COST SIMULATION OF AN INFLATION-LINKED AND A FLOATER BOND WITH BACKTESTING

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ABSTRACT

In this paper we focus on simulating and backtesting the costs of two special government securities, from the point of view of the issuer. Our research has two main goals. The first one is to assess the costliness of an inflation-linked bond in comparison with a floater one. The second one is to backtest the simulation results on real market data. We carry out the cost simulations with Monte Carlo simulation. The basis of the calculations is the Cox-Ingersoll-Ross interest rate model for the floater bond; and a first order autoregressive model for the inflation-linked bond. Our findings are: (i) the inflation-linked bond appears to be more expensive than the floater one and this relationship holds true for ex-ante (simulated) and ex-post (actually realised) costs as well; and (ii) the simulations predict the total present value of the costs adequately for both instruments, but the individual cash flows of the floater bond are significantly under- or overestimated in the different years. This shortcoming is in line with our expectations, since the model is calibrated on a tranquil period but applied on a very volatile one.

INTRODUCTION

A wide range of financial models, intending to describe the behaviour of different market processes and to predict the future movements in the market have a great and general problem. Namely, the model parameters are estimated from historical databases, but then the models are applied to capture future market movements when the circumstances are not necessarily the same. The events of the last decade or so provide great examples of rapidly changing market environments. Built upon this observation, one of our motivations in this paper is to examine what happens when we calibrate a model on a tranquil period but apply it to predict financial market movements in a more volatile environment.

This phenomenon will appear in this paper when we estimate the future cash flows of two hypothetic bonds as if they were issued in Hungary in 2006. The model calibrations are carried out on a database of a tranquil period (1999-2006), while the backtesting of the estimations is based on a very volatile period (2006-2011). We expect that discrete estimations might have only modest predicting power but since we simulate more (four or five) cash flows of the bonds chosen, we give a chance that on the long run the models approximate the average costliness of the instruments acceptably.

The examined bonds are an inflation-linked and a floater bond. The core motivation was to measure the costliness of the indexed bond because the issuance of such a Hungarian government security was a relevant and current topic in 2006. As benchmark instrument we chose a floater bond since these two types of bonds have a very important common feature: their future nominal cash flows are not known in advance, i.e. have to be estimated. Since we analyse bonds with five years maturity, we already know the ex-post, realised values of the relevant risk factors (especially interbank interest rate and inflation), hence we can perform a comprehensive backtest as well.

The rest of the paper is organised as follows. First we introduce the basic features of traditional (fixed or floater) and inflation-linked bonds. Afterwards, we shed some light on the evolution of the indexed bonds' market, highlighting also the scarce experiences that Hungary has with this bond type. Then, we present the theoretical background and the outputs of the cost simulations. Finally, we analyse and backtest the results and conclude our findings.

TRADITIONAL BONDS

A traditional bond is a debt instrument that obligates the issuer to make specified payments on predetermined dates for the bondholder. The most important features of a bond are its *face value* (it is also called *principal* or *notional amount*) which is the debt that has to be paid back; and its *coupon rate* which determines the interest payment that has to be paid after the outstanding notional amount (Bodie et al., 2008).

There are two basic types of bonds, the *fixed rate* and the *floating rate* (or *floater*) bond. In case of the first type the coupon rate is a fixed percentage of the face value, while in case of a floater it is varying according

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to a current market rate called *fixing* or *benchmark rate*. In practice, the interest payment of a floater is usually the chosen market rate plus a spread. Since the market rate is changing continuously, the cash flow of a floater bond will change from one payment date to the other as well. It is important to mention that the payment is determined always one period in advance, according to the current value of the fixing rate. The benchmark is usually an interbank rate, i.e. the interest rate that banks use for lending to each other, like for example the London Interbank Offered Rate (*Libor*).

Besides these two types of bonds, there are numerous innovations in the bond markets (e. g. the inverse floater or the asset-backed bonds) out of which we introduce one special type, the inflation-linked bond in more detail, since this is in the focus of our research.

INFLATION-LINKED BONDS

Inflation-linked bonds (*IL-bonds*) belong to the class of indexed bonds. The speciality of these instruments is that their payments are tied to a general price index (Bodie et al., 2008). An IL-bond, contrary to a fixed rate bond where the coupon rate is expressed in nominal terms, has a *real coupon* which is a fix percentage of the *real value* of the principal. More precisely, when the consecutive cash flow of the IL-bond falls due, the face value is multiplied with an *index factor* that represents the inflation of the time period passed since the last payment. The cash flow is determined then as the product of the real coupon and this modified face value.

