

Yield Curve Construction of a Financial Obligation : Case « Microinsurance Foresight » product

Construction de la Courbe des Taux d'une Obligation Financière : Cas produit « Prévoyance de la micro-assurance »

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Abstract

The main objective of any life insurance company is to assess the value and profitability of its business. In developing countries, the insurance sector is only interested in people from the middle and wealthy classes, but excludes those from vulnerable social backgrounds. In these countries, including Morocco, the generalization of social coverage can only be part of the long term. By extension, and regardless of a country's level of wealth, the rate of expansion of the coverage of social protection systems is an important indicator of well-being and development. The objective of this article is to construct the yield curve of a financial obligation of the “Microinsurance pension” product at the end of the year. This construction will allow the determination of the value of new microinsurance business subscribed in a certain period without taking into account the value of existing business (the Value of Existing Business).

Keywords :

Microinsurance ; Rate Curve ; Projection ; Estimate ; Cash Flows.

Résumé

Toute entreprise d'assurance vie a pour objectif principal d'évaluer la valeur et la rentabilité de son business. Dans les pays en développement, le secteur de l'assurance s'intéresse seulement aux personnes issues de la classe moyenne et aisée mais écarte celles qui sont issues des milieux sociaux fragilisés. Dans ces pays, y compris le Maroc, la généralisation de la couverture sociale ne peut s'inscrire que dans le long terme. Par extension, et quel que soit le niveau de richesse d'un pays, le rythme d'élargissement de la couverture des systèmes de protection sociale est un indicateur important de bien-être et de développement.

L'objectif du présent article consiste à construire la courbe des taux d'une obligation financière du produit « Prévoyance de la micro-assurance » en fin d'année. Cette construction permettra la détermination de la valeur des affaires nouvelles de la micro-assurance souscrites en une certaine période sans tenir compte de la valeur des affaires déjà existantes (la Value of Existing Business).

Mots clés :

Micro-assurance ; Courbe des taux ; Projection ; Estimation ; Cash Flows.

Introduction

Improving the living conditions of low-income populations has always been at the heart of the public policies of States, the strategic decisions of major international financial and non-financial institutions, in this case the World Bank, the International Monetary Fund (IMF), the Microcredit institutions...

Is it indeed a major concern of all political actors and decision-makers in the first place in order to ensure the well-being of the poor and also to facilitate their inclusion in the societies in which they live. Many are the efforts made, the treaties signed, the programs put in place to respond to this major socio-economic problem. Nevertheless, the birth of the famous microcredit program or more broadly microfinance has borne fruit. It is a program dedicated exclusively to populations appearing at the lowest level of the pyramid hierarchy in a given economy. Microfinance was born in the early 1970s with the "Grameen Bank" in Bangladesh. Microcredits are distributed through different channels; non-governmental organizations (NGOs), commercial banks, associations and a good number of microfinance institutions (MFIs) with a view to improving the daily lives of weakened strains. However, he warned that these microcredits are not the only solution intended to protect this vulnerable social class. Micro-entrepreneurs are not immune to the various risks likely to occur (death, illness, disability, fire, etc.) at any time and put an end to their projects. When a disaster arises, these micro-entrepreneurs will have to face unforeseen expenses to repair the damage in the event of a natural disaster or to take care of the funerals themselves or their families following death or illness. One thing is inevitable, the repayment of the loans contracted is almost impossible. Therefore, insurance to cover against this bundle of risks is essential, by claiming the simplification of procedures as confirmed Wipf, J. and Garand, D. (2012).

At the end of 2021; the company, object of our study is held to make an assessment relative to this promising product. It is a question of evaluating the profitability of the microinsurance portfolio based on all the data we have to better respond to this problem. This is the framework for the yield curve approach, which consists in determining the value of new business. It is a profitability curve and an instrument for measuring the financial performance of a life insurance portfolio and an essential decision-making tool for any life insurance company. The construction of this curve is based on the projection of the population covered by the micro-insurance mechanism which will be used to project incoming flows and outgoing flows. Therefore, the questions are asked: What approach seems adequate to empirically analyze the

construction of the yield curve of a financial obligation of the “Microinsurance foresight” product at the end of the year? What are the considerations that should guide the choice of one model over another?

