Paper 024-2011

A Goal Programming Approach to Strategic Bank Balance Sheet Management

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ABSTRACT

Efficiently managing a bank's balance sheet while maximizing returns and at the same time taking into account conflicting goals such as minimizing risk, subject to regulatory and managerial constraints, is a complex task. Using a trial and error approach can only deliver sub-optimal solutions. Given the cost of capital, the total capital available and bank management's risk appetite, managers need to answer the question of whether there exists an 'optimal' balance sheet composition of assets and liabilities that will enable their organization to achieve its strategic goals.

Taking the current balance sheet as a starting point, this paper proposes a multi-objective approach to move from the current balance sheet to the 'optimal' balance sheet, whilst taking Basel Pillars 1 and 2 regulatory capital limits into account.

INTRODUCTION

The efficient management of any firm's balance sheet to maximize returns while taking conflicting goals, like minimizing risk, into account is a difficult problem. It is a dynamic problem in the sense that decisions made today will affect what can be done in the future. This calls for a multi-period approach which introduces more uncertainty into the challenge. This problem can certainly not be solved optimally using a trail-and-error or "what-if" approach.

Given the cost of capital and the total capital available, the firm's management wants to address the following very important strategic issue:

> *Does there exist an "optimal" balance sheet composition of assets and liabilities that, given the corresponding estimated returns and costs, regulatory and managerial constraints, will enable the firm to achieve its strategic goals?*

Typical strategic goals are expected returns, risk, liquidity, capital adequacy, growth in market share, etc. Since these goals are in conflict with each other simple Linear Programming will not suffice and one has to resort to a multi-objective approach like Goal Programming.

In the process of trying to address this challenge, the current balance sheet can be used as a starting point. Changes to the balance sheet, in order to create a pro-forma optimal balance sheet, would have to take the following onto account:

- The expected risk and return of the different asset classes.
- The target balance sheet composition, i.e. the exposures of the asset classes as a percentage of the total balance sheet. These targets can depend on the state of the economy.
- The maximum growth in asset class exposures that can be accomplished given the view of management on future market conditions and available resources.
- The maximum decrease or increase of current asset class exposures that can be accomplished over a given the time horizon.
- Regulatory and economic capital that will be needed to cover the risk associated with the different asset class and risk exposures, depending on the required granularity.
- "Transaction costs", because changing the composition of the balance sheet does not always come for free. For example, growing the vehicle and asset finance exposure might imply a bigger collections department.

This paper formulates the strategic balance sheet management (SBSM) problem as a goal programming problem. It covers the different building blocks, in terms of data, stochastic models and software technology that are needed to implement the proposal in practice. The single period approach will be demonstrated on a hypothetical (South African) bank using SAS/OR® PROC OPTMODEL.

A partial multi-period model is also formulated. Formulating the complete model is out of scope of this paper. For example, to formulate the two new Basel III liquidity requirements (LCR and NSFR) in mathematical terms, one will have to introduce additional notation to be able to accommodate the different multipliers that are applicable to different assets and liabilities their corresponding maturity profiles.

THE MAIN ASPECTS OF THE METHODOLOGY

In this section we will take a closer look at the main aspects that need to be addressed to successfully solve the SBSM problem.

Segmenting assets and liabilities

The segmentation and the granularity of the segmentation of the assets and liabilities are driven by a number of factors. The following gives an incomplete list of possible factors:

- ***Data availability***: Data must be available to build forecasting models for all the balance sheet drivers for each segment. This is usually a big problem and even if the data is available, building and maintaining a large number of models can be an ambitious undertaking.
- ***Regulatory requirements***: To include regulatory capital and liquidity constraints one must be able to compute capital and liquidity requirements for each feasible solution. For example, under the new Basel III Net Stable Funding Ratio (NSFR) and Liquidity Coverage Ratio (LCR) requirements, banks have to split their assets and liabilities into maturity buckets and report on their funding profile. Tier I and Tier II capital requirements also have an influence on the segmentation of a bank's assets. Furthermore, if one wants to include a direct relationship between credit risky assets and the total risk weighted assets (RWA), the segmentation will have to include a split into risk buckets. For example, segmenting the mortgage portfolio according to probability of default (PD) and loan to value (LTV) ratio might give valuable information to the mortgage portfolio manager.
- ***Portfolio management***: The solution(s) produced by the optimization must make it possible for the different portfolio managers to act upon. If the portfolio managers are not able to translate the proposed optimal solution into targets that make sense to the business, the optimization results will be wasted.
- ***Tractability***: The mathematical formulation of the optimization problem is fairly easy, but depending on the complexity that one wants to include, the segmentation can have a huge impact on the size of the problem and the resulting speed of obtaining a solution. For example, including integer variables to model lot sizing and other go-no-go decisions can make the problem intractable. Also, if one wants to take a multi-period approach and use a stochastic program to model the evolution of risk drivers and future decisions explicitly, the granularity of the segmentation can have exponential impact on the size of the problem. Finally and most importantly, if the mathematical optimization problem includes non-linearities, the size of the problem that can be solved will decreases dramatically. Non-linearities will have an impact on both the number of decision variables that can be included and the identification of a global optimal solution.

