9) the expected profit for the 3 years of purchase of product A is £250.2367603.

$$\frac{11550}{(1+3.5\%)^2} \times 65.95\% + \frac{11937.5}{(1+3.5\%)^{2.5}} \times 6.77\% + \frac{12325}{(1+3.5\%)^3} \times 3.93\% + \frac{5814.4253}{(1+3.5\%)^3} \times 3.84\% - 10000 = 250.23676 \quad (9)$$

It suggests that if the cost of purchasing the structured product, including the price of the product, consultancy costs, intermediary fees, etc., can be controlled within £250.23676, we consider the product to be profitable and worth investing in.

Repeating the above steps, we calculate expected returns for all possible durations of product A (2 to 7 years) and for all potential durations (from 2 to 6 years) of product B. The results are shown in the table 3 below (keep to two decimal places):

Table 3: Expected return of product A, B.

Period(Y)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.7	7
Product A	217.0	244.8	250.2	255.3	262.3	275.4	288.4	301.9	315.5	331.0	244.8
Product B	215.4	273.8	300.0	316.4	333.0	349.0	363.9	378.7	394.6		

3.2. Result Analysis

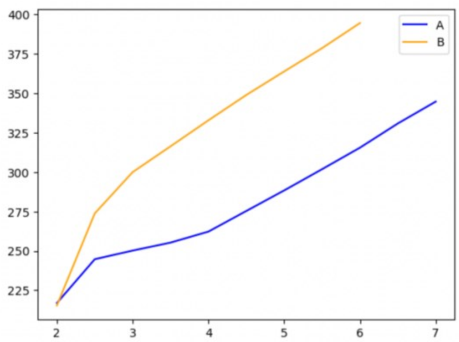

Figure 5: Visualization of expected return of product A, B.

Figure 5 shows the expected earnings of products A and B for each year, from which we can draw the following conclusion: (1) product B's expected earning is higher than that of product A. This paper considers that product B's overall earnings are higher than that of products A. Mainly because product B has a higher knock-out rate, it offsets the risk of breaking the threshold to product B. (2)

The longer the term of AB products, the higher the yield. After 4 years, the expected yield slope for AB products is almost the same, indicating that they are all affected by the term, and the same extent of the expected increase in yields. (3) In the second year, the expected return of product B was higher than that of product A, but during the short period from the second and a half to the third year, product B's return was significantly higher than product A. Compared to product A's relatively smooth curve, the slope for product B is greater and increases steadily.

3.3. Sensitivity Analysis

Next we only target product A, selected different factors for the expected return of product A for sensitivity analysis.

3.3.1. The Maturity Time

This may be due to the long-term interest rate risk that leads to the longer duration of the FTSE 100 index, the higher the volatility rate; and the likelihood and magnitude of upward and downward fluctuations in the FSTE 100, as shown in the analogue road map (Figure 2.3) above, are significantly higher. Corresponding to the results of the above-mentioned calculation of expected returns, we can conclude that the potential returns of structured product A linked to the FTSE100 index are greater over a longer period.

3.3.2. The Volatility

Since the historical volatility rates in the above and the GARCH model calculated as 17.67% and 16.20% respectively, in analyzing the impact of the volatile rate on expected returns, this paper further sets the volatilities at 17.5% and compares them with the expected return at the above 16.20%.

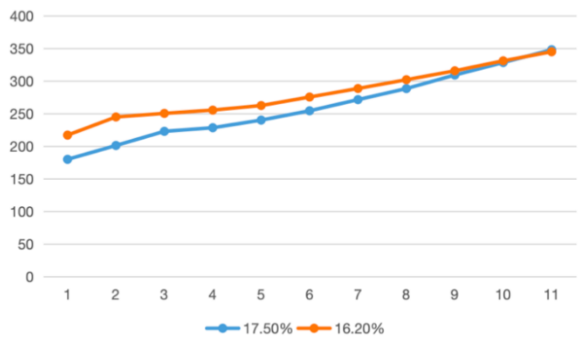

Figure 6: Compare different volatility.

As shown in figure 6, long-term structured products are more advantageous than short-term products with higher volatility rates. On the one hand, the likelihood of long-term crashes is higher, and on the other hand, it is more likely to hit the long term. After analysis, it appears that the combination of long-term market risk fluctuations and the volatility of the product itself act as a hedge, leading to increased long-term predicted returns for the product.

3.3.3. The Risk-free Interest Rate

As a result of the impact of the epidemic in 2019 and 2020, the rate of interest on British 10-year government bonds has risen rapidly, stagnating at around 3% to 4% for the past three years. Therefore, in analyzing the effect of risk-free interest rates on expected returns, this paper reduces the rate to 2%, which is also the average of the interest rate on UK 10-year Government bonds for the last five years, compared to the expected return at the above-mentioned 3.5%.

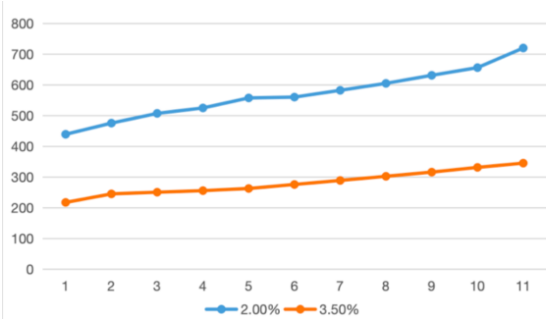

Figure 7: Compare different interest rate.

Referring to figure 7, we found that two percent risk-free interest rates and three percent non-risk interest rates had little effect on the behavior of the simulation and the probability of occurrence of the various circumstances, so their impact on expected returns was mainly attributable to the depreciation model. The lower the risk-less interest rate, the higher the expected return for the structured product.

4. Conclusion

From the perspective of the individual customer, it is important to compare similar items A and B, taking into account various alternatives available in different years, in order to select the most appropriate product. This also includes considering the mode of purchase. Within the Lowes' product interface, product B is designated as "advised only". This classification is based on a comprehensive examination of the FTSE 100 index and the outcomes of 100,000 Monte Carlo simulations. The findings indicate that product B generates higher returns compared to product A. However, there are inherent risks involved. According to the sensitivity analysis provided, the primary risk stems from fluctuations in risk-free interest rates. The primary reason for this is the significant rise in the yields of British 10-year government bonds, which have surged by almost 270 percent in the last five years. This increase has been driven by factors such as diseases and inflation.

From the issuer's perspective, it is important to assess if the yield rate of 8.5% for product B is excessively high and should be moderately decreased. Product B has more favorable output conditions compared to product A. Therefore, it is necessary to raise compensation benefits accordingly to compensate for the relative challenges of outputting conditions. This will help attract consumers in the market who are substantially more inclined to take risks. However, it is probable that 8.5 percent of product B is excessive, leading to predicted returns for product B that are considerably greater than those for product A.

Finally, this article solely analyzes the issue from the perspective of product pricing and suggests further exploration by integrating sales data of structured products. In the future, structured products based on the FTSE100 index will gradually become part of investors' wealth management options. In future research, the author or other scholars might further investigate the impact of other risks by combining consumer preferences for consumer products with behavioral finance.

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