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MULTI-CRITERIA MODELLING OF INTEGRATED ASSET & LIABILITY MANAGEMENT IN A COMMERICAL BANK

Abstract

One of the most important category of risk banks face is the financial risk. Asset & Liability Management (ALM) is a set of techniques used to manage financial risk. Growing instability in the financial world made ALM a great challenge for both researchers and practitioners.

A basic structure of the ALM model, based on the anticipated cash flows, is constructed. It comprises the main financial risks: interest rate, foreign exchange, liquidity and capital risk. The illustration models which are set up in a framework of the linear programming, deterministic or stochastic, are presented. The simplified cases with simulated data, illustrating the activity of a commercial bank in Poland, are solved with the aid of interactive goal programming.

Keywords

Financial risk management, asset & liability management, commercial banking, multiple criteria decision making, interactive goal programming, stochastic programming.

INTRODUCTION

Banks are the major part of the financial markets and the financial risk is a serious matter for them. This is why the Asset & Liability Management (ALM) is evolving rapidly in the banking industry. Another important factor contributing to the development of risk management was the rapid advance in the state of information technology.

The aim of this paper is an analysis of multi-criteria methods which can support the decision making in ALM process. The general background for the decision making support model is presented.

The assumptions for a satisfactory ALM model are:

- the realization of an integrated asset and liability management,
- the openness and flexibility (easy modifications according to variable external conditions and changing of the bank management preferences),
- the adequacy to real processes in a bank.

1. ASSET & LIABILITY MANAGEMENT IN A BANK

ALM is the set of techniques used to manage important issues of financial risk. ALM also deals with the structure of the balance sheet, given funding constraints, regulatory and profitability targets [1].

The main important factors contributing to the rapid evolvement of the Asset & Liability Management (ALM) are:

- Banks are the major part of the financial markets and the financial risk is a serious matter for them.
- The growth of instability in the financial markets.
- The growth of trading activity.
- The development in derivatives and growth of derivatives activity.
- The rapid advance of the state of information technology.

The enormous development of both theory and practice of risk management in last thirty years deserves the name of the 'risk management revolution' [3].

There are several risks, several possible targets, several measures of each dimension of risk, several types of tools and techniques [13]. This is the reason why the ALM is a complicated, multi-step and multidimensional process.

The main steps of ALM process are:

1. Recognizing the main types of financial risk and their sources.
2. Choosing the appropriate risks' measures which constitute a base for the risk management system.
3. Establishing the set of financial instruments which are used for hedging purposes.

Of course there are many other technical problems which arise during the implementation phase, but they are not the subject of this paper. In the literature different views of the scope of the ALM can be found. They depend in part on the author opinions. The same situation is in banks, where the concrete ALM process depends strongly on the view of bank's authority. Despite of these differences there exists the core content of the ALM. It comprises the interest rate risk, foreign exchange risk, liquidity and capital management.

2. BASIC FRAMEWORK

The foundations of a model are as follows:

- The risk is a result of the uncertainty of future cash-flows.
- We consider a finite period of time divided into finite number of periods.
- All cash-flows take place only at the end of any period (simplification).

We need an index set to distinguish various financial instruments used for risk management. It is convenient to use three finite sets of indices. As a result every cash flow is identified by time, currency and the additional features as follows:

- $t \in T$ – indicates the time period,
- $v \in V$ – indicates the currency of the instrument,
- $z \in Z$ – indicates definite instrument in given currency,

where T, V, Z – finite sets.

Then every financial instrument is characterized by the set of its cashflows

$$x = [x_t(v, z)], \quad t \in T \tag{1}$$

For given v and z the instrument becomes:

- a vector – deterministic case,
- a random vector – stochastic case.

With each financial instrument we associate a decision variable – a single non-negative number

$$x_t(v, z) \tag{2}$$

which determines all cash-flows of the instrument. The detailed description of the financial instruments with their cash-flows will be presented later, in the section describing the illustrative model. Below we provide two examples examples illustrating the way of deriving cash-flow structure from the generic characteristics of the instrument.