Forecasting the balance sheet

The funding of the balance sheet will depend on the cash inflows and cash outflows of the bank at certain points in time. These cash flows can be contractual and/or behavioral and in addition will depend on the stochastic evolution of risk drivers. Following is a list of possible modules that can form part of a SBSM framework:

- ***Risk driver scenario generator***: Since any SBSM methodology must be forward-looking, consistent scenarios of the possible evolution of the main balance sheet drivers will have to be generated. For financial institutions the main drivers are interest rates. SAS/ETS® is the SAS technology that is applicable in this regard. If one wants to use SAS® Risk Dimensions as part of the software framework, one should try to use PROC MODEL as far as possible.
- ***Predictive models***: These models include those that predict future credit demand and availability of funds for each risk diver scenario.
- ***Credit risk component models***: Models that map the risk drivers to probability of default (PD), exposure at default (EAD) and loss given default (LGD) are needed to forecast the RWAs and expected losses (EL) for each asset segment. SAS® Enterprise Miner can be used to develop and estimate these models.
- ***Customer behavior models***: These include Prepayment curves, PD curves and LGD curves, which should be based on vintage analysis and depend on the main risk drivers. The transition of accounts between credit risk buckets or grades should also be included. (see Figure 1 below)

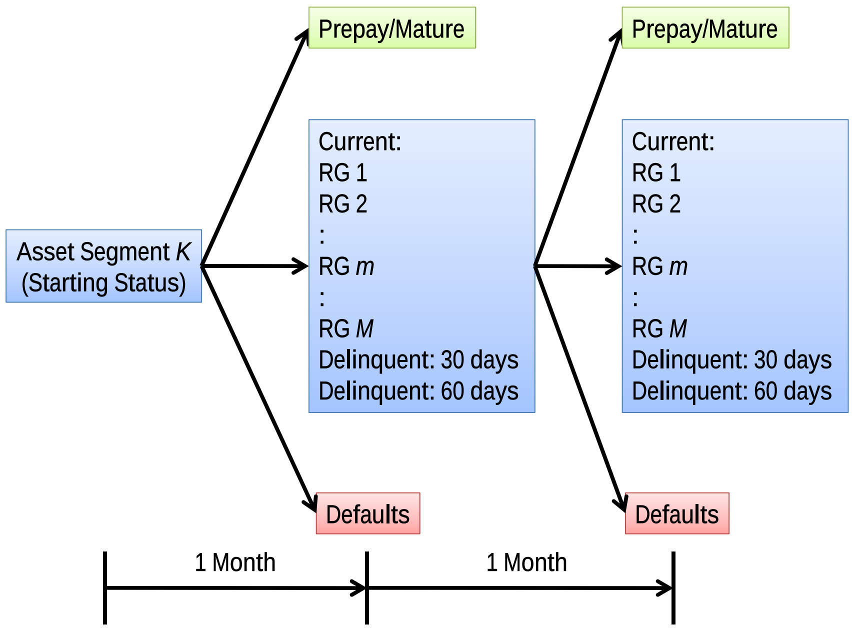

Figure 1: Transition of customers over time

- ***Cash flow simulator***: Most banks have an asset liability management (ALM) system that projects future cash flows for individual assets and liabilities. What we need here is a simulator that project expected cash flows for each asset or liability segment and it is important that these cash flows be based on behavior models. We propose that SAS® Risk Dimensions be used as cash flow simulator.

MATHEMATICAL OPTIMIZATION: A REVIEW

In this section we give a short review of mathematical optimization and use a hypothetical bank as an example to fix some ideas.