The first part will establish the theoretical framework for the construction of the yield curve, and it will give a more or less detailed overview of the different construction methods adopted by the literature review.

The second part will be devoted to the estimation of the yield curve in order to obtain the risk-free rates and the discount factors that will be used in the projection of cash flows.

1. Selective empirical literature review

1.1. Definition of the yield curve

In finance, the yield curve of a financial obligation constitutes the graphic representation of the interest rates observed at a given moment according to their maturities. These rates are generally actuarial rates or zero coupon rates. The most widely used yield curve is the zero coupon yield curve. It is represented on a benchmark with the bond's maturity on the abscissa axis and the interest rate on the ordinate.

A strongly positive yield curve can be interpreted as an acceleration of growth and inflation. Moreover, it can also reflect a lack of confidence in the ability of central banks to control inflation or even a slippage in the budget.

A steeply negatively sloping yield curve can be interpreted as slower growth, lower inflation, or reduced government borrowing.

In practice, on each financial market there is at all times, not a yield curve, but a multitude of yield curves.

We can distinguish two types of curves:

- ❖ Market curves or observed curves: they are constructed directly from quotations on the markets.
 - Swap rate curve;
 - Government bond yield curve.
- ❖ Implicit curves: these are deduced from market quotations of instruments such as bonds and swaps.
 - Zero-coupon rate curve;
 - Curve of forward rates;
 - Curve of instantaneous forward rates;
 - Par yield curve.

1.2. Yield curve construction methods

The constitution of the zero coupon rate curve is based on the construction of the rate curve from market data. The construction of the curve is made necessary by the fact that there are not enough zero-coupon bonds listed on the market, or if there are, they often have less liquidity than coupon bonds. Therefore, we cannot obtain the zero coupon rates for a continuous suite of maturities.

We devote this paragraph to presenting a quick overview of a few methods for constructing a yield curve from market data.

1.2.1. Bootstrap method

The Bootstrap method or the step-by-step method developed by Booth, J., Butler, R., and Hall, P. (1994). is a technique based on the assumption that the theoretical price of a bond is the sum of its flows discounted at the zero-coupon rates of the maturity of each flow. This is a multi-step method that allows you to reconstruct a zero coupon curve step by step or segment by segment of maturity.

In practice this amounts to:

- For the segment of the curve less than 1 year

We proceed to an extraction of the zero coupon rates thanks to the prices of the zero coupon securities quoted on the market and we pass thereafter to a linear or cubic interpolation in order to obtain a continuous curve.

- For the segment of the curve ranging from 1 year to 2 years

We observe the price and characteristics of the bond with the earliest maturity among bonds with maturities between 1 and 2 years. This title pays two flows, namely the discount factor of the first flow known thanks to the first step and the discount factor of the second flow which is the solution of the following non-linear equation:

$$P(0, t_2) = C \times P_{ZC}(0, t_1) + (100 + C) \times P_{ZC}(0, t_2)$$

With $t_1 \leq 1$ and $1 < t_2 \leq 2$ and C : the coupon

- For the segment of the curve ranging from 2 years to 3 years

In this step, we repeat the actions of the previous steps based on securities with a maturity between 2 and 3 years.

We proceed in this way until we obtain the segment of the curve of the desired maturity.

1.2.2. Méthode par interpolation

Generally, these interpolations are linear or cubic.

In the case of linear interpolation, we must have two zero coupon maturity rates t_1 and t_2 so that we can interpolate the maturity rate $t_1 < t < t_2$ by the following formula :

$$R(0, t) = \frac{(t_2 - t) \times R(0, t_1) + (t - t_1) \times R(0, t_2)}{(t_2 - t_1)}$$