Let us start with the purchase of the instrument with coupon payments. A decision variable $x_t(v, z)$ is a volume which is purchased. At the time of purchase, there is the negative cash-flow $-x_t(v, z)$. In next consecutive periods $t' > t$, there is the series of coupon payments of the form $r_{t''}(v, z)x_{t''}(v, z)$, where $r_{t''}$ are the interest rates. At the maturity we have interest payment plus capital return: $x_{t''}(v, z) + r_{t''}(v, z)x_{t''}(v, z)$, $t'' > t'$.

In the case of purchase of interest rate call option, the decision variable $x_t(v, z)$ is the principal amount of the option and $t > 0$. At the beginning period we pay for the option: $-r_0(v, z)x_0(v, z)$, where $r_0(v, z)$ is the unit price of the option (expressed as percentage). At the exercise date, the conditional flow $x_t(v, z)[r_t(v, z) - \hat{r}_t(v, z)]+$, $t > 0$ takes place, where $\hat{r}_t(v, z)$ is the exercise rate of the option (we use the notation $[u]+ = \min\{0, u\}$).

3. MODEL ASSUMPTIONS

The division of the model constituents into hard constraints and criteria is, to the high degree, the matter of the analyst's choice. So the presented model can be regarded as one of many other versions equally possible. Here we restrict ourselves to the linear model. Consequently we use the linear forms of general expressions presented below.

3.1 Constraints

From the modelling point of view there are two types of constraints:

1. deterministic

$$Bx \leq b \tag{3}$$

where matrix B and vector b are deterministic.

2. stochastic

$$H(\xi)x \leq h(\xi) \tag{4}$$

where both matrix H and vector h generally depend on random parameters.

According to their origin the constraints can be divided into three groups:

i. Market and technical limits.
ii. Constraints which are imposed by the legal system of the country. (e.g. the bottom limits for the capital adequacy ratio and for cash reserves.)
iii. Internal risk management constraints.

It should be noted that the above division has a rather formal character. In practice all three groups have much in common – the sources of concrete restrictions can lie in all of the above groups. For instance capital adequacy ratio limit and cash reserves limits definitely belong to the second group. However they can be regarded as the part of internal risk management constraints as well. It is common that the management of a bank imposes more strict conditions on cash reserves and sometimes on capital adequacy ratio.

3.2. Criteria

When the problem of risk management is of concern, the decision maker should:

- minimize the several types of risk,
- maximize profitability or worth of a bank.

4. MODEL DETAILS

4.1. Market and Technical Limits

These limits have to be proposed by the bank specialists and confirmed by the management of a bank. Most of them are upper limits for bank's dealers transactions and open positions. They have the deterministic form (3).

4.2. Legal System Constraints

4.2.1. Capital Adequacy Ratio

We set the bottom limit for the capital adequacy ratio. This is a deterministic constraint which can be written as the following inequality

$$A_0 - \sum_{v \in \mathcal{V}} \sum_{z \in \mathcal{Z}_a} w(v,z) q_0(v,v_0) x_0(v,z) \leq \frac{C}{\omega} \tag{5}$$

where A_0 initial value of the weighted sum of risk assets from the balance sheet, $Z \supset Z_a$ – contains only asset transactions, $q_0(v, v_0)$ translates transaction in foreign currency v into local currency v_0, $w(v, z)$ – risk factors, C – equity of the bank, ω – the minimal level of the capital adequacy ratio.

4.2.2. Cash Reserves

These arise as the recurrence series of inequalities

$$\sum_{z \in \mathcal{Z}} \sum_{t'=0}^{t} [x_{t'}(v,z) + p_{t'}(l,v)] \geq l_t(l,v), \quad t \in \mathcal{T},\ v \in \mathcal{V} \tag{6}$$

where $p_{t'}(l, v)$ – the initial level of cash reserves of currency v at time t', $l_t(l, v)$ – the minimal requirement of cash at time t.

4.3. Criteria

An explanation should be given for the reasons for choosing the specific measures for criteria in the model. Among many possibilities, sensitivity measures were chosen. Thanks to their simplicity and convenience, they are widely used in bank practice, as it was proven by the investigation made in US and foreign banks [10]. In the last years a more sophisticated measure achieved a great success: the downside risk measure – Value at Risk [3; 8]. However it should be noted that it has its own disadvantages. It does not satisfy the conditions attributed to proper risk measures [12]. Moreover, such a risk measure introduced into banking supervisory regulations can even deepen the market crises [2]. The additional advantage of sensitivity measures chosen here is that they are linear in decision variables (under the special assumptions, the minimization of VaR can also be done by linear programming [9]).

