Risk-adjusted pricing of bank's assets based on cash flow matching matrix

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RISK-ADJUSTED PRICING OF BANK'S ASSETS BASED ON CASH FLOW MATCHING MATRIX

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Abstract. *To price bank's assets correctly, it is important to know cost of funds. But funding cost calculation is complicated due to the fact that banks fund long-term assets through short-term liabilities. As a result, assets with a given time to maturity are usually financed by several liabilities with different maturities. To calculate funding cost it needs to know how cash flows are matched between assets and liabilities. For this it`s used cash flow matching matrix or funding matrix. In the paper, a new algorithm of filling of a two-dimensional funding matrix that is based on the golden rule of banking and modified RAROC-approach is proposed. It provides positive definiteness and uniqueness of the matrix. The matrix shows terms to maturity and amounts of liability cash flows which fund the asset cash flow with a given term to maturity. Examples of partially and fully filled matrices are presented. It is proposed an approach to risk-adjusted pricing that is based on this funding matrix and RAROC-approach adapted to cash flows. The developed approach to pricing integrates organically credit and liquidity risks. It takes into consideration expected credit losses and economic capital (unexpected credit losses) for all lifetime of asset cash flows and not one-year period traditionally used in RAROC.*

Key words: *asset pricing, funding matrix, economic capital, cash flow at risk, risk-adjusted return on capital (RAROC), cash flow matching, interest rate, asset, liability*

Introduction

To price bank's assets correctly, it is important to know cost of funds. But funding cost calculation is complicated due to the fact that banks fund long-term assets through short-term liabilities (Haan and End, 2012). As a result, assets with a given time to maturity are usually financed by several liabilities with different maturities. In general case, assets-liabilities mismatch is defined by accessibility of funds with different maturities in different markets or, in other words, prevalent supply of term funding.

To calculate interest rates for funding follow to use cash flow matching matrix or funding matrix. Note that to build a funding matrix the entire range of assets and liabilities maturities are grouped into *N* time buckets.

A one-dimensional funding matrix (row vector) is broadly known. This is the simplest matrix which shows only excess or shortfall of funding (liquidity gap, gap_i) in each i-th time bucket (Bessis, 1988; Sinkey, 2002; Deutsche bank, 2012):

$$gap_i=CFA_i-CFL_i,$$

where CFA_i, CFL_i are cash flows of bank's assets and liabilities belonging to i-th time bucket.

However, such a matrix does not give a clear understanding of these important parameters:

- how much assets are financed according to the golden rule of banking: "assets and liabilities should not have mismatched maturities" (Hübner, 1853) or, in other words, about closed liquidity positions. Herewith, the closed liquidity position for each i-th time bucket is equal to minimal value of cash flows of assets (CFA_i) and liabilities (CFL_i) correspondently, and;
- what amount of liabilities with what maturities funds asset with a given maturity.

However, for right asset pricing, it is crucial to know these parameters. That is why it is essential to use advanced two-dimensional funding matrix.

It should be noted that literature concerning to building the two-dimensional funding matrix is very limited. Only some investigators and practitioners are interested in construction of such a funding matrix (see, for example, Skyrta and Stovbchatiy, 1997; Veselov, 2012). The main lack of these approaches is that the maturities of assets and liabilities are not taken explicitly into consideration.

Meanwhile, there is a need for such a two-dimensional funding matrix which gives a full picture of assets funding and a clear understanding of the liabilities' financing the assets of the given maturity. Such matrices were developed by Derkach, Smoliy and Linder (2000), Voloshyn (2002). In such matrices, time to maturity of assets increases from top to bottom (with i-th row) and the one of liabilities does from left to right (with j-th column). Herewith, time buckets of assets and liabilities with the same numbers of row and column are identical.

An element $a_{i,j}$ of funding matrix shows a partial or full sum of liabilities belonging to j-th bucket that funds assets belonging to i-th bucket. To build the matrix, follow to aggregate:

- asset cash flows into each i-th time bucket and create the column vector CFA_i of size N, and;
- liability cash flows into each j-th time bucket and create the row vector CFL_j of size N.

By the funding matrix, aggregated cash flows of liabilities CFL_j are matched with the aggregated cash flows of assets CFA_i.