Calculating the future cash flows of an IL-bond is not as evident as in case of a traditional fixed bond, hence the pricing of the bond poses some problems as well. The first difficulty is that in most of the cases we do not know what the exact rate of the inflation in the last time period was. These data are available only with a few months delay, which means that we have to have a certain delay in the indexation as well. The second problem is the definition of the inflation. It is not clear which indicator should be used. There are several possibilities, like the GDP deflator or the consumer price index. It is one of the most important questions at the issuance of an IL-bond, which indicator to be used.

An important characteristic of an IL-bond is the payment method of the principal's inflation increments. These increments could be redeemed at the time of the corresponding coupon payment, but in practice it is more widespread that they are paid in one sum at maturity. At this point it is worth to mention that since economies might face not only inflation but deflation as well, being indexed to a price level does not necessary mean increasing payments in nominal terms.

From the point of view of our analysis, it is important to emphasise that future cash flows involve uncertainty either for floater, or for IL-bonds. With other words, both instruments have cash flow risk. An essential difference is that the following payment of a floater is always known in advance. In Table 1 we listed those parameters that define the cash flows of a fixed rate, an inflation-linked and a floater bond.

Table 1: Factors defining the cash flows of bonds

Fixed rate	**Inflation- linked**	**Floating rate**
Face value	Face value	Face value
Maturity	Maturity	Maturity
Frequency of coupon payment	Frequency of coupon payment	Frequency of coupon payment
Principal payment method	Principal and inflation increment payment method	Principal payment method
Coupon	Real coupon	Spread
	Price index	Fixing curve

Index Calculation and Pricing

The central question in determining the cash flow and the price of an IL-bond is the calculation of the index factor. For the purposes mentioned it is indispensable to use a method that enables us to determine the price index at any time. Given that inflation statistics are available only monthly, this might be difficult, but there are several ways to handle this problem. In practice the prevailing method is the Canadian model, for this reason we introduce it briefly.

The Canadian model was elaborated in 1991. The essence of this model is that we do not need the nominal value of the next coupon payment for determining the price; we only need the value of the price index. The price index at any day is calculated as the linear interpolation of two preceding index values. Since the inflation data are published at least with a two months delay and usually only monthly, this means that these indices will be the two and three month earlier price index values. Equation (1) shows the price index calculation on an arbitrary day t_0.

$$PI_{t_0} = PI_{M-3} + \frac{t_0 - 1}{D}\left(PI_{M-2} - PI_{M-3}\right) \tag{1}$$

where PI is the price index, M stands for the month of t_0, and D is the number of days in month M.

The index factor of Equation (2) – which is used to modify the principal – is the ratio of the price index on the examined day (PI_{t0}) and on the basis day (PI_B).

$$IF_{t_0} = \frac{PI_{t_0}}{PI_B} \tag{2}$$

For more information about inflation-linked securities in general see Deacon et al. (2004).

International Markets

IL-bonds have been issued in a bigger amount after the Second World War in countries like Brazil, Argentina, or Finland. That time the main reason for the issuance in these countries was the two-digit inflation rate. With the issuance the government wanted to show its commitment to decrease inflation in the following years. (Pecchia and Piga, 1995). The global market for IL-bonds started to grow notably in 1981, when the British government has started to issue IL bonds, called IL-Gilts. The reason for the issuance was that the inflation expectation of the government was lower than that of the market. The government hoped that it could save on interest expenses in this way (Farkas et al., 2005). The market experienced another significant increase when several countries introduced inflation targeting monetary policy, like Canada, Sweden, Australia, etc.

Nowadays, the total outstanding amount of the IL-bonds on the three biggest markets are $500 billion TIPS (Treasury Inflation-Protected Securities) in the USA, $300 billion IL-Gilts in the UK, and $200 billion OATi/OAT€i IL-bonds in France[1].

Since the basic of our simulations and backtesting is a Hungarian IL-bond, we summarise the experiences of this country with indexed government bonds.

