SimBEL: Calculate the best estimate in life insurance with Monte-Carlo techniques

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Best estimate calculation

- Under Solvency II, liabilities in life insurance are valued based on a market consistency principle (Kemp, 2009; Vedani et al., 2017), taking into account:
  - financial options and guarantees,
  - future management actions, e.g. profit sharing rules,
  - the policyholder’ behavior,
  - both undertaking and financial risks.

- A stochastic Asset Liability Management (ALM) model based on Monte-Carlo balance sheet projection is generally implemented to compute the best estimate of liabilities (see art. 77 directive Solvency II)

\[
BE_t = \mathbb{E} \left[ \sum_{u>t} \delta_u CF_u \right]
\]

- \( \delta_u \), the stochastic deflator at time \( u \);
- \( CF_u \), the net payment cash-flows at time \( u \).
European Literature

- **Profit sharing** rules (see e.g. Grosen and Løchte Jørgensen, 2000; Bacinello, 2001; Ballotta *et al.*, 2006; Kling *et al.*, 2007).

- **ALM** (see e.g. Bauer *et al.*, 2006; Hainaut, 2009).

- **Policyholder’s behavior** (see e.g. Planchet and Thérond, 2007; Milhaud *et al.*, 2011; Bauer *et al.*, 2006; Eling and Kochanski, 2013).

- The French valuation model is rarely described, but is quite complex as insurers have a higher leeway to distribute profit sharing (Borel-Mathurin *et al.*, 2015).
Aims

▶ In France, most of such valuation models are developed by commercial firms or directly by insurers. They are no available for students, researchers, ...

▶ No package to forecast assets and liabilities is available for insurance obligations.

▶ An ALM model requires algorithms to forecast both assets and liabilities at a very granular level under the local gaps. It is coupled with an Economic Scenarios Generator (ESG).

▶ With large asset and liability portfolios, the computation can be very time consuming.

▶ Our aims:
  ▶ Develop a flexible R-package to compute easily the best estimate of a life participating contract, especially a French euro-denominated contract.
  ▶ Usable for the Solvency Capital Requirement (SCR) computation.
  ▶ Flexible architecture allowing to project both data and assumptions as it is required for example for the Own Risk Solvency Assessment (ORSA) purpose.
The R-package SimBEL

- The package is implemented in an oriented object fashion in S4.
- An access to the last development version on GitHub is available on demand.
- The user guide and a large documentation (in French at the moment) is available.
- To install the package
  ```r
  library(devtools)
  library(githubinstall)
  install_github("xxx", auth_token = "yyy")
  ```
- To load the package
  ```r
  library(SimBEL)
  ```
Overview of the calculation process

The best estimate is calculated following this general process (Laurent et al., 2016)

1. **Generate risk neutral scenarios**
2. **Forecast balance sheet and P&L in local gap**
   - Compute assets and liabilities values and cash-flows before profit
   - Apply buy-and-sell strategies for assets
3. **Apply profit sharing rules**
   - Contractual and legal constraints
   - Take in account policyholders’ expectations and behaviors
   - Use profit sharing reserves and compensation between insured.
4. **Revaluate liabilities**
   - Instantaneous or time-smoothing
   - Compute final balance sheet and P&L

Loop over time

Monte-Carlo loop
Overview of the structure (only cash flows projection)
Main functionalities

1 Liability module

- Both saving and retirement products with participation can be modeled.
- The liability side is modeled using model points, which represent the technical characteristics of each contract.
- An user should provide additionally:
  - Technical assumptions (tables with mortality rates and static lapse rates, parameters for dynamic lapses),
  - expenses assumptions,
  - the current value of other provisions.
Main functionalities

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Main functionalities

2 Asset module

- Four asset classes are modeled:
  - Fixed bonds (Gouv. and Corporate),
  - Equities,
  - Properties,
  - Cash account.