4.3.1. Interest Rate Risk

As the criterion we take the minimization of change of market value of bank's equity due to interest rate change. Let's define

$$D_X^n = D_X PV_X = \sum_t t\gamma_t \, cf_{X,t}(x) \tag{7}$$

where $X = A$ for assets, $X = L$ for liabilities,
D_X, PV_X and $cf_{X,t}(x)$ – duration, present value and sum of all positive (negative) cash-flows at the moment t of assets (liabilities), respectively, γt – discount factor. As the risk is minimal for zero gap between assets and liabilities, we can write down

$$D_L^n - D_A^n \to 0 \tag{8}$$

4.3.2. Foreign Exchange Risk

As a measure of the foreign exchange risk with we propose foreign currency position. It is defined for each foreign currency as follows:

$$P_t(v) = p_t(v) + \sum_{z\in\mathcal{Z}_f} x_t(v,z), \quad t \in \mathcal{T} \tag{9}$$

where $P_t(v)$ – position for period t and for foreign currency v, $p_t(v)$ – initial position for period t and currency v, $Z \supset Z_f$ – transactions changing position in a given foreign currency.

The minimal risk occurs when the position is zero (closed), so similarly to the interest rate case, we write down

$$P_t(v) \to 0 \tag{10}$$

4.3.3. Profitability

We can express the profit-loss of all the transactions as

$$\sum_{v\in\mathcal{V}} \sum_{z\in\mathcal{Z}} \sum_{t\in\mathcal{T}} \gamma_t \, R[r_t(v,z)] \, x_t(v,z) \, q_t(v,v_0) \to \max \tag{11}$$

where

$$R[r_t(v,z)] = \begin{cases} \pm r(v,z), & \text{for interest rate transactions} \\ \pm(r-\hat{r})^+ & \text{for options} \\ 1, & \text{for FX transactions} \end{cases} \tag{12}$$

The sign ± in above expressions depends on the meaning of specific transaction (profit or cost in interest rate transaction, purchase/sell of call or put option). $q_t(v, v_0)$ translates transaction in foreign currency v into local currency v_0; γ_t is a discount factor.

4.4. Uncertainty in the model

We need some kind of realistic model, closely describing reality on the one hand and not too complicated on the other. Let's assume that the uncertainty is introduced to the model by the randomness of market parameters: interest rates and foreign exchange rates. If we want to limit ourselves to the linear programming we have to restrict the distributions of random variables to the discrete finite case. The deterministic model can be obtained as a special case under the assumption that all random parameters have single-valued distributions.

4.5. General Form of the Model

As the result of the above assumptions we obtain the multicreterial linear programming model. We are going to use the interactive goal programming procedure for solving it, so we present it in the form

$$\begin{array}{rcl} \min_{x,y}\,[cy] & & \\ Bx & \leq & b \\ H(r,q)x & \leq & h(r,q) \\ G(r,q)x - y^{+} + y^{-} & = & g \\ x, y & \geq & 0 \end{array} \tag{13}$$

where we use auxiliary constraints for goals. $y+$ and $y-$ are over- and underachievement variables, vector g represents the aspiration levels of goals. In deterministic case the above model can be solved as it stands. In stochastic case we need to find its deterministic equivalent [6].

4.5.1. Deterministic equivalent of stochastic model

It has been shown that stochastic goal programming model is a particular case of stochastic linear programming with recourse [5]. In our case it is convenient to formulate it as the multistage recourse program.

We need additional auxiliary variables y′ which serve to compensate the violation of stochastic constraints in some realizations of random parameters. The number of variables y′ is equal to the number of stochastic inequalities in (13).