Definition:

Optimization is concerned with the maximization or minimization of a specific objective through the allocation or configuration of scarce resources that are under the control of management.

Basic elements of optimization:

- ***Decision variables***: These can be continuous or discrete variables (or levers) that are under control of management.
- ***Objective function***: The objective function depends on the values of the decision variables and determines how the decision maker will choose between different feasible solutions. In the case of goal programming, the objective function will contain a term for each goal or target.
- ***Constraints***: The constraints determine set of feasible solutions. These can be policy constraints, liquidity restrictions, regulatory or legal constraints, etc. Some of the constraints can be “hard constraints” but other can be “soft constraints”. Soft constraints will usually be treated as targets and then be included in the objective function.
- ***Data***: The data consists of problem parameters, balance sheet formulas, scenarios to represent the future evolution of the economy, scenario dependent management strategies, etc.

Example: A single-period model for a hypothetical (South African) bank

In South Africa banks have to submit, on monthly basis, BA900 returns to the South African Reserve Bank. The BA900 return gives a maturity breakdown of the asset and liabilities of the institution. Figure 2 below gives a high-level breakdown of the BA900 balance sheet.

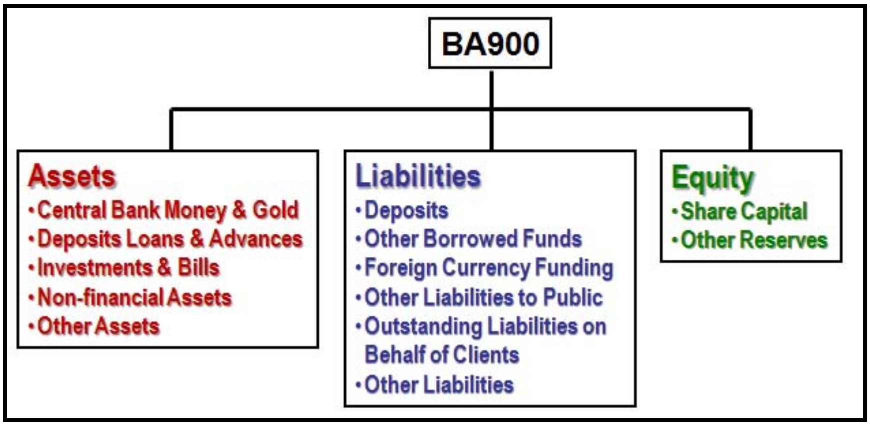

Figure 2: Balance Sheet Breakdown

Each line of the BA900 Return has a line number and all the formulas are specified in terms of these line numbers. Figure 3 below shows an example of how the roll-up calculations are structured in terms of the line numbers.

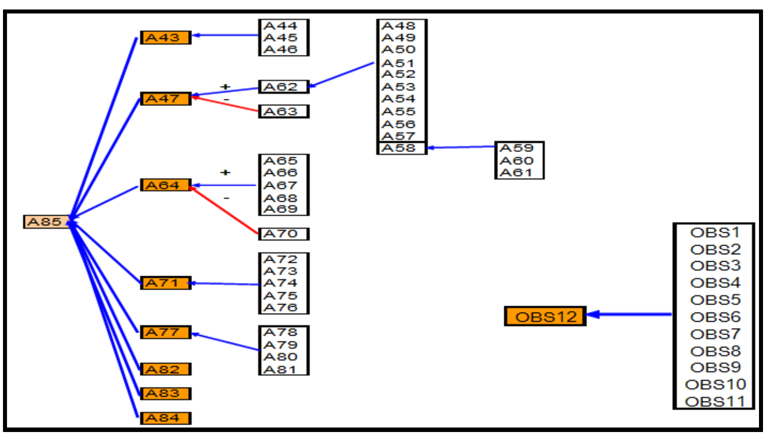

Figure 3: Balance Sheet Roll-up Calculations

To calculate the required regulatory capital the risk weighted assets (RWA) have to be calculated according to Basel II regulations. The RWA depends on the riskiness of the specific exposure and for this reason the assets have to be segmented into risk buckets. Figure 4 below gives a diagrammatic illustration of a typical segmentation.

Current Balance Sheet Exposures

	Domestic				Foreign			
Assets	RW: 0%	RW: 10%	...	RW: 150%	RW: 5%	RW: 10%	...	RW: 150%
• Central Bank Money & Gold								
• Deposits Loans & Advances								
• Investments & Bills								
• Non-financial Assets								
• Other Assets								

Figure 4: Asset Segmentation According to Riskiness

For each of the exposures expected returns must be estimated or predicted using stochastic models and expert opinion.