In the second type, we proceed by segment of curves. First, we define a first segment between t_1 and t_4 where we have four rates $R(0, t_1)$, $R(0, t_2)$, $R(0, t_3)$ et $R(0, t_4)$. Second, we define the rate $R(0, t)$ of maturity t by :

$$R(0, t) = at^3 + bt^2 + ct + d$$

Finally, under the constraint that the curve passes through the four points, we are led to solve the following system :

$$\begin{cases} R(0, t_1) = at_1^3 + bt_1^2 + ct_1 + d \\ R(0, t_2) = at_2^3 + bt_2^2 + ct_2 + d \\ R(0, t_3) = at_3^3 + bt_3^2 + ct_3 + d \\ R(0, t_4) = at_4^3 + bt_4^2 + ct_4 + d \end{cases}$$

1.2.3. Vasicek's model

The model of Vasicek O. (1977) is a classic model based on the description of the evolution of interest rates. It is a one-factor model because it stipulates that a single parameter is at the origin of the deformations of the rate curve, this parameter is the short rate. This rate is modeled in the form of an Ornstein-Uhlenbeck type process, whose evolution is governed by the following stochastic equation:

$$dr_t = a(b - r_t)dt + \sigma dW_t$$

- Parameter b represents the long-term average of the short rate around which this rate evolves.
- The parameter represented the margin of variation of the short rate in the interval $[t, t + 1]$ or even the speed of reversion to the mean.
- The parameter σ represents the volatility.

1.2.4. Spline models

These models are based on modeling the discount function. They are characterized by great flexibility which allows them to reconstruct all the curve shapes found on the market. However, they present parameters that cannot be interpreted from a financial point of view. We generally distinguish between polynomial splines and exponential splines.

The method of polynomial splines consists in estimating the rate curve by polynomials defined by pieces. We commonly consider standard writing as in the following example:

$$B(0, s) = \begin{cases} B_0(s) = d_0 + c_0s + b_0s^2 + a_0s^3, s \in [0, 5] \\ B_5(s) = d_1 + c_1s + b_1s^2 + a_1s^3, s \in [5, 10] \\ B_{10}(s) = d_2 + c_2s + b_2s^2 + a_2s^3, s \in [10, 20] \end{cases}$$

Under the constraint of continuity and double derivability at the 5-year and 10-year maturity connection points.

Here, the refresh function has 12 parameters.

For $i=0, 1$ and 2 , we have:

$$\begin{cases} B_0^{(i)}(5) = B_5^{(i)}(5) \\ B_{10}^{(i)}(5) = B_5^{(i)}(10) \end{cases}$$

Then, we impose the constraint of a discount factor equal to 1 for maturity 0 : $B_0(0) = 1$

By using all of these 7 constraints, the number of parameters to be estimated drops to 5. Then, we write the functions in the following form:

$$B(0, s) = \begin{cases} B_0(s) = d_0 + c_0s + b_0s^2 + a_0s^3, s \in [0, 5] \\ B_5(s) = 1 + c_0s + b_0s^2 + a_0[s^3 - (s-5)^3] + a_1(s-5)^3, s \in [5, 10] \\ B_{10}(s) = 1 + c_0s + b_0s^2 + a_0[s^3 - (s-5)^3] + a_1[(s-5)^3 - (s-10)^3] + a_2(s-10)^3, s \in [10, 20] \end{cases}$$

We can generalize to any number of fittings. Let k_i pour $i = 1, \dots, m$, be the connection points in ascending order (in the previous case, we had $m = 2$, $k_1 = 5$ et $k_2 = 10$).

The general function is then:

$$B(0, s) = 1 + c_0s + b_0s^2 + a_0s^3 + \sum_{i=1}^m (a_i - a_{i-1})(s - k_i)_+^3$$

$$\text{With the rating } (s - k_i)_+^3 = \max(s - k_i, 0)^3$$

The exponential spline model was introduced by Vasicek OA and Fong HG (1982), where the system is written as follows:

$$B(0, s) = \begin{cases} B_0(s) = d_0 + c_0e^{-as} + b_0e^{-2as} + a_0e^{-3as}, s \in [0, 5] \\ B_5(s) = d_1 + c_1e^{-as} + b_1e^{-2as} + a_1e^{-3as}, s \in [5, 10] \\ B_{10}(s) = d_2 + c_2e^{-as} + b_2e^{-2as} + a_2e^{-3as}, s \in [10, 20] \end{cases}$$

We reduce the problem to 7 parameters to be estimated under the same regularity constraints and under the constraint linked to the discount factor. The alpha parameter is an additional adjustment parameter that makes the problem nonlinear. The idea of this method is to solve the problem as if it were fixed, then to find its optimal value.