- An user should provide:
  - ESG tables for asset projection,
  - a reference portfolio for future reinvestments,
  - an investment strategy,
  - the current value for asset provisions,
  - fees on asset.
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Main functionalities

3 Balance sheet modules
   - Asset and liability are linked together with an object called a Canton.
   - When projecting a Canton, ALM and surplus appropriation scheme are applied.

4 Best estimate module
   - Project a Canton for each simulation.
   - Calculate the best estimate based on the initial situation of a canton.
Main functionalities

3 Balance sheet modules
   ▶ Asset and liability are linked together with an object called a Canton.
   ▶ When projecting a Canton, ALM and surplus appropriation scheme are applied.

4 Best estimate module
   ▶ Project a Canton for each simulation.
   ▶ Calculate the best estimate based on the initial situation of a canton.
Loading data

- Lots of data and parameters are required.
- A module is designed to feed all these data from a repository contained csv files.
- Create a Canton for each shock defined in Solvency II standard formula.
Loading data

- To load the addresses for data repositories.

```r
root <- new("Initialisation", root_address = getwd())
root <- set_architecture(root)
```

- To load data related to initialize a Canton.

```r
init_SimBEL(racine)
```

- To create and save a Canton for each shocked situation as defined by the standard formula.

```r
init_scenario(racine)
```
Canton class

- A Canton stores the current picture of the balance sheet and all parameters to project it.

```plaintext
canton@annee  # Number of projection years
canton@hyp_canton  # Some general assumptions
canton@mp_esg  # Extraction of an ESG table for the current projection year and simulation
```

- To call the Asset portfolio.

```plaintext
canton@ptf_fin
```

- To call the Liability portfolio.

```plaintext
canton@ptf_passif
```
Asset side

- 4 main asset classes are considered:
  - Equity,
  - Property,
  - Fixed bonds,
  - Cash account.

- The package computes usual asset cash-flows (rents, dividends, coupons) and computes the value of assets each year.

- An external ESG is used.
Liability side

French saving contracts

- Periodic premiums.
- Two guarantees rates:
  - a technique rate $r_{tech}$,
  - a minimal interest rate $r_{tmg}$ over $T_{tmg} = 1$ or $2$ years.

\[
    r_{\min}(t) = \max\left(r_{tech}, r_{tmg} I_{t \leq T_{tmg}}\right)
\]

- A contractual surplus distribution scheme as a ratio $\rho$ of the financial result.

- Benefits are paid:
  - at the term of the contract,
  - in case of a partial lapse,
  - in case of a total lapse,
  - when the insured dies.
Liability side

Pension contracts

- A common annuity contract with $m$ regular payments over the year,
- Reversionary annuity is considered with the rate $\mu$.
- Mathematical reserves are given by

$$a_{x}^{(m)} = a_{x}^{(m)} + \mu a_{y}^{(m)} - \mu a_{xy}^{(m)}$$

- A **contractual surplus distribution** scheme can be considered.
- No lapse.
Dynamic behaviors

The model computes insured expectations in term of participation each year. It depends on:

- the average rate offered by competitors,
- the participating rate given last year.

**Dynamic lapses** may be triggered if the last participation rate is not satisfactory.

\[
q(r_{cib}, r_{rev}) = \begin{cases} 
RC_{\max} & \text{if } r_{rev} - r_{cib} \leq \alpha \\
RC_{\max} \frac{r_{rev} - r_{cib} - \beta}{\alpha - \beta} & \text{if } \alpha < r_{rev} - r_{cib} \leq \beta \\
0 & \text{if } \beta < r_{rev} - r_{cib} \leq \gamma \\
RC_{\min} \frac{r_{rev} - r_{cib} - \gamma}{\delta - \gamma} & \text{if } \gamma < r_{rev} - r_{cib} \leq \delta \\
RC_{\min} & \text{if not.}
\end{cases}
\]

with the parameters \(\alpha, \beta, \gamma, \delta\).