Expected Returns

	Domestic				Foreign			
Assets	RW: 0%	RW: 10%	...	RW: 150%	RW: 5%	RW: 10%	...	RW: 150%
• Central Bank Money & Gold								
• Deposits Loans & Advances								
• Investments & Bills								
• Non-financial Assets								
• Other Assets								

Figure 5: Expected Returns per Asset Class and Riskiness

To simplify our exposition we will only look at the one period single scenario case.

Preliminary Mathematical Formulation:

The structure of following mathematical formulation makes the implementation of the mathematical model in PROC OPTMODEL very easy.

Index Sets

$I = \{1,2,\ldots, M\}$ = Line numbers of assets in BA900 form
$J = \{1,2,\ldots, N\}$ = Indices representing different risk classes
$K = \{1,2,\ldots, M\}$ = Line numbers of liabilities in BA900 form

Problem Data

- $R_{i,j}$ = expected return on the *i*-th asset (balance sheet item) belonging to the *j*-th risk class
- C_k = expected return on the *k*-th liability (balance sheet item)

Current Balance Sheet Data

- $A_{i,j}$ = amount currently "invested" in the *i*-th asset belonging to the *j*-th risk class
- L_k = current amount of the *k*-th liability

Growth Constraint Data

- $U\_A_{i,j}$ = upper bound on the growth of the *i*-th asset belonging to the *j*-th risk class as a % of the current exposure
- $L\_A_{i,j}$ = lower bound on the growth of the *i*-th asset belonging to the *j*-th risk class as a % of the current exposure
- U_L_k = upper bound on the growth of the *k*-th liability as a % of the current liability amount
- L_L_k = lower bound on the growth of the *k*-th liability as a % of the current liability amount

Decision Variables

- $X\_A_{i,j}$ = amount "invested" in the *i*-th asset belonging to the *j*-th risk class
- X_L_k = the *k*-th liability amount

Constraints

- Balance sheet roll-up constraints (example)

$$X\_A_{85,k} = X\_A_{43,k} + X\_A_{47,k} + X\_A_{62,k} + X\_A_{64,k} + X\_A_{71,k} + X\_A_{77,k} + \sum_{i=82}^{84} X\_A_{i,k}$$

- Management constraints (growth example)

$$X\_A_{i,j} \le U\_A_{i,j} \times A_{i,j}$$

- Regulatory reserve constraints (e.g. liquid assets, Tier I & II capital)
- Capital adequacy

Goal Constraints

- Solvency target
- Liquidity target

- Market share
- KPI targets
- Concentration risk
- Etc.

Objective Function

$$\max Z = \text{Total net return - Total regulatory capital - Deviations from targets}$$

$$= \left(\sum_{i \in I} \sum_{j \in J} X\_A_{i,j} \times R_{i,j} - \sum_{k \in K} X\_L_k \times C_k \right)$$

$$-10\% \times \sum_{i \in I} \sum_{j \in J} X\_A_{i,j} \times RW_j$$

$$- \sum_{t \in Targets} P_t \left[d_t^+ + d_t^- \right]$$

where $P_1 > P_2 > \ldots > P_T > 0$, captures the priorities assigned to T targets; d_t^+ and d_t^- capture the target over- and under achievement.