There are at least two approaches to building a two-dimensional matrix taking explicitly into consideration time to maturity (Derkach, Smoliy and Linder, 2000; Voloshyn, 2002). The principle of the first approach (Derkach, Smoliy and Linder, 2000) is the following: liability with the longest term to maturity should first fund asset with the longest term to maturity. If after this an excess of the liability remains, then it should finance the asset with shorter term to maturity, i.e. belonging to the nearest time bucket and etc. After matching the longest liability, the liability with shorter term to maturity (in the next time bucket) should be matched and etc. until all the liabilities will be treated.

The disadvantage of this approach is the mistaken calculation of closed liquidity positions, i.e. those that are corresponding to the golden rule of banking (Hübner, 1853). Note that ignorance of the closed liquidity positions does not allow correct estimating of funding cost and, accordingly, price of assets.

To overcome this shortfall Voloshyn (2002) proposed two-stage approach to cash flow matching. During the first stage the liabilities are matched by the following principle: the liability belonging to the given time bucket should first finance the asset belonging to the same time bucket. Thus, the diagonal elements that correspond to assets and liabilities with the same time to maturity (being in row and column with the same number $i=j$) are first filled.

During the second stage the remaining non-diagonal elements of the matrix are filled in accordance with the first approach by Derkach, Smoliy and Linder (2000), i.e. the excess of the liability with the longest term to maturity should finance the asset with the longest term to maturity and etc.

The downside of both approaches (Derkach, Smoliy and Linder, 2000; Voloshyn, 2002) is that capital is first allocated on the longest-term assets. However, the capital could be allocated between assets with different maturities, for example, as according to *RAROC*-approach (Bessis, 1988). Besides, these approaches use book value of assets and liabilities, but not cash flows.

In this paper, the task of risk-adjusted pricing of term fixed-rate assets that are funded through term fixed-rate liabilities under cash flow mismatch is stated. The developed approach to asset pricing is fully based on undiscounted cash flows and utilizes the golden rule of banking and *RAROC*-approach adapted to cash flows.

Cash flows and cash flows at risk

Before considering the new approach to building a funding matrix, concern what kinds of cash flows and cash flows at risk are generated by assets and liabilities (CorporateMetrics, 1999; Yan, Hall and Turner, 2011).

Assets and liabilities generate the following cash flows:

- CFA_i and $CFL_j \geq 0$ is contractual cash flows belonging to i-th bucket for assets and j-th bucket for liabilities correspondently;
- $CFA_i^{\exp} \geq 0$ is expected cash flow of assets belonging to i-th bucket, i.e. cash flow that a bank plans to receive taking into account credit losses of cash flow;

- $CFA_i^{worst}(p) \geq 0$ is the worst-case cash flow of assets belonging to i-th bucket and calculated with the given confidence level p (CorporateMetrics, 1999).

Theoretically, there are also catastrophic cash flows which will not be considered here.

Thus, expected and unexpected cash flows are examined from the downside risk point of view, i.e. risk of decreasing cash flows less than contractual ones.

Further, if required, the cash flows could be split into cash flows of principals and interests.

Let the deviation of asset cash flow from the contractual value be caused by credit risk. So, the one is expected cash flow at credit risk and, at the same time, equal to undiscounted expected credit losses:

$$cfar_i^{\exp} = CFA_i - CFA_i^{\exp} \equiv EL_i \text{ , (1)}$$

where $cfar_i^{\exp}$ is expected cash flow at risk for i-th bucket (during period m_i), EL_i is undiscounted expected credit losses for i-th bucket (during period m_i) forming column vector.

Using results by Bohn and Stein (2009), and expressing the undiscounted expected credit losses through cash flows, write it in the following form:

$$EL_i = pd_i \times ldg_i \times CFA_i \text{ ,}$$

where pd_i is a probability of borrower's default during the time m_i, lgd_i is loss given default.

The deviation of the unexpected cash flow of assets from expected value is an unexpected cash flow at risk and, at the same time, equal to undiscounted economic capital:

$$cfar_i^{un\exp} = CFA_i^{\exp} - CFA_i^{un\exp}(p) \equiv EC_i \text{ ,} \qquad (2)$$

where $cfar_i^{un\exp}$ is unexpected cash flow at risk for i-th bucket (during period m_i), EC_i is undiscounted economic capital for i-th bucket (during period m_i) forming column vector.