The deterministic equivalent looks as follows

$$\begin{array}{rcll} \min_x E_{r,q}\{cx + Q_1(x,r,q) + Q_2(x,y',r,q)\} & & & \\ Bx & \leq & b & \\ H(r,q)x - Wy' & \leq & h(r,q) & \quad (14) \\ G(r,q)x + W'y' - y^+ + y^- & = & g & \\ x, y, y' & \geq & 0 & \end{array}$$

where $E_{r,q}$ stands for expectation value with respect to the distributions of r, q. $Q_2(x, y', r, q)$ is the recursion function of the third stage, defined as follows

$$Q_2(x,y',r,q) = \min_y\{c^T y \mid y \geq 0\} \tag{15}$$

$Q_1(x, r, q)$ is the recursion function of the second stage, given by the formula

$$Q_1(x,r,q) = \min_{y'}\{d^T y' \mid y' \geq [H(r,q)x - h(r,q)]^+\} \tag{16}$$

5. ILLUSTRATIVE MODEL

For the illustrative model two time periods $T = \{0, 1, 2\}$ and two currencies $V = \{1, 2\}$ ($v = 1$ for local currency) were chosen. The detailed presentation of all decision variables with their cash flows is given below.

5.1. Decision Variables and Cash-Flows

5.1.1. Short term fixed interest rate transactions (e.g. treasury bills)

Purchase The first two variables ($z = 1$) describe the purchase of the bills which mature at the first period, the next two ($z = 2$) – of those which mature at the second period.

$$x_t(v,1) = \begin{bmatrix} -x_0(v,1) \\ [1 + r_0(v,1)]\, x_0(v,1) \\ 0 \end{bmatrix} \tag{17}$$

$$x_t(v,2) = \begin{bmatrix} -x_0(v,2) \\ 0 \\ [1 + r_0(v,2)]\, x_0(v,2) \end{bmatrix} \tag{18}$$

Sell Similar to the purchase case, we have 4 variables for selling:

$$x_t(v,3) = \begin{bmatrix} x_0(v,1) \\ -\left[1 + r_0(v,1)\right] x_0(v,1) \\ 0 \end{bmatrix} \tag{19}$$

$$x_t(v,4) = \begin{bmatrix} x_0(v,4) \\ 0 \\ -\left[1 + r_0(v,4)\right] x_0(v,4) \end{bmatrix} \tag{20}$$

As the interbanking transactions look similar, we can easily include them in the model (here we skip them so as not to expand the size of the model).

5.1.2. Coupon bonds

Again 4 variables are assigned to purchase and 4 to the selling of instruments with coupons.

Purchase

$$x_t(v,5) = \begin{bmatrix} -x_0(v,5) \\ \left[1 + r_0(v,5)\right] x_0(v,5) \\ 0 \end{bmatrix} \tag{21}$$

$$x_t(v,6) = \begin{bmatrix} -x_0(v,6) \\ r_0(v,6)x_0(v,6) \\ \left[1 + r_1(v,6)\right] x_0(v,6) \end{bmatrix} \tag{22}$$

Sell

$$x_t(v,7) = \begin{bmatrix} x_0(v,7) \\ -\left[1 + r_0(v,7)\right] x_0(v,7) \\ 0 \end{bmatrix} \tag{23}$$

$$x_t(v,8) = \begin{bmatrix} x_0(v,8) \\ -r_0(v,8)x_0(v,8) \\ -\left[1 + r_1(v,8)\right] x_0(v,8) \end{bmatrix} \tag{24}$$

5.1.3. Foreign Exchange Transactions

These transactions occur in pairs. The inflow of one currency is accompanied by the outflow of the other. Here we have 2 spot transactions and 4 forward transactions.

Spot FX

$$x_t(1,9) = \begin{bmatrix} x_0(1,9) \\ 0 \\ 0 \end{bmatrix}, \quad x_t(2,9) = \begin{bmatrix} -q_0(1,2)x_0(1,9) \\ 0 \\ 0 \end{bmatrix} \tag{25}$$

$$x_t(2,10) = \begin{bmatrix} x_0(2,10) \\ 0 \\ 0 \end{bmatrix}, \quad x_t(1,10) = \begin{bmatrix} -q_0(2,1)x_0(2,10) \\ 0 \\ 0 \end{bmatrix} \tag{26}$$