Hungarian Market

The Hungarian Government Debt Management Agency (*GDMA*) started the issuance of the first (and only one so far) inflation-linked government security in 1998. As a consequence of the lack of interest from investors, the IL-bond was auctioned only four times, with continuously decreasing demand.

After the maturity of the IL-bond, Farkas et al. (2005) analysed the cost efficiency of the instrument from the viewpoint of the GDMA. The authors used two methods, cost analysis with future value calculation, and break-even inflation calculation. Their main result was that the ex-post cost efficiency of the IL-bond is rather questionable.

After the maturity of the first IL-bond, it has been suggested that GDMA might have tried to issue a new one. It seemed to be possible that the market of Hungarian government bonds became more mature and that the issuance of a new IL-bond could be successful. This was the main reason why Dancs (2006) made an analysis and simulated the future costs of a hypothetic five year maturity IL-bond assuming an issuance in 2006. In what follows we reproduce these simulations with slight modifications and extend the analysis with backtests[2].

EX-ANTE COST-ESTIMATION

In this part we are simulating the expected costs of two hypothetic government bonds issued by the GDMA on the 1st of March 2006. The next part will backtest the results. The characteristics of the two hypothetic bonds are summarised in Table 2.

Table 2: Characteristics of the bonds

Type	**Inflation-linked**	**Floater**
Currency	EUR	EUR
Face value	10,000	10,000
Issue date (d/m/y)	1/3/2006	1/3/2006
Maturity (d/m/y)	1/3/2011	1/3/2011
Interest payment period	annual	annual
Principal payment method	at maturity with inflation increments	at maturity
Real coupon / Spread	1.9%	0.01%
Price index / Fixing curve	HICP[3] euro area (ex tobacco)	Libor 12M

When determining the characteristics of the bonds, our main goal was to ensure comparability. Not only the two bonds have the same issue and payment dates, both are also denominated in the same currency (euro), hence we do not have to estimate future FX rates. The most decisive point was choosing the real coupon of the IL-bond and the spread of the floater. We intended to examine bonds that have the same issue price which for the sake of simplicity equals the face value. In this way, the initial revenue of the issuer is identical for the two bonds. Market circumstances (i.e. comparable data of relevant Hungarian and European sovereign bonds) and experts' estimations were considered to determine the real coupon and the spread that matches this criterion. However, we have to keep in mind that possible under- or overestimation of these parameters may influence which bond turns out to be more expensive.

For both bonds, we give ex-ante estimations on their future cash flows. The methodology used is Monte Carlo simulation, so the first step is identifying the stochastic processes that determine the cash flows. In case of the floater bond we model future Libor path with the Cox-Ingersoll-Ross interest rate model, while in case of the IL-bond we estimate the index-factor with the help of an autoregressive model. Parameter calibrations are based on historical data.

[1] Data sources: US Department of the Treasury, UK Debt Management Office, Agence France Tresor.

[2] We have to complete the story by adding that in 2006 GDMA decided on not issuing new IL-bond. It did not launch such instrument for institutional investors in the following years either. However, from 2009 there exists a similar retail security for small investors.

[3] Harmonised Index of Consumer Prices, a comparable indicator of inflation in the EU states. HICP for the euro area is the weighted average of the price indices in the member countries.

Modelling the Libor

The Cox-Ingersoll-Ross model (*CIR-model*) is a continuous, one factor stochastic interest rate model, first proposed by Cox et al. (1985). In this model the instantaneous interest rate dynamics are given by the following stochastic differential equation:

$$dr_t = \alpha(\beta - r_t)dt + \sigma\sqrt{r_t}\,dW_t \quad (3)$$

where α, β and σ are positive constants, r_t is the interest rate, t is time. W_t denotes the standard Wiener process, a continuous-time stochastic process used very frequently in quantitative finance.

The most important characteristics of the Wiener process are as follows: (i) the trajectories are continuous, (ii) the increments on disjunctive time intervals are independent, (iii) the increments are stationary i.e. increments on time intervals with the same length have the same probability distribution, and (iv) the increment W_t-W_s is distributed normally with zero expected value and (t-s) variance. For further information on Wiener process and generally on the mathematical background of quantitative finance see Medvegyev (2007), while Cairns (2004) gives a comprehensive discussion specifically about interest rate models.