1.2.5. Nelson and Siegel model

The method of Siegel AF and Nelson CR (1987) is one of the most important methods for estimating zero-coupon yield curves in the context where it offers a function that meets several criteria. These criteria stipulate that it is necessary to have a function whose number of parameters to be estimated is reasonable and whose form is flexible. In addition, the curve obtained must be relatively smooth to facilitate the reading of forward rates.

This method assumes that the forward rate is the solution of a second-order differential equation. The instant forward rate $f_t(\theta)$ is defined by :

$$f_t(\theta) = \beta_0 + \beta_1 \exp\left(-\frac{\theta}{\tau_1}\right) + \beta_2 \left(\frac{\theta}{\tau_1}\right) \exp\left(-\frac{\theta}{\tau_1}\right)$$

τ_1 : Maturity

Where the zero coupon rate is defined by:

$$R_t(\theta) = \frac{1}{\theta} \int_0^\theta f_t(u) du$$

Then the functional proposed by Nelson and Siegel is the following:

$$R_t(\theta) = \beta_0 + (\beta_1 + \beta_2) \left(\frac{1 - \exp\left(-\frac{\theta}{\tau_1}\right)}{\frac{\theta}{\tau_1}} \right) - \beta_2 \exp\left(-\frac{\theta}{\tau_1}\right)$$

The flexibility of this function makes it easy to calculate the partial derivatives of R_t with respect to each of the parameters β . These derivatives are called the sensitivities of the zero-coupon rates to the parameters β .

The parameters to be estimated are then: $(\beta_0, \beta_1, \beta_2, \tau_1)$.

Some of these parameters have a meaning and therefore an economic interpretation. We have:

$$\lim_{\theta \rightarrow +\infty} R_t(\theta) = \beta_0 \text{ et } \lim_{\theta \rightarrow 0} (R_t(\theta) - \beta_0) = \beta_1$$

β_0 : The level factor ie the long rate.

β_1 : The turnover factor ie the difference between the instantaneous short rate and the long rate.

β_3 : The slope factor.

τ_1 : A scale parameter intended to remain fixed over time.

In this model, we seek to minimize the quadratic difference between the price of the bond given by the model and that observed on the market.

1.2.6. Svensson's model

The model of Svensson LE (1994) presents an extension of the model of Nelson and Siegel by introducing a fourth term and a second parameter of form to the expression of the instantaneous rate of Nelson and Siegel. The rate is then written in the following form:

$$f_t(\theta) = \beta_0 + \beta_1 \exp\left(-\frac{\theta}{\tau_1}\right) + \beta_2 \left(\frac{\theta}{\tau_1}\right) \exp\left(-\frac{\theta}{\tau_1}\right) + \beta_3 \left(\frac{\theta}{\tau_2}\right) \exp\left(-\frac{\theta}{\tau_2}\right)$$

Svensson, through these adjustments, wanted to improve the flexibility and accuracy of Nelson Siegel's model, especially in the short-term sector.

The expression of zero coupon rates then becomes:

$$R_t(\theta) = \beta_0 + (\beta_1 + \beta_2) \left(\frac{1 - \exp\left(-\frac{\theta}{\tau_1}\right)}{\frac{\theta}{\tau_1}} \right) - \beta_2 \exp\left(-\frac{\theta}{\tau_1}\right) + \beta_3 \left[\frac{1 - \exp\left(-\frac{\theta}{\tau_2}\right)}{\frac{\theta}{\tau_2}} - \exp\left(-\frac{\theta}{\tau_2}\right) \right]$$

β_3 : additional curvature parameter which mainly affects the short part of the curve.

τ_2 : scale parameter.

The vector of parameters to be estimated is the following : $(\beta_0, \beta_1, \beta_2, \beta_3, \tau_1, \tau_2)$

2. Case study : Construction of the BAM yield curve

In this article, we have opted for the last two models in the estimation of the zero-coupon yield curve at 31/12/2021.