Forward FX

$$x_t(1,11) = \begin{bmatrix} 0 \\ x_1(1,11) \\ 0 \end{bmatrix}, \quad x_t(2,11) = \begin{bmatrix} 0 \\ -q_1(1,2)x_1(1,11) \\ 0 \end{bmatrix} \tag{27}$$

$$x_t(1,12) = \begin{bmatrix} 0 \\ 0 \\ x_2(1,12) \end{bmatrix}, \quad x_t(2,12) = \begin{bmatrix} 0 \\ 0 \\ -q_2(1,2)x_2(1,12) \end{bmatrix} \tag{28}$$

$$x_t(2,13) = \begin{bmatrix} 0 \\ x_1(2,13) \\ 0 \end{bmatrix}, \quad x_t(1,13) = \begin{bmatrix} 0 \\ -q_1(2,1)x_1(2,13) \\ 0 \end{bmatrix} \tag{29}$$

$$x_t(2,14) = \begin{bmatrix} 0 \\ 0 \\ x_2(2,14) \end{bmatrix}, \quad x_t(1,14) = \begin{bmatrix} 0 \\ 0 \\ -q_2(2,1)x_2(2,14) \end{bmatrix} \tag{30}$$

5.1.4. Interest Rate Options

In these transactions the conditional cash-flows appear which depend on the difference between option's exercise rate and the market rate in some future period. In our model we use the purchase of call and put options. The construction of these cash-flows and the notation are explained by the examples in the section 2 (Basic Framework).

Table 1

The list of goals in a model

No.	v	t	meaning
1	1	–	interest rate risk
2	2	–	interest rate risk
3	2	0	FX risk
4	2	1	FX risk
5	2	2	FX risk
6	1	–	profit

Call

$$x_t(v,15) = \begin{bmatrix} -r_0(v,15)x_0(v,15) \\ [r_1(v,15) - \hat{r}_1(v,15)]^+ \, x_0(v,15) \\ 0 \end{bmatrix} \tag{31}$$

$$x_t(v,16) = \begin{bmatrix} -r_0(v,16)x_0(v,16) \\ 0 \\ [r_2(v,16) - \hat{r}_2(v,16)]^+ \, x_0(v,16) \end{bmatrix} \tag{32}$$

Put

$$x_t(v,17) = \begin{bmatrix} -r_0(v,17)x_0(v,17) \\ [\hat{r}_1(v,15) - r_1(v,17)]^+ \, x_0(v,17) \\ 0 \end{bmatrix} \tag{33}$$

$$x_t(v,18) = \begin{bmatrix} -r_0(v,18)x_0(v,18) \\ 0 \\ [\hat{r}_2(v,18) - r_2(v,18)]^+ \, x_0(v,18) \end{bmatrix} \tag{34}$$

It makes the total of 30 decision variables.

5.2. Goals

The first 2 goals represent the interest rate risk for 2 currencies, as it was described in Section 4.3.1. Next 3 goals deal with foreign exchange risk (Section 4.3.2). The last one is the profitability of all transactions (see Section 4.3.3). The numbers and meanings of goals are summarized in Table 1.

5.3. Numerical tests

Distributions of random parameters are limited to three scenarios with probabilities: $p_1 = 0.25$, $p_2 = 0.5$ and $p_3 = 0.25$. For the deterministic model the same data were used with probabilities: $p_1 = p_3 = 0$, $p_2 = 1$.

Table 2

Interest rates (p.a.) for balance sheet transactions

		p1		p2		p3	
v	z	1	2	1	2	1	2
1	1	0,05450		0,05450		0,05450	
2	1	0,02070		0,02070		0,02070	
1	2		0,05650		0,05650		0,05650
2	2		0,02080		0,02080		0,02080
1	3	0,05450		0,05450		0,05450	
2	3	0,02070		0,02070		0,02070	
1	4		0,05650		0,05650		0,05650
2	4		0,02080		0,02080		0,02080
1	5	0,05450		0,05460		0,05470	
2	5	0,02070		0,02075		0,02079	
1	6		0,05650	0,05455	0,05657	0,0545	0,05660
2	6		0,02080	0,02073	0,02088	0,02078	0,02093
1	7	0,05450		0,05454		0,05458	
2	7	0,02070		0,02074		0,02077	
1	8		0,05650	0,05455	0,05659	0,05458	0,05664
2	8		0,02080	0,02074	0,02086	0,02077	0,02090

In the technical constraints (3), we put $B = I$ and $b = [20]$. In constraint for capital adequacy ratio (5) we put $C = 100$, $A_0 = 1220$, and $\omega = 0.08$.