Using results by Bohn and Stein (2009) and expressing the undiscounted unexpected credit losses through cash flows, write it in the following form:

$$EC_i = k_p \times \sqrt{pd_i \times (1 - pd_i)} \times CFA_i \text{ ,}$$

where k_p is a quantile of order p.

It is worth to note that there are expected and unexpected cash flows from liabilities caused by deposit risk. But they will not be investigated here.

The above-mentioned kinds of cash flows and cash flows at risk are presented on Fig. 1 (using results of Bessis, 1988).

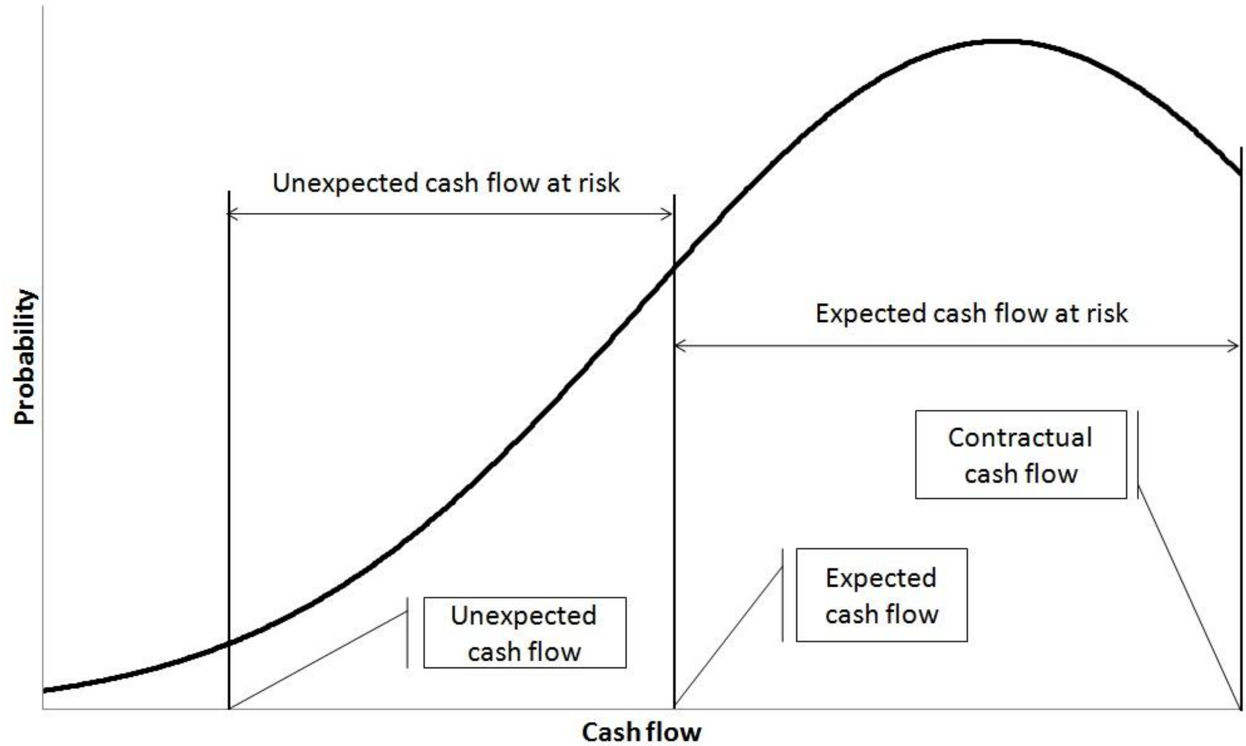

Figure 1. Density of probability of cash flows and cash flows at risk for *i*-th bucket (charted using results of Bessis, 1988).

Further, for brevity, the word "undiscounted" in terms of "expected credit losses" and "economic capital" will be omitted.

New funding matrix

The cash flows of interests from the liabilities do not fund the assets as the liability principals do, and the cash flows of interests from the assets do not absorb liquidity as the asset principals do. Therefore, the funding matrix should be based on **principal** cash flows of the assets and liabilities. But, naturally, the interest cash flows influence on bank's liquidity. In the funding matrix, this influence is taken into account through capital that includes profit. Note that the full matching of cash flows is achieved by taking into consideration the economic capital.