PROC OPTMODEL Code Segments

Below we give some OPTMODEL code segments to illustrate the implementation.

```
PROC OPTMODEL;

/* Create index sets */
    set II  = 43..85; /* Asset indices            */
    set JJ  = 1..12;  /* Off Balance Sheet indices */
    set KK  = {'RC1', 'RC2', 'RC3', 'RC4', 'RC5', 'RC6'};   /* Risk Class indices        */
    set Bnd = {'UB', 'LB'}; /* Bounds */

/* Declare matrices to hold data */
    number ReturnAsset{II,KK};
    number ReturnOffBS{JJ,KK};
    number RW{KK};
    number UBound_Asset{II};
    number UBound_OffBS{JJ};
    number Growth_Asset{II,Bnd};
    number Growth_OffBS{JJ,Bnd};
    number Current_Asset{II,KK};
    number Current_OffBS{JJ,KK};
    number CurrentCapital;
    number CurrentReturn;
    number CurrentROC;
```

```
/* Read ALL data */
    read data dataDir.Asset_Returns into [II] {k in KK} <ReturnAsset[II,k] = col(k)>;
    read data dataDir.OffBS_Returns into [JJ] {k in KK} <ReturnOffBS[JJ,k] = col(k)>;
    read data dataDir.RWs into [KK] RW;
    read data dataDir.UBound_Assets into [II] UBound_Asset;
    read data dataDir.UBound_OffBS  into [JJ] UBound_OffBS;
    read data dataDir.Growth_Assets into [II] {k in Bnd} <Growth_Asset[II,k]  = col(k)>;
    read data dataDir.Growth_OffBS  into [JJ] {k in Bnd} <Growth_OffBS[JJ,k]  = col(k)>;
    read data dataDir.Current_Asset into [II] {k in KK}  <Current_Asset[II,k] = col(k)>;
    read data dataDir.Current_OffBS into [JJ] {k in KK}  <Current_OffBS[JJ,k] = col(k)>;

/* Declare decision variables */
    VAR Asset{II,KK} >= 0.0,
        OffBS{JJ,KK} >= 0.0,
        dp1 >= 0.0,
        dm1 >= 0.0,
        dp2 >= 0.0,
        dm2 >= 0.0,
        AddCapital >= 0.0;
```

```
/* Portfolio composition constraints */
    con ConAsset43{k in KK}: Asset[43,k] =  sum{i in 44..46} Asset[i,k];
    con ConAsset47{k in KK}: Asset[47,k] = Asset[62,k] - Asset[63,k];
    con ConAsset58{k in KK}: Asset[58,k] =  sum{i in 59..61} Asset[i,k];
    con ConAsset62{k in KK}: Asset[62,k] =  sum{i in 48..58} Asset[i,k];
    con ConAsset64{k in KK}: Asset[64,k] = (sum{i in 65..69} Asset[i,k]) - Asset[70,k];
    con ConAsset71{k in KK}: Asset[71,k] =  sum{i in 72..76} Asset[i,k];
    con ConAsset77{k in KK}: Asset[77,k] =  sum{i in 78..81} Asset[i,k];
    con ConAsset85{k in KK}: Asset[85,k] = Asset[43,k]+Asset[47,k]+Asset[62,k]+Asset[64,k]+Asset[71,k]
                                         +Asset[77,k]+Asset[82,k]+Asset[83,k]+Asset[84,k];

    con ConOffBS12{k in KK}: OffBS[12,k] = sum{j in 1..11} OffBS[j,k];

/* Portfolio Growth constraints */
    con Grwth_Asset_UB1{i in 44..46, k in KK}: Growth_Asset[i,'UB']*Current_Asset[i,k] >= Asset[i,k];
    con Grwth_Asset_UB2{i in 59..61, k in KK}: Growth_Asset[i,'UB']*Current_Asset[i,k] >= Asset[i,k];
    con Grwth_Asset_UB3{i in 48..57, k in KK}: Growth_Asset[i,'UB']*Current_Asset[i,k] >= Asset[i,k];
    con Grwth_Asset_UB4{i in 65..69, k in KK}: Growth_Asset[i,'UB']*Current_Asset[i,k] >= Asset[i,k];
    con Grwth_Asset_UB5{i in 72..76, k in KK}: Growth_Asset[i,'UB']*Current_Asset[i,k] >= Asset[i,k];
    con Grwth_Asset_UB6{i in 78..84, k in KK}: Growth_Asset[i,'UB']*Current_Asset[i,k] >= Asset[i,k];
```

A MULTI-PERIOD MODEL

Assumptions:

- Each asset or liability segment can be considered as homogeneous.
- Assume that we have all the building blocks, as mentioned above, in place.
- All income statement items that are not directly dependent on the cash flows produced by the assets and liabilities, can be expressed as a percentage of net interest income or some other income statement item that depends linearly on these cash flows. For example, non-interest expenses.
- To balance the balance sheet, all surpluses will be invested in the interbank market.
- All funding liabilities are held to maturity.
- The vintage of all assets and liabilities are known at all times.
- A single (expected) scenario of future values for all risk drivers is available.

At a high-level the steps of our proposed methodology are as follow:

Step 1: Use the assets and liabilities on the current balance sheet as inputs and project scenario dependent expected future cash flows for each period (monthly in our case) over the planning horizon using the *cash flow simulator*. The outputs from this step will, for example, contain expected pre-payments, expected losses and expected risk weighted assets.