In liquidity constraints for all t, t' and scenarios: $p_{t'}(l, v) = 5.3$, $l_t(l, v) = 5$ for $v = 1$ and $p_{t'}(l, v) = 2.7$, $l_t(l, v) = 2$ for $v = 2$.

The interest, exchange rates and other parameters are chosen to simulate the Polish market in the middle of 2004. They are presented in Tables 2, 3 and 4.

In both cases: deteministic and stochastic, the interactive goal programming was used as a solving procedure [11]. Calculations were performed with Microsoft Excel and with its accompanying optimization procedure Solver.

In interactive goal programming procedure, at every stage, several optimizations with single criterion are performed. The deterministic equivalent of stochastic programming model (14) contains the equality constraints for every goal. In the case of interest risk and FX forward positions, they are duplicated for every realization of random parameters. Consequently, for them, we need to solve the optimization problem with the third stage recursion function (15), for every realization of random parameters separately.

Table 3

Exchange rates for spot and forward FX transactions

			p1		p2		p3	
	t	0	1	2	1	2	1	2
v	z							
1	9	0,21552						
2	10	4,66						
1	11		0,2153		0,21552		0,2158	
1	12			0,2154		0,21552		0,2158
2	13		4,665		4,66		4,655	
2	14			4,666		4,66		4,657

Table 4

Exercise rates for interest rate options (in column t = 0 option prices)

			p1		p2		p3	
	t	0	1	2	1	2	1	2
v	z							
1	15	0,00000015	0,05450		0,05460		0,05470	
2	15	0,00000015	0,02070		0,02075		0,02079	
1	16	0,00000015		0,05650		0,05657		0,05660
2	16	0,00000015		0,02080		0,02088		0,02093
1	17	0,00000015	0,05450		0,05454		0,05458	
2	17	0,00000015	0,02070		0,02074		0,02077	
1	18	0,00000015		0,05650		0,05659		0,05664
2	18	0,00000015		0,02080		0,02086		0,02090

Table 5

Deterministic model. The complete first iteration of multiple interactive goal procedure and potency matrices for the next two iterations (B-best, W-worst). Aditional constrains (ac): goals 1-5 – upper limit for absolute value; goal 6 – lower limit

	1	2	3	4	5	6
1	0,0000	-0,2379	0,6316	-0,5688	2,0000	-0,0027
2	2,0000	-0,2265	-3,3104	-1,0000	6,3986	0,0517
3	-2,9172	-0,2418	0,0000	0,0601	2,0000	-0,0229
4	-2,6385	-0,2414	0,0603	0,0000	2,0000	-0,0212
5	-0,0000	-0,2566	2,6060	-0,5688	0,0000	-0,0878
6	5,5844	-1,0000	-3,3104	-1,0000	5,6223	0,0616
B	0,0000	-0,2265	0,0000	0,0000	0,0000	0,0616
W	5,5844	-1,0000	-1,0000	-1,0000	6,3986	-0,0878
ac	2	1	1	1	2	-0,1
B	0,0000	-0,2330	0,0000	0,0000	0,0000	0,0249
W	2,0000	-0,9978	0,6316	-1,0000	2,0000	-0,0715
ac	1	1	1	1	1	-0,1
B	0,0000	-0,2414	0,0000	0,0000	0,0000	-0,0110
W	1,0000	-1,0000	1,0000	-0,7035	1,0000	-0,0715

Tables 5 and 6 contain the result of calculations performed for deterministic model.

Tables 7, 8 and 9 present results of calculations for stochastic model.

6. CONCLUDING REMARKS

Presented model:
offers integrated approach to ALM management,
is founded on cash-flows basis,
is general and easy to modify,
takes into account the random nature of market parameters.

It is an attempt to develop the auxiliary tool for a complicated management process such as ALM. In the light of the analysis performed it becomes clear that relatively simple methods can considerably improve the procedure of ALM in a bank. Previous experience shows that the problem is not only academic. However not many, the real-life implementations of optimization methods in financial management in a bank were reported. Let us mention two of them. The goal programming model was implemented in large Greek commercial bank [4]. The two-stage linear programming model [7] was a step towards the stochastic programming as it used a number of alternative scenarios and the expected values for the goals.