Without loss of generality, the book capital is assumed to be equal to the economic one. Thus, a bank fully uses its capital for extracting profit from the risky activity.

To take into account credit risk in the funding matrix, utilize the economic capital and the expected principal cash flows of assets. The expected principal cash flow of assets is equal to the contractual principal cash flow of assets after the undiscounted expected credit losses of the asset principals (see formula (1)).

A funding matrix may be constructed as of current date as well as of future one. Then, the existing or predicted cash flows of principals are applied. Correspondently, it is dealt with estimation of risk-adjusted performance or pricing of assets.

Note that a funding matrix is a positively defined square one $A = [a_{i,j}]$ with size NxN, where N is the total number of time buckets. For the correctly filled matrix the following balance constraints exist:

$$\sum_j a_{i,j} + EC_i = CFA_i^{\exp},$$

$$\sum_i a_{i,j} = CFL_j \text{ for all } i, j = 1, \ldots, N,$$

where $CFA_i^{\exp}$ is expected principal cash flow of assets belonging to i-th bucket, CFL_j is contractual principal cash flow of liabilities belonging to j-th bucket.

When the matrix is not yet filled, the following imbalances of assets (dbA_i>0) and liabilities (dbL_j>0) may be presented:

$$dbA_i = CFA_i^{\exp} - \sum_j a_{i,j} - EC_i, \quad (3)$$

$$dbL_j = CFL_j - \sum_i a_{i,j} \text{ for all } i, j = 1, \ldots, N. \quad (4)$$

The following algorithm is proposed to resolve these imbalances and provide positive definiteness and uniqueness of the matrix. The algorithm is based on three principles.

According to *RAROC*-approach capital could be allocated on each risky asset. But each asset has the certain term to maturity. So, from this the capital term structure arises. Thus, the first principle says: an asset cash flow with some term to maturity should be funded by capital allocated on this cash flow.

The second one is the rephrased the golden rule of banking (Hübner, 1853): an asset cash flow with some term to maturity should second be funded by a liability cash flow with the same time to maturity. Usage of this rule allows accurately define closed liquidity positions.

Then, the united principle is the following: the asset cash flow with some term to maturity should be first funded through both economic capital on this asset cash flow and the liability cash flow with the same term to maturity. Note that using formula (2) the economic capital on the asset cash flow could be allocated with respect to its term to maturity.

The proposed approach differs from the existing ones due to the fact that it uses:

- **undiscounted principal** cash flows of assets and liabilities;
- **expected** cash flows of assets, i.e. decreased on expected credit losses;
- economic capital allocated **on each** asset cash flow.

Consider the algorithm of building the funding matrix. The diagonal elements that define the closed liquidity positions are equal to:

$$a_{i,i} = \min\left(CFA_i^{\exp} - EC_i, CFL_i\right). \quad (5)$$

Calculate new imbalances (formulæ (3 and 4)) and fill non-diagonal matrix elements using the third principle: the excess of the liability cash flow with the given term to maturity should fund the remaining unfunded residual of the asset cash flow with the longest term to maturity and etc.

So, beginning from the last column ($j=N$) find the first j-th column with the liability imbalance $dbL_j>0$. Then seek for the first i-th row from below where the asset imbalance $dbA_i>0$ exists. Decrease or resolve the liability imbalance dbL_j by assigning the following value to the matrix element $a_{i,j}$:

$$a_{i,j} = \min\left(dbA_i, dbL_j\right). \quad (6)$$

Running up from $i=N$ to $i=1$, fill the remaining matrix elements until imbalance dbL_j becomes equal zero. Then go over to the next j-th column where the liability imbalance is above zero ($dbL_j>0$) and repeat the procedure until the next imbalances dbL_j will be liquidated. As a result, full cash flow matching will be achieved.

The matrix filled by such a procedure may be named the “golden” funding matrix because it corresponds to the golden rule of banking.

Keep in mind that the proposed approach assumes: short-term liabilities which fund long-term assets will be renewed (rolled over).

The examples of partially and fully filled by the proposed algorithm matrices are presented in Tables 1 and 2 correspondently.