As one may observe, the interest rate in the CIR-model follows a mean-reverting process with long-term average β: when $r_t<\beta$, the drift term in Equation (3) becomes positive so the interest rate will increase and vice versa. The speed of adjustment to the long run mean is measured by α. The volatility term is proportional to the square root of the interest rate level. Cox et al. (1985) also showed that the future interest rate in their model (conditional on its current value) has a non-central chi-squared distribution.

When using the CIR-model for simulation purposes, we have to find the values of the model's three parameters. Here we present a possible method developed by Chan et al. (1992). This approach is based on the econometric estimation procedure called Generalised Method of Moments (*GMM*). For more information about GMM in general see Hansen (1982). Another application of the method for interest rate models can be found in Li (2000).

Chan et al. (1992) developed their procedure to estimate the parameters of the following general interest rate model:

$$dr_t = \alpha(\beta - r_t)dt + \sigma r_t^{\gamma} dW_t \quad (4)$$

It is easy to see, that Equation (4) gives the CIR-model if we substitute γ=0.5.

In Equation (5) we discretise (4) with the Euler approximation.

$$r_t = \alpha\beta\delta_t + (1 - \alpha\delta_t)r_{t-1} + \sigma r_{t-1}^{\gamma}\sqrt{\delta_t}\,e_t \quad (5)$$

where δ_t is the length of time between two observations of r_t, and e_t are independent, standard normal random variables.

Let us rewrite Equation (5) in the following form:

$$r_t - r_{t-1} = \alpha\beta\delta_t - \alpha\delta_t r_{t-1} + \varepsilon_t \quad (6)$$

The first two moments (expected value and variance) of the variable ε_t can be determined quickly by comparing Equation (5) and (6):

$$E(\varepsilon_t) = 0 \quad (7)$$

$$E(\varepsilon_t^2) = \sigma^2\delta_t r_{t-1}^{2\gamma} \quad (8)$$

where *E()* denotes expected value. The parameters are estimated with the null hypotheses of Equations (6), (7) and (8).

For estimating the future cash flows of the floater bond we model the future Libor rates with the CIR-model defined in Equation (3). Model calibration is based on a historical database which contains daily Libor rates from 1st December 2000 to 1st March 2006, all in all a sample of 1,340 observations. We use the above described GMM method and substitute δ_t=1/250=0.004 in Equation (6). (We have observations for trading days, hence one calendar year contains 250 Libor rates.) Table 3 shows the results of the parameter estimations.

Table 3: Calibration of the CIR-model

Parameter	Estimated value	t-statistic	p-value
α	0.937	2.990	0.003
β	0.025	10.885	0.000
σ	0.001	26.780	0.000

Once the parameter values of the CIR-model are determined, then we can estimate the future cash flows of the floater bond. As it has been pointed out, the next cash flow and the principal payment at maturity of a floater bond are always known. Therefore, from all cash flows of the bond there remain only four unknown interest payments to be estimated. Table 4 illustrates in details which cash flows are subjects of our simulations and which are fixed at issuance. Afterwards, Figure 1 shows relative frequencies of the four estimated payments generated from 10,000 simulations.

Table 4: Cash flows of the floater bond
(*italic* expressions are to be estimated)

Date	Cash flow	Payment type
1/3/2006	+10,000	Issue price
1/3/2007	-309	Interest
1/3/2008	-10,000*$Libor_{1/3/2007}$	*Interest*
1/3/2009	-10,000*$Libor_{1/3/2008}$	*Interest*
1/3/2010	-10,000*$Libor_{1/3/2009}$	*Interest*
1/3/2011	-10,000*$Libor_{1/3/2010}$	*Interest*
1/3/2011	-10,000	Principal

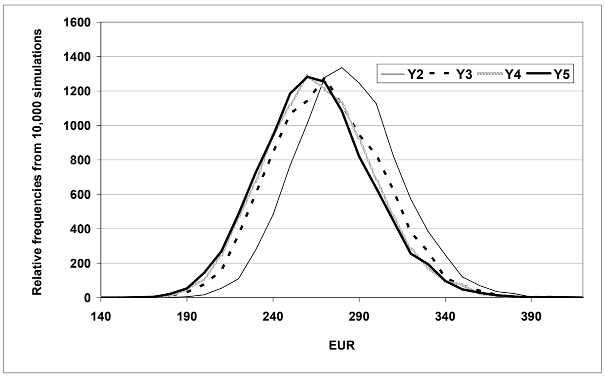

Figure 1: Relative frequencies of the floater bond's estimated cash flows

We will analyse the results in comparison with the cash flows of the IL-bond.