Although the models mentioned have some similarities with the model presented here, both were designed to support the financial planning process rather than risk management. They are based on balances rather than on cash-flows and they are designed for longer time periods (years).

The model proposed in this article is a further step in the development of optimization methods designed for ALM. In natural way it suggests further issues and research directions:
- incorporating other types of risk into the model (e.g. credit risk),
- taking into account other risk measures (e.g. non-linear measures),
- developing the stochastic content of the model.

Table 6

Deterministic model. Nonzero variables of the last solution with profit optimization

v	z	x	v	z	x
1	2	18,814	1	8	20,000
1	3	3,045	1	12	4,640
2	3	20,000	2	13	0,296
2	4	18,969	1	16	20,000
2	5	19,669	2	16	20,000
2	6	20,000			

Table 7

Stochastic model. The initial solution of multiple interactive goal procedure with the potency matrix (best, worst)

goal no.		1	2	3	4	5	6	best	worst
int. rate									
	p1	-0,000	-0,024	-2,917	-0,010	-0,024	5,554	0,000	5,554
v=1	p2	-0,000	-0,012	-2,902	-0,005	-0,012	5,576	0,000	5,576
	p3	-0,000	0,000	-2,887	-0,000	-0,000	5,587	0,000	5,587
	p1	-0,249	0,000	-0,258	-0,243	-0,254	-1,000	0,000	-1,000
v=2	p2	-0,250	-0,000	-0,259	-0,243	-0,255	-1,000	0,000	-1,000
	p3	-0,252	-0,000	-0,262	-0,244	-0,258	-1,000	0,000	-1,000
FX pos.									
t=0		0,632	0,626	-0,000	0,629	0,626	-3,310	0,000	-3,310
	p1	1,416	1,416	2,039	0,000	1,416	-1,000	0,000	2,039
t=1	p2	1,416	1,416	2,039	0,000	1,416	-1,000	0,000	2,039
	p3	1,416	1,416	2,039	0,000	1,416	-1,000	0,000	2,039
	p1	0,001	0,001	0,001	1,427	0,001	5,623	0,001	5,623
t=2	p2	0,000	0,000	0,000	1,427	0,000	5,623	0,000	5,623
	p3	-0,003	-0,003	-0,003	1,426	-0,003	5,623	-0,003	5,623
profit		-0,088	-0,094	-0,016	-0,027	-0,087	0,176	0,176	-0,106

Table 8

Stochastic model. Potency matrices for the next 2 iterations with additional constraints (ac)

		2			3		
		ac	B	W	ac	B	W
int. rate							
	p1	0,700	0,000	0,693	0,600	0,000	0,595
v=1	p2	0,700	0,000	0,700	0,600	0,000	0,600
	p3	0,700	0,000	0,707	0,600	0,000	0,606
	p1	0,400	0,000	-1,000	0,200	0,000	0,000
v=2	p2	0,400	0,000	-0,102	0,200	0,000	0,000
	p3	0,400	0,000	-0,700	0,200	0,000	-0,800
FX pos.							
t=0		0,400	0,000	0,400	0,300	0,000	0,300
	p1	0,400	0,000	0,400	0,300	0,000	0,300
t=1	p2	0,400	0,000	0,400	0,300	0,000	0,300
	p3	0,400	0,000	0,400	0,300	0,000	0,300
	p1	0,800	0,001	0,801	0,700	0,001	0,700
t=2	p2	0,800	0,000	0,800	0,700	0,000	0,700
	p3	0,800	-0,003	0,799	0,700	-0,003	0,700
profit		-0,030	0,086	-0,030	-0,20	0,070	-0,020

Table 9

Stochastic model. Nonzero variables of the last solution with profit optimization

v	z	x	v	z	x	v	t		y'
1	2	20,000	2	6	20,000	1	1	p1	9,318
1	3	20,000	1	8	13,296	1	1	p2	9,311
2	3	20,000	1	9	3,248	1	1	p2	9,305
2	4	18,668	1	12	6,031	2	2	p1	1,000
1	5	11,948	2	13	1,300	2	2	p2	1,001
2	5	18,668	2	18	20,000	2	2	p3	0,199

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