- \(r_{rev}\), the participation rate given by the insurer,
- \(r_{cib}\), the participation rate expected by the insured.
Surplus scheme

- In France, an insurer has an high leeway to manage the profit sharing over the time by:
  - immediate or differed participation by endowing a surplus reserve called the *Provision pour participation aux bénéfices* (PPB),
  - possibility to discriminate some contracts,
  - a legal constraint on financial and technical results applicable for all the liability portfolio.

- An insured may want to distribute profits beyond the contractual guarantees to avoid future lapses. It depends on:
  - financial products,
  - the amount of unrealized capital gains or losses
  - how policyholder’ expectations are heterogeneous,
  - the amount of PPB.

- A algorithm with priorities is implemented in the package.
Liability classes

- **Two classes**: euro-denominated French saving and pension guarantees.
- Each instantiation of these classes is a product with specific features in terms of expenses and contractual profit sharing rate.
- Liabilities are projected on an annual basis.
- Example for a saving product

```r
ee1 <- canton@ptf_passif@eei[[1]]  # The first saving product class(ee1)  # "EpEuroInd"
```
### Liability classes

- Model points are stored in a `data.frame` object.

```r
str(ee1@mp)
```

<table>
<thead>
<tr>
<th>'data.frame': 15 obs. of 29 variables:</th>
</tr>
</thead>
<tbody>
<tr>
<td>num_mp : int 1 2 3 ...</td>
</tr>
<tr>
<td>...</td>
</tr>
<tr>
<td>age : int 40 40 40 ...</td>
</tr>
<tr>
<td>gen : int 1900 1900 1900 ...</td>
</tr>
<tr>
<td>num_tab_mort : Factor w/ 1 level &quot;TM2&quot;: 1 1 1 ...</td>
</tr>
<tr>
<td>chgt_enc : num 0.007 0.007 0.007 ...</td>
</tr>
<tr>
<td>...</td>
</tr>
<tr>
<td>pm : int 900 11600 12000 ...</td>
</tr>
<tr>
<td>nb_contr : int 1 1 1 ...</td>
</tr>
<tr>
<td>anc : int 0 0 0 ...</td>
</tr>
<tr>
<td>...</td>
</tr>
<tr>
<td>tx_cible : Factor w/ 1 level &quot;Meth1&quot;: 1 1 1 ...</td>
</tr>
<tr>
<td>prime : int 0 0 0 ...</td>
</tr>
<tr>
<td>tx_tech : num 0 0 0 ...</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>
Liability cash flows

- Technical assumptions are attached to the liability portfolio.

```r
canton@ptf_passif@ht # All technical assumption
# The mortality table 'TM1'
canton@ptf_passif@ht@tables_mort[["TM1"]]
```

- To compute premiums

```r
prem <- calc_primes(ee1)
```

- To compute lapse and mortality rates

```r
rates <- calc_proba_flux(ee1, ptf_passif@ht)
```

- To compute minimal revalorisation rates and target rates

```r
tx_min <- calc_tx_min(ee1)
target <- calc_tx_cible(ee1, list(ptf_passif@ht, list_rd = list(0.02, 0.01, 0.01, 0)))
```
Liability cash flows

- To compute benefits

\[
\text{ben} \leftarrow \text{calc\_prest}(\text{ee1}, \text{rates}, \text{tx\_min}, \text{an} = 1, \\
\text{method} = \text{"normal"}, \text{tx\_soc} = 0.155)
\]

- To compute mathematical reserves

\[
\text{pm} \leftarrow \text{calc\_pm}(\text{ee1}, \text{prem}[\text{"flux"}], \text{ben}[\text{"flux"}], \\
\text{target}, \text{tx\_min}, \text{an} = 1, \text{method} = \text{"normal"}, \\
\text{tx\_soc} = 0.155)
\]