Step 2: For each asset segment and each liability segment, use the same cash flow simulator to project expected (forward starting) cash flows with a starting exposure amount of one unit (say $1 million), for each period within the planning horizon. For example, if an asset (segment) is bought at time *t*, then all cash flows from this asset prior to time *t* will be zero, the cash outflow at time *t* will be a unit amount and future cash in- and out-flows from the asset will start one period after time *t*.

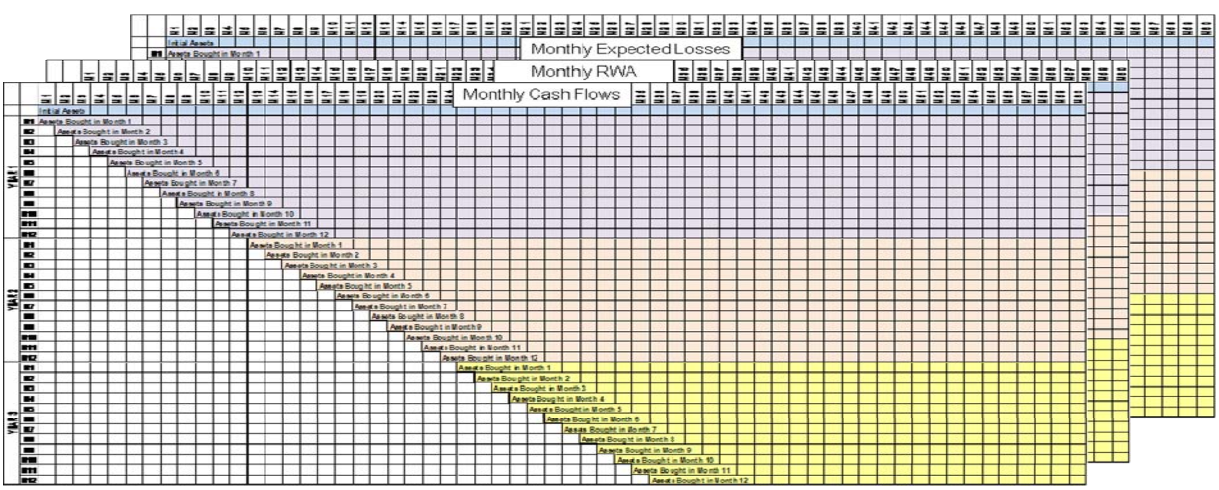

Figure 6: Cash flows, RWAs and Expected Losses per cohort over time

Step 4: Formulate the multi-period decision problem as a linear program (see formulation below) where the decision variables are the multipliers that must be applied to the unit amounts. The formulation includes all constraints: balance sheet accounting relationships, growth targets and bounds, regulatory implied constraints, etc.

Step 5: Specify the mathematical formulation and inputs to the optimizer, solve and export results.

Step 6: Do sensitivity analysis and stress testing.

Figure 7 (below) gives a summary of the building blocks and data flows.

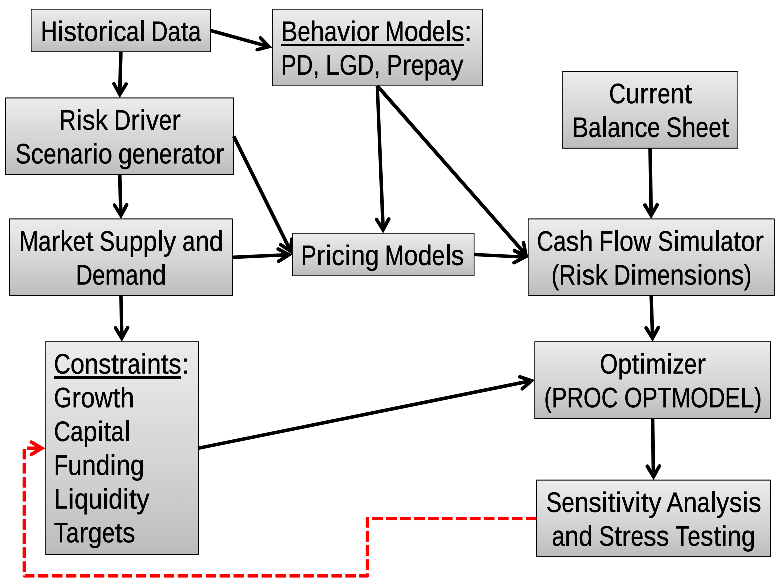

Figure 7: Summary building blocks of proposed methodology

A partial mathematical formulation of the multi-period model

Formulating the complete model is out of scope of this paper. For example, formulating the two new Basel III liquidity requirements in mathematical terms is complicated, because different multipliers apply to different assets and liabilities and depends on the maturity profile of these at future time points. The same applies for the Tier I and Tier II capital requirements. For this reason we will only provide a partial formulation.