2.1. Data processing

In order to develop a zero-coupon rate curve, we used the rate curve published by Bank Al-Maghrib since it is the main source we have for making our estimate.

The yield curve on the BAM website is laid out as follows:

Table N°1: Benchmark rate on the secondary market for treasury bills dated 31/12/2021
(in millions of dirhams)

Due date	Transactions	Weighted average rate	Value date
30/01/2022	393.29	2,45%	04/01/2022
08/02/2022	221.62	2,50%	04/01/2022
14/03/2022	246.91	2,50%	31/12/2021
18/04/2022	150.05	2,47%	31/12/2021
30/05/2022	73.17	2,51%	31/12/2021
15/08/2022	40.75	2,53%	31/12/2021
20/02/2023	23.58	2,68%	31/12/2021
25/05/2023	59.68	2,69%	31/12/2021
05/04/2025	45.21	2,94%	31/12/2021
03/03/2026	53.96	3,03%	29/12/2021
02/06/2031	169.87	3,44%	31/12/2021
15/06/2032	321.79	3,62%	04/01/2022
16/04/2035	117.22	3,77%	29/12/2021
05/08/2036	176.77	3,89%	29/12/2021
19/02/2041	126.11	4,24%	28/12/2021
04/02/2042	20.46	4,38%	31/12/2021
19/02/2052	129.95	4,92%	04/01/2022
Total	2370.39		

Source: Bank Al-Maghrib website

We note from the table above that the maturities are unspecified, discontinuous and their number is limited. This lack of data forces us to produce a new table containing more maturities or at least those we need in our work (our projection period is 4 years).

2.2. Results and analyzes

It is true that the Nelson and Siegel model does not make it possible to reconstruct all forms of yield curves, in particular the forms with a bump and a trough. This limitation of the model can be remedied by the Svensson model.

In addition, the Nelson and Siegel model lacks adjustment flexibility for maturities greater than 7 years, which is not our case, since the maturities we have are less than or equal to 4 years.

2.2.1. Results of the Nelson and Siegel Model

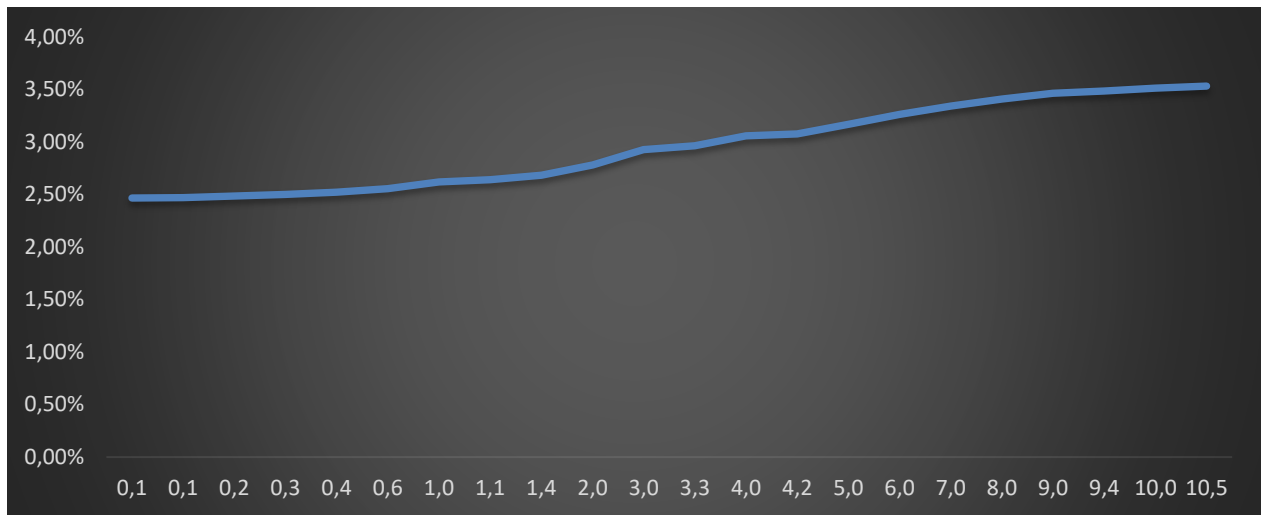
In this step, we used the Excel solver to estimate the parameters of the two models.