- To forecast liability portfolio over 1 year

\[
\text{proj} \leftarrow \text{proj\_annee\_av\_pb}(
\text{an} = 1, \text{x} = \text{ptf\_passif}, \\
\text{tx\_soc} = 0.155, \text{coef\_inf} = 1, \\
\text{list\_rd} = \text{list}(0.02, 0.01, 0.01, 0))
\]
Liability cash flows

► Cash-flows and mathematical reserves are aggregated by product

```
# Outputs
# Cash-flows by product
proj[["flux_agg"]]
# Mathematical reserves and the number of contracts
proj[["stock_agg"]]
```

► These outputs can be used to build some checks.
Asset cash-flows

- Four asset classes: their dynamics are given by the ESG tables.
- To print asset allocation.

```r
print_alloc(canton@ptf_fin)
```

- For each class, the current "picture" of assets is stored in a data.frame.

```r
# Bond portfolio
canton@ptf_fin@ptf_oblig
```

- To calculate cash-flows and market values for bonds

```r
# Coupons and terminal cash-flows
calc_flux_annee(canton@ptf_fin@ptf_oblig)
# Market value
calc_vm_oblig(canton@ptf_fin@ptf_oblig, canton@mp_esg@yield_curve)
```
Canton forecasting

- A Canton can be very easily projected over 1 year:
  - Asset and liabilities cash-flows,
  - Apply ALM and profit sharing rules,
  - Compute P&L and other balance sheet items,
  - Set the value of an updated Canton.

```r
result_proj_an <- proj_an(canton, nb_annee, pre_on = FALSE)
canton_updated <- result_proj_an[["canton"]]
# Extract cash flows by product
result_proj_an[["output_produit"]][["flux"]]
# Extract financial results
result_proj_an[["result_fin"]]
```
Best estimate calculation

- A best estimate objet is defined with a Canton and ESG tables

```r
class(be)
[1] "Be"
# The initialized Canton
be@canton
# ESG tables
be@esg
```

- Compute Monte-Carlo simulations

```r
# To run simulation #10
run_be_simu(be, 10L, pre_on = F)
# To run all the simulations
be_results <- run_be(be, pre_on = F)
# Extract the amount of best estimate
be_results[["be"]][@tab_be
# Extract the average cash-flows
be_results[["be"]][@tab_flux
```
Performances

- Some functions are developed using the library `Rcpp`.
- The function `run_be()` can be speed up and allows parallel computing with the package `doParallel`.
- Our performances are rather good with R!

**Table**: Performances with 1,000 simulations in minutes by using 1 core (Intel Core i7-5500U 2.40GHz) and 8 GB RAM.

<table>
<thead>
<tr>
<th>Number of model points for each Asset class</th>
<th>Number of Saving and Retirement model points (for each)</th>
<th>Computation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>13.2</td>
</tr>
<tr>
<td>100</td>
<td>1000</td>
<td>14.0</td>
</tr>
<tr>
<td>100</td>
<td>10000</td>
<td>24.7</td>
</tr>
<tr>
<td>1000</td>
<td>100</td>
<td>13.8</td>
</tr>
<tr>
<td>1000</td>
<td>1000</td>
<td>15.0</td>
</tr>
<tr>
<td>1000</td>
<td>10000</td>
<td>26.1</td>
</tr>
</tbody>
</table>
Perspectives

- We hope this package may be used by academics.
- It may be useful for different topics:
  - to improve our understanding of the effect of contract features on the economic capital for risk management perspectives
  - to study optimal asset allocation strategies,
  - to study the effect of the risk neutral ESG on the value of life insurance products,
  - to develop relevant Monte-Carlo simulation techniques.
Future developments

- Increase performances.
- Include UL products and contract an other specificities.
- Add new asset classes (e.g. floating rate bonds).
- Develop a toolkit with indicators for the results analysis.
- Take the inputs from the user with more security.
- Extend our group of developers.
Profit sharing algorithm


References II