In the given examples (Table 1 and 2) economic capital is allocated supposing that the specific economic capital (on one unit of assets cash flow) is equal to ec=8%. Then:

$$EC_i = 8\% \times CFA_i^{\exp}. \quad (7)$$

Note that for simplicity in the expression (7) differences between expected and contractual cash flows of assets were neglected.

Only on base of the funding matrix it becomes possible to build a local balance of cash flows for each i-th time bucket (Fig. 2).

Table 1. Example of the partially filled (after filling diagonal elements) funding matrix with 5x5 size, mln. USA dollars

Time to maturity	**Less than 1 month (j=1)**	**1 to 3 months (j=2)**	**3 to 12 months (j=3)**	**1 to 2 years (j=4)**	**2 to 3 years (j=5)**	*Economic capital, EC_i*	*Total asset expected cash flows, $CFA_i^{\exp}$*	*Asset imbalances, dbA_i*
Less than 1 month (i=1)	**32 200**					*2 800*	*35 000*	*0*
1 to 3 months (i=2)		**25 000**				*5 600*	*70 000*	*39 400*
3 to 12 months (i=3)			**9 200**			*800*	*10 000*	*0*
1 to 2 years (i=4)				**10 000**		*2 800*	*35 000*	*22 200*
2 to 3 years (i=5)					**5 000**	*2 348*	*29 348*	*22 000*
Total liability cash flows, CFL_j	*85 000*	*25 000*	*40 000*	*10 000*	*5 000*	*14 348*	*179 348*	*0*
Liability imbalances, dbL_j	*52 800*	*0*	*30 800*	*0*		*0*	*0*	

Table 2. Example of the fully filled (by algorithm (3-6)) funding matrix with 5x5 size, mln. USA dollars

Time to maturity	**Less than 1 month (j=1)**	**1 to 3 months (j=2)**	**3 to 12 months (j=3)**	**1 to 2 years (j=4)**	**2 to 3 years (j=5)**	*Economic capital, EC_i*	*Total asset expected cash flows, $CFA_i^{\exp}$*	*Asset imbalances, dbA_i*
Less than 1 month (i=1)	**32 200**					*2 800*	*35 000*	*0*
1 to 3 months (i=2)	**39 400**	**25 000**				*5 600*	*70 000*	*0*
3 to 12 months (i=3)			**9 200**			*800*	*10 000*	*0*
1 to 2 years (i=4)	**13 400**		**8 800**	**10 000**		*2 800*	*35 000*	*0*
2 to 3 years (i=5)			**22 000**		**5 000**	*2 348*	*29 348*	*0*
Total liability cash flows, CFL_j	*85 000*	*25 000*	*40 000*	*10 000*	*5 000*	*14 348*	*179 348*	*0*
Liability imbalances, dbL_j	*0*	*0*	*0*	*0*		*0*	*0*	

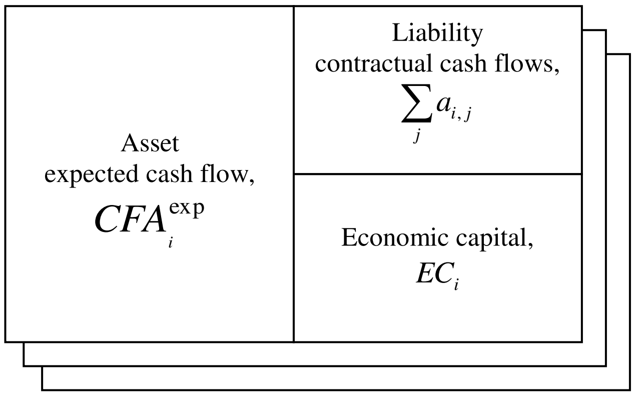

Figure 2. A local balance of undiscounted cash flows from assets and liabilities belonging to i-th time bucket

Risk-adjusted pricing of assets based on funding matrix

New approach to risk-adjusted pricing of assets will be based on the funding matrix and *RAROC* approach adapted to cash flows.

Note that the difference between the proposed approach from *RAROC* one lies in using of undiscounted cash flows, expected and unexpected credit losses.