The initial values of the model are: [0,01; 0,01; 0,01; 1].

The Excel solver proceeds by minimizing the sum of the squares of the residuals by adjusting the values of the parameters of the Nelson and Siegel functional. The estimated parameter vector is as follows:

$$[\beta_0; \beta_1; \beta_2; \tau_1] = [0,03993449; -0,09019786; -0,00899693; 2,01603671].$$

Figure 1 : The zero-coupon yield curve estimated by the Nelson and Siegel model



Source: Produced by us

An important point, the interest rates used to construct the yield curve as shown in Figure 1 correspond to the rates of zero-coupon bonds, that is to say the rates of debt securities whose interest is capitalized, then paid when the principal is repaid.

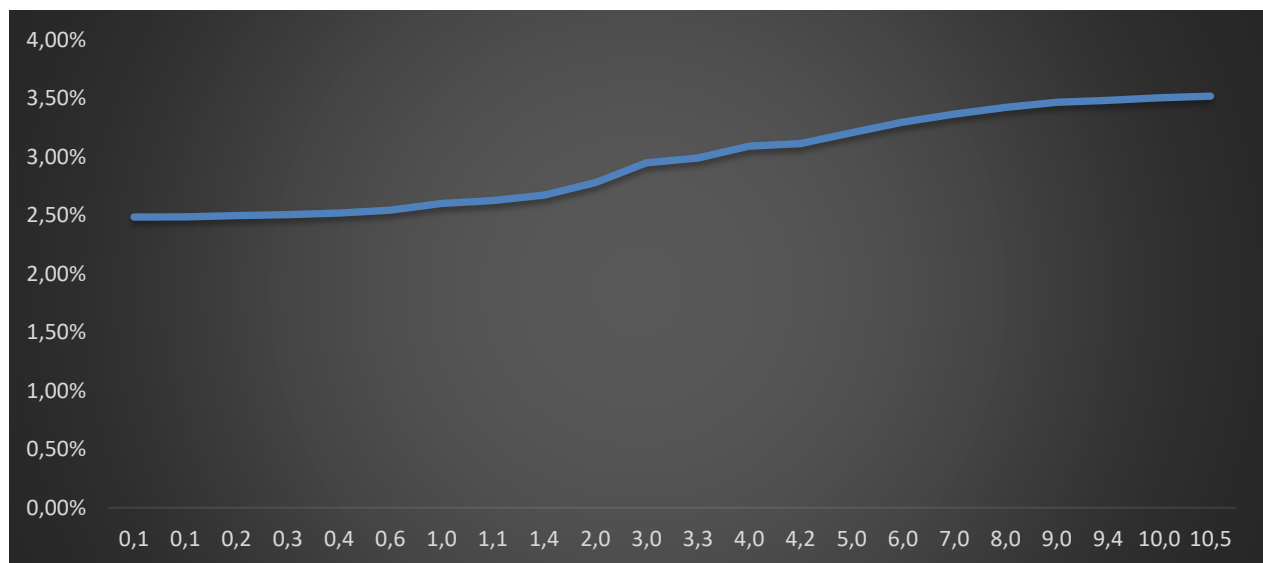
2.2.2. Svensson Model Results

The initial values of the model are: [0,01; 0,01; 0,01; 1; 1].

Similarly, the estimated parameter vector is as follows:

$$[\beta_0; \beta_1; \beta_2; \tau_1; \tau_2] = [0,03840461; -0,03146429; -0,01252183; 4,37099e - 06; 1,298810978; 1,010978544]$$

Figure 2: The zero-coupon yield curve estimated by the Svensson model



Source: Produced by us

Similarly, the interest rates used to construct the yield curve as shown in Figure 2 correspond to zero-coupon bond rates, i.e. to the rates of debt securities whose interest is capitalized, then paid when the principal is repaid.