Modelling the Index Factor

For estimating the future costs of the IL-bond we have to predict future index factors. Our goal is capturing the main characteristics of the price index chosen without building a complicated model about the whole economy and making assumptions on wide range of macroeconomic aggregates.

We will model the inflation with the following first order autoregressive process:

$$\Delta HICP_M = a\Delta HICP_{M-1} + b\overline{Libor}_M + \eta \quad (9)$$

where $\Delta HICP_M$ is the month-on-month inflation measured by the annual rate of change of the price index given in Table 2, $\overline{Libor}_M$ is the average level of the Libor rate in month *M* and η is normally distributed residual term. The autoregressive feature of the model defined in Equation (9) is easily justifiable: sequential month-on-month statistics measure the inflation of highly overlapping periods.

We estimate regression of Equation (9) with Ordinary Least Squares method. We use historical data of HICP in the euro area from mid-1999 to mid-2005. Since data are available on a monthly basis, we have 74 observations. Table 5 shows the results of the parameter estimations.

Table 5: Estimation of the autoregressive model

Parameter	Estimated value	t-statistic	p-value
a	0.904	24.219	0.000
b	0.060	2.725	0.008

The adjusted R-square of the autoregressive model is 72 percent. From the following simulations' point of view, it is important to test the normality of the residuals. We performed Jarque-Bera test and received a p-value of 68 percent. It means that rejecting the null hypothesis of normality would be a wrong decision with probability of 68 percent.

In case of the IL-bond, we have to estimate five cash flows. The initial revenue of the issuer is known (under our assumption the real coupon is set so that the issue price is the face value), but all the other payments, including the principal redemption at maturity, depend on future inflation. Similarly to the floater bond, we summarise in a table the cash flows indicating the factors that should be estimated (Table 6). Relative frequencies of the five estimated interest payments generated from 10,000 simulations are depicted in Figure 2.

Table 6: Cash flows of the IL bond
(*italic* expressions are to be estimated)

Date	Cash flow	Payment type
1/3/2006	+10,000	Issue price
1/3/2007	-10,000*$IF_{1/3/2007}$*1.9%	*Interest*
1/3/2008	-10,000*$IF_{1/3/2008}$*1.9%	*Interest*
1/3/2009	-10,000*$IF_{1/3/2009}$*1.9%	*Interest*
1/3/2010	-10,000*$IF_{1/3/2010}$*1.9%	*Interest*
1/3/2011	-10,000*$IF_{1/3/2011}$*1.9%	*Interest*
1/3/2011	-10,000*$IF_{1/3/2011}$	*Principal*

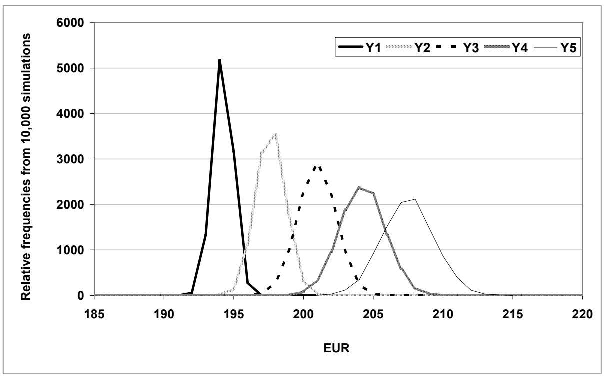

Figure 2: Relative frequencies of the IL-bond's estimated cash flows

Interpreting the Results

In Figure 1 and Figure 2 it is worth to observe that the cash flows' distribution is flatter in each year for the floater bond. This means higher variance which is in line with the construction of the bonds. In case of the IL-bond the magnitude of the costs is predetermined by the real coupon and 'only' the modifying index factor is unknown, while in case of the floater bond it is the coupon itself that we estimate. The latter means higher uncertainty especially for initial years where the index factor represents the inflation of shorter periods.

Another observation is that both the mean and the variance (the flatness) of the IL-bond cash flows are increasing significantly in time. This is due to fact that later cash flows have to compensate the investor for the inflation of a longer period. This feature results in higher and more volatile nominal cash flows as time passes. In the next section we will compare the estimated cash flows of the two bonds and will also backtest the results.