The suggested approach to pricing employs the modified *RAROC* principle: for period of time $m_{i,}$ the expected to **receive** interest income from assets should cover the interest expense on liabilities that fund assets (funding cost), operating cost, undiscounted expected credit losses, and provide target return on economic capital:

$$RA_i = \frac{\sum_j a_{i,j} \times RL_j + OC_i + EL_i + EC_i \times RoEC}{CFA_i^{\exp}}, \quad (8)$$

where RA_i is a zero-coupon interest rate on the asset cash flow with time to maturity m_i belonging to *i*-th bucket, RL_j is a zero-coupon interest rate on the liability cash flow with time to maturity m_j belonging to *j*-th bucket, OC_i is operating cost for asset cash flow lifetime m_i, EL_i is undiscounted expected credit losses of principal cash flow of assets for period m_i, EC_i is undiscounted economic capital on the asset cash flow belonging to *i*-th bucket, *RoEC* is target return on economic capital, $CFA_i^{\exp}$ is undiscounted expected principal cash flow of assets belonging to *i*-th bucket. In expression (8) taxation is neglected.

An interest rate calculated by the proposed approach fully reflects unique features of activity of a certain bank: bank's possibility to attract facilities from markets, target return on economic capital, prevalent operating cost and undiscounted expected credit losses of cash flows.

Comparing the calculated interest rate with the market one, the bank may define its own advantages and weaknesses: on which maturity the bank wins market and on which maturity it loses. Thus, the clear understanding of what price on assets should be set is achieved.

It follows to notice that only two-dimensional funding matrix allows forming local balance of incomes and expenses for *i*-th bucket (Fig. 3). Such a balance is a part of cash flow statement, namely "Net cash used in operating activities before changes in operating assets and liabilities".

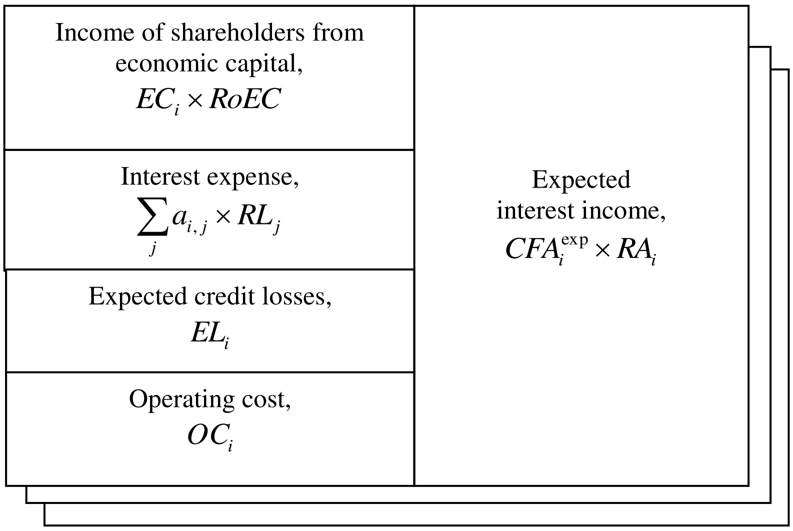

Figure 3. A local balance of incomes and expenses for *i*-th bucket for period of time m_i

Further, compare the proposed approach to assets pricing and *RAROC*-approach. Results are presented in Table 3.

Table 3. Comparison of proposed and *RAROC* approaches to assets pricing

Parameters	The proposed approach	*RAROC*-approach
Period (horizon)	All lifetime of assets	Traditional one year
Exposure	Cash flows	Traditional book (present) value
Cash flows	Undiscounted	Discounted
Term structure of funds	Taken into account	May be taken into account but method is not discussed

The proposed approach has the following advantages.

- It allows direct estimating zero-coupon yield curve on assets. Applying such a curve assets with complex structure of cash flows, for example, mortgage loans may be priced.
- It`s fully based on cash flow approach and organically integrates credit and liquidity risks since it uses undiscounted cash flows.
- The approach may be also applied to pricing of liabilities. In this regard, the funding matrix is employed to calculate the interest rate on which the liability cash flow with the given term to maturity works.

Remind that in this approach the short-term liabilities that fund the long-term assets are assumed to be renewed (rolled over). Besides, note that the proposed approach is based on estimation of expected credit losses and economic capital (unexpected credit losses) for all lifetime of assets and not one-year period traditionally used in *RAROC*.