In what follows, asset, asset segment and asset class are used interchangeably. The same applies for liabilities.

a) Index sets

$IAssets = \{1,2,\ldots,NI\}$ = the set of all initial assets on the bank's current balance sheet
$NAssets = \{1,2,\ldots,N\}$ = the set of all new assets in which the bank can invest
$Assets = IAssets \cup NAssets$ = the set of all assets
$ILiabs = \{1,2,\ldots,MI\}$ = the set of all initial liabilities on the bank's current balance sheet
$NLiabs = \{1,2,\ldots,M\}$ = the set of all new liabilities which the bank can use to raise funds
$Liabs = ILiabs \cup NLiabs$ = the set of all liabilities
$Time1 = \{0,1,2,\ldots,T_1\}$ = the set of decision times
$Time2 = \{0,1,2,\ldots,T_2\}$ = the set of all times, $T_1 < T_2$

b) Data and parameters
Cash flows:

$CFA_{i,t}$ = cash flow of the i-th asset, $i \in Assets$, in period t, $t = 0, 1,\ldots, T_2-1$

$CFL_{j,t}$ = cash flow of the j-th liability, $j \in Liabs$, in period t, $t = 0, 1,\ldots, T_2-1$

RWAs:

$RWA_{i,t}$ = risk weight of the i-th asset, $i \in Assets$, in period t, t = 0, 1,…, T_2-1

Expected losses:

$ELA_{i,t}$ = expected loss from the i-th asset, $i \in Assets$, in period t, t = 0, 1,…, T_2-1

c) Decision variables

$A_{i,t}$ = amount invested the i-th new asset, $i \in NAssets$, in period t, t = 0, 1,…, T_1-1

$L_{j,t}$ = amount funded from the j-th new liability, $j \in NLiabs$, in period t, t = 0, 1,…, T_1-1

Note: The calculation of cash flows will depend on the vintage of the asset or liability. This means that although we will have similar assets and liabilities, all assets and all liabilities are different.

d) Financial statement variables

NII_t = net interest income in period t, t = 0, 1,…, T_1-1
EL_t = expected losses in period t, t = 0, 1,…, T_1-1
NIR_t = non-interest revenue in period t, t = 0, 1,…, T_1-1
NIE_t = non-interest expense in period t, t = 0, 1,…, T_1-1
Etc.

e) Constraints

Budget constraints
Cash flow constraints
Book run-off constraints (including defaults and prepayments)
Income statement constraints (example)

$$NII_t = \sum_{i \in IAssets} CFA_{i,t} + \sum_{i \in Assets} A_{i,t} \times CFA_{i,t} - \sum_{j \in ILiabs} CFL_{j,t} - \sum_{j \in Liabs} L_{j,t} \times CFL_{j,t}$$

Balance sheet identity constraints
Liquidity constraints (LCR and NSFR)
Tier I and Tier II capital constraints
Capital adequacy constraints
Managerial constraints (targets, policy, etc.)
Risk concentration constraints
Funding profile constraints
Performance constraints (e.g. return on RWA)

f) Objective function

$$\min Z = \text{Deviations from targets}$$
$$= \sum_{k \in Targets} P_k \left[d_k^+ + d_k^- \right]$$

where $P_1 > P_2 > \ldots > P_K > 0$, captures the priorities assigned to K targets; d_k^+ and d_k^- capture the target over- and under achievement.

Note: For some targets only under achievement may be penalized in which case the over achievement will be dropped from the objective function.

CONCLUSION

This paper outlined a methodology which can be applied to strategic balance sheet management. Although this may seem ambitious at first, the author is convinced that all the necessary software technology is currently available to tackle the problem and solve it.

Using a single scenario as input into the optimization and then afterwards do a sensitivity analysis and stress testing is not satisfactory. A valuable extension of the model would be to apply a Stochastic Programming approach using a tree structure to represent the evolution on uncertain risk drivers.

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