2.2.3. Kolmogorov Smirnov test for the choice of the adequate model

Among these two models, the most appropriate should be selected for estimating zero coupon rates. To do this, we used the Kolmogorov Smirnov test.

The Kolmogorov Smirnov test is a very common nonparametric fit test. The Kolmogorov Smirnov statistic, D_n , is directly constructed from the notion of Kolmogorov Smirnov distance between two distribution functions. This distance is defined as the greatest difference between the two functions.

The statistic is therefore : $D_n = \max_x |F_n(x) - F_0(x)|$.

The null hypothesis (H_0) and alternative hypothesis (H_1) are as follows :

H_0 : The two samples follow the same distribution law.

H_1 : The distributions of the two samples are different.

We performed this test with XLSTAT software. We will test the hypothesis at the 5% level of significance.

Nelson et Siegel model

D	0,294
p-value	0,559
alpha	0,05

Given the p-value > 5%, we already accept the estimation by this model.

Svensson's model

D	0,299
p-value	0,540
alpha	0,05

Similralry, the p-value > 5%, then we already accept the estimation by this model.

Since $D_{0,05}(NS) < D_{0,05}(Svensson)$, we conclude that the model retained and which gives a good estimate is the Nelson and Siegel model.

This estimate enables us to obtain zero coupon rates or spot rates. These rates also present the risk-free rates used in the investments which generate the financial products on the reserve and the financial products on the solvency margin.

In order to have the discount factors, it is first necessary to calculate the forward rates from the spot rates. Generally, the forward rate is calculated as follows:

$$F(t_1, t_2) = \left[\frac{(1 + r_2)^{d_2}}{(1 + r_1)^{d_1}} \right]^{\frac{1}{d_2 - d_1}} - 1$$

$F(t_1, t_2)$: The forward rate between t_1 and t_2

r_1 : The zero maturity coupon rate t_1

r_2 : The zero maturity coupon rate t_2

d_1 : The number of years between the initial date and the maturity t_1

d_2 : The number of years between the initial date and the maturity t_2

In our case, the forward rate is as follows:

$$F(t) = \left[\frac{(1 + r(t))^t}{(1 + r(t-1))^{t-1}} \right] - 1$$

t : La maturité

$F(t)$: The forward rate with maturity t

$r(t)$: The spot maturity rate t

Secondly, we calculate the discount factors (the deflators) from the forward rates as follows:

$$Deflator_t = \frac{1}{(1 + F(t))} * Deflator_{t-1}$$

t : La maturité

$F(t)$: The forward rate with maturity t

$Deflator_t$: Le facteur d'actualisation associé à la maturité t

We summarize all of the above in the following table (Table 2), which only includes the maturities that interest us in the calculations.

Table 2: The different rates corresponding to the projection years from 2022 to 2025

Maturity	Year	Spot rate	Forward rate	Discount factor
				100%
1	2022	2,62%	2,62%	97,45%
2	2023	2,78%	2,94%	94,67%
3	2024	2,93%	3,22%	91,71%
4	2025	3,06%	3,45%	88,65%

Source: Produced by us

Conclusion

The purpose of this article was to construct the yield curve for a life insurance product and in particular a microinsurance product. In other words, it was a question of determining a tool making it possible to evaluate at the end of the year the value of the new business underwritten in 2021.

Before proceeding with the construction, it was inevitable to make a descriptive analysis of our data to be able to understand the behavior of the population with regard to the mechanism of microinsurance. Additionally, we analyzed microinsurance performance indicators with the aim of providing critical insight into product performance.

As for the construction of the yield curve, a plurality of approaches and theories has been mobilized to better respond to the central problem, and then we only opted for the Nelson Siegel model and the Svensson model. This construction was made with the aim of estimating risk-free rates, used in financial products, and deflators. The next step was to project the assets and liabilities of the provident product for the death benefit based on the results of the demographic projections. Finally, we moved on to the projection of the net result where the projection covered 4 years since the expiry dates of the contracts are between 2022 and 2025.

As a perspective, this construction, based on demographic and financial projections, will help the insurance company subsequently assess the European Embedded Value of this portfolio by adding the New Business Value to the Value of Existing Business.

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