Example of calculation of zero-coupon interest rate on risky assets

Bring example of calculation of zero-coupon interest rate on risky assets (bullet loans) with term to maturity belonging to “1 to 2 years” or i=4-th bucket. Average term of existing of assets is equal to m_i=1.5 year.

Despite of the fact that incomes, costs, expenses and losses required for calculation are considered for all lifetime of assets in order to estimate an interest rate, it is convenient to utilize these annualized parameters: incomes, costs, expenses and losses.

Let annual return on economic capital be equal to $RoEC$=20%, annual specific operating cost (on one unit of assets cash flow) oc=2%, annual specific undiscounted expected credit losses (on one unit of assets cash flow) el=0.64%.

The zero-coupon yield curve, the liability cash flows that fund the asset cash flow belonging to i=4-th bucket and annual interest expense are presented in Tables 2 (see i=4-th row) and 4.

Table 4. Result of calculation of interest expense per one year for assets pricing

Parameters	**Less than 1 month (j=1)**	**1 to 3 months (j=2)**	**3 to 12 months (j=3)**	**1 to 2 years (j=4)**	**2 to 3 years (j=5)**	**Total**
Interest rate on the liability cash flow	6.00%	8.00%	10.00%	12.00%	13.00%	**8.96%**
Liability cash flow, mln. USA dollars	13 400		8 800	10 000		**32 200**
Interest expense, mln. USA dollars	804	0	880	1 200	0	**2 884**

Input data for calculation and result of calculation of zero-coupon interest rate on risky assets with term to maturity belonging to i=4-th bucket are given in Table 5.

Table 5. Calculated zero-coupon interest rate on risky assets (formula (8))

Items	**Exposure, mln. USA dollars**	**Rate**	**Income/ Expense, mln. USA dollars**
	(1)	(2)	(1x2)
Liability cash flow that fund assets cash flow	32 200	8.96%	2 884
Economic capital	2 800	20.00%	560
Operating cost, % of asset cash flow	35 000	2.00%	700
Expected credit losses, % of asset cash flow	35 000	0.64%	224
Asset expected cash flows	35 000	**12.48%**	4 368

Calculating the interest rates for all buckets it may define the zero-coupon yield curve on risky assets. This yield curve may be used to price assets with complex structure of cash flows, for example, mortgage loans, etc.

As a result of using undiscounted cash flows, the computed interest rate is higher than the one calculated by applying *RAROC*-approach. The difference between these interest rates is equal to premium for liquidity risk (Voloshyn, 2013).

Shortly consider some consequences of utilizing the proposed approach.

Firstly, it reveals the drawback of widely used approach when the price of assets is calculated from price of liabilities with the same maturity. In practice the deficit of long-term liabilities exists. Under normal (positive) yield curve a bank uses cheaper short-term liabilities to fund its long-term assets. So, the usage of traditional approach leads to **overpricing** long-term assets because actual funding cost appears to be lower.

Secondly, the proposed approach can be applied to funds transfer pricing owing to knowledge what liabilities finance assets with a certain maturity.

Conclusion

To price the risky assets it`s necessary to employ a two-dimensional funding matrix. The proposed three rules for building such a matrix provide its positive definiteness and uniqueness. Among this rules the golden rule of banking plays a significant role and helps to define closed liquidity positions. This point is crucial for right pricing.

This matrix gives the clear understanding about distribution of cash flows between assets and liabilities. Only this matrix allows forming the local balances of principals and interest income & expense for each time bucket.

The offered principle for asset pricing guarantees that expected to receipt (not accrual) interest income from asset cash flows over its lifetime period will cover the funding and operating costs, undiscounted expected credit losses and provide target return on economic capital.

The proposed approach has the following advantages. Firstly, it allows direct estimating zero-coupon yield curve on assets and yield curve on assets with complex structure of cash flows. Secondly, it organically integrates credit and liquidity risks since it uses undiscounted cash flows. Thirdly, the approach may be also applied to liability pricing.

Further investigation can be directed on development of pricing methodology taking into account liabilities risk (early withdrawal and rollover risks), multicurrency cash flows, off-balance-sheet facilities (drawdown risk), cash flows from new business, and how maturity mismatch affects interest rate margin.

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