ANALYSIS AND BACKTEST OF THE RESULTS

In Table 7 and Table 8 we summarise the results of our estimations and also inform the reader about what cash flows would have actually realised ex-post. From the estimations we present the mean and the 95th percentile (pctl. in the Tables) of the 10,000 simulations. Since we are talking about the issuer, from our point of view the main risk is having higher costs than expected or estimated. This is why we included in the Tables an upper percentile. Furthermore, we also calculated the present values of the annual cash flows (PV in the Tables), which is important because of comparability. We would like to know which bond is cheaper on the whole, so we have to add all the future costs of the bonds, and since it is not fair to sum up cash flows due at different times, we discounted all the payments to the date of the issuance. For discounting we used a flat 3% yield curve. The choice of the fair discount curve is of course influencing the results, but from our points of view (comparing the two bonds and testing the simulations) this impact is so small that we decided on not going into the very depth of this financial problem.

Table 7: Actual and estimated cash flows of the floater bond

Date	Cash flow		
	actual	estimated (ex-ante)	
	(ex post)	mean	95% pctl.
1/3/2007	309.14		
1/3/2008	417.71	278.55	330.37
1/3/2009	448.00	266.64	320.69
1/3/2010	212.94	261.87	314.75
1/3/2011	10,129.75	10,260.31	10,315.26
PV	**10,031.06**	**9,890.01**	**10,082.70**

Table 8: Actual and estimated cash flows of the inflation-linked bond

Date	Cash flow		
	actual	estimated (ex-ante)	
	(ex post)	mean	95% pctl.
1/3/2007	193.42	193.73	194.82
1/3/2008	199.80	197.16	198.85
1/3/2009	202.00	200.46	202.64
1/3/2010	203.41	203.73	206.34
1/3/2011	11,171.28	11,101.95	11,267.80
PV	**10,378.15**	**10,315.03**	**10,465.06**

The first purpose of our calculations was comparing the costs of the two bonds. Our results show that the IL-bond turns out to be more expensive, the present value of all the future payments is higher for this instrument. This statement holds true for the ex-ante, estimated costs and for the ex-post, actually realised cash flows as well.

At this point we have to come back to the problem of setting the real coupon and the spread of the bonds. The calibration of these parameters is of course influencing the final conclusion. If the bonds with these parameters could not have been issued at face value, we should have included the issue price in the calculations as well. Because of this uncertainty it is useful to mention that if the real coupon is unchanged, the spread of the floater bond should be increased to 80-90 basis points so that the actual present values of the two instruments were approximately equal. All in all, our opinion is that the assumptions do not involve so much uncertainty that the relative costliness of the bonds would change.

Our second goal was backtesting the simulation results. As we expected, Libor showed much higher volatility between 2006 and 2011 than it was estimated according to the previous, much tranquil period. The actual cash flows are significantly underestimated in the first two years and then significantly overestimated in the second two years. However, for that very reason the total cash flow (in present value) is estimated quite well. For the IL-bond, the payment estimations are generally acceptable separately and in present value as well – the exception is the second cash flow which is higher than the estimated 95th percentile.

We have to remark that the main uncertainties in our assumptions, namely the value of the real coupon and the spread of the floater bond are not affecting the accuracy of the estimations. If these parameters were different, that would change the actual and the estimated cash flows in the same way.

CONCLUSION

In this paper we presented the main features of the inflation-linked bonds. Since it was a case at issue for Hungary in 2006, we examined a hypothetic IL-bond launched in that year by GDMA. We analysed this bond from the point of view of costliness, the benchmark instrument was a floater bond. We made ex-ante (as we were in 2006) cost-simulations for both bonds and also backtested the results. The base of the Monte Carlo simulations was the CIR-model for the floater and an autoregression for the IL-bond. Our simulations suggest that the IL-bond would have been more expensive and this result is confirmed by the ex-post data as well. Backtests also showed that the CIR-model failed to capture the individual annual costs of the floater bond. This was an anticipated shortcoming since we calibrated the model according to a period prior to 2006, i.e. not taking into account the financial crises which brought high volatility and unexpected movements in the financial markets. Nevertheless, the simulations predicted the total present values of the cash flows adequately for both bonds.

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