ON APPLICATION OF PHYSICAL MODELS IN BANKING RISK ESTIMATION: VALUING THE DEMAND DEPOSITS

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Abstract. *The paper presents a review of existing approaches to valuation of demand deposits. Special attention is paid to the approach for demand deposits valuation, which is based on relaxation phenomenon. Such phenomenon may be observed in magnetic, ferromagnetic and ferroelectric materials, as well as in the elastic, electric, and magnetic behavior of materials, and is defined as a delay or lag in the response of a linear system, measured relative to the expected linear steady state (equilibrium) values. The bank rate-setting mechanism for demand deposits is found to resemble closely the anelastic relaxations.*

The proposed framework may be applied in the course of risk assessment and management in commercial banks, as well as for banking regulatory policy development by supervisory authorities.

Keywords: *banking risks, demand deposits, core deposits, relaxation, anelastic model.*

Glossary: ***Core deposits*** *– the part of customers' demand accounts that are expected to remain with a savings institution for a relatively long period of time and may be counted as a stable source of funds for lending.*

Demand deposits *– accounts from which deposited funds can be withdrawn at any time without any notice to the depository institution, in contrast to term deposits, which cannot be accessed for a predetermined period.*

1. Introduction

One of the popular methods for liquidity and interest rate risk valuation in a bank is gap analysis, applying the allocation of assets and liabilities into a number of time baskets according to the time remaining till their maturity (or revaluation, in case of interest rate gap calculation), with further determination of the gap in each time basket. The positive gap, or excess of assets over liabilities, shows that in the respective time interval a bank is able to cover its liabilities by the maturing assets. The negative gap

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implies the necessity of attracting additional financing or selling a part of assets to ensure liability fulfillment, and indicates the presence of liquidity risk (the possibility of not being able to obtain the needed liquidity on the markets, and the risk of bearing excessive costs due to raising additional funding).

A common problem, which arises during liquidity gap profile creation, is related to the fact that calculation requires data both on outstanding balances of bank's assets and liabilities, and on their maturity schedule. The balances are known, but not necessarily the maturities. Some of the items have no determined maturity and in practice may generate liquidity flows any time, depending on the customer discretion.

Of mentioned items, demand deposits are a case of major importance. First of all, the size of this item is often significant in comparison to liquidity stock. Secondly, low rates established on this product make demand deposits a desirable funding source in terms of decreasing the total cost of funding. However, instead the added "cost" of these deposits to a bank is provision to a client of a free option of withdrawal at any day. Thus, the analysis of demand deposits is a necessary and challenging part of asset-liability management, especially useful in liquidity planning and potential liquidity need forecasting, as well as in interest rate risk management.

In the light of recent evolution of physical model application in economics, which allow embracing the key features of decision-making agents' behavior, the use of such model for demand deposit valuation would provide new insights into the core deposits phenomenon and enable the construction of underlying theory, not just the single model to use.

2. Literature review

The previous research on the topic proposes several solutions to deal with deposits with non-determined maturity. Still, currently there is no agreement on which approach should be used to determine the duration and value of demand deposits.

The simplest decision proposed is to group all demand deposits into one maturity basket with the latest future date possible (the bank's horizon or beyond), thus excluding them from the gap profile [1]. Opposite extreme solution, as embodied in Ukrainian banking regulation, envisages including all demand deposits to the shortest maturity basket available. Both cases mentioned are likely unrealistic, as they would create the significant negative gaps in one time interval, and oversized positive gaps – in the remaining ones. Payant [2] calls such methods "simply more educated guesses, substantiated through documentation".

One more approach is to divide demand deposits into stable (core) and unstable (volatile) part, based on historical observations path [1,2]. Still, the history may provide not enough information for predicting future outcomes, as the market conditions are changing.

Another approach is to apply modeling in estimating durations of demand deposits. Often, demand deposit balances outstanding or rates on them are being related to variables such as interest rates or economic growth. So, Sheehan [3] proposes to use either Treasury bill rates or the opportunity cost of funds; O'Brien [4] uses 3-month Treasury bill yield; while OTS [5] previously applied secondary-market certificate of deposit yields, and then switched to LIBOR swap yields. The models applied vary from equilibrium-based approach [6] to contingent claims perspective [4,7] to discounted cash-flow modeling [5]. All mentioned works come to the conclusion that the analysis of demand deposits is important for managing financial institution's profitability.

The analysis of previous literature on the topic reveals the necessity of further research on the topic, as the existing models show lack of coherence with practical rate-setting mechanisms and behavior of market agents. This could potentially lead to over – or under-estimation of actual duration of demand deposit stocks, and as a result, to inconsistency of banking risk estimates.

3. Application of an elastic relaxation framework for analysis of demand deposits

In order to develop a model for valuation of stable part of demand deposits, it should be taken into account that the rates for such deposits are usually set by a group of decision-making agents in a bank, who react to exogenous market forces (changes in market rates, actions of competitor banks etc.) and seek to maintain the existing balances, and to maximize profits given the presence of market forces. Poorman [8], following Hawkins and Arnold [9], states that in such case, three main postulates may be formulated about the rate-setting mechanism:

1) for every market rate there is a unique equilibrium rate, and vice versa;

2) equilibrium response is achieved only after the passage of sufficient time;

3) the relationship between market rate and the one set by a bank is linear.

Previously, the attempts were made to approximate this process by regression models trying to capture the relationship between market rate movements and resulting changes in bank-set rates, or by means of partial adjustment models. However, Hawkins and Arnold [9] find the parallel between the above-mentioned postulates and the assumptions underlying the relaxation processes in condensed-matter physics, including magnetic, dielectric, and anelastic relaxations. This allows creating a consistent framework for demand deposits pricing, in which the primary stressor is market rates movement and the response variable is the deposit rate. As Poorman notes, the list of other stressors may comprise costs of deposit servicing, competitor responses, macroeconomic factors and other variables [8].

Relaxation (or hysteresis) in physics is defined as a delay or lag in the response of a linear system, measured relative to the expected linear steady state (equilibrium) values. This phenomenon occurs in magnetic, ferromagnetic and ferroelectric materials, as well as in the elastic, electric, and magnetic behavior of materials, in which a lag occurs between the application and the removal of a force or field and its subsequent effect. Hawkins and Arnold [9] and Poorman [8], examining the bank rate-setting mechanism in the relaxation framework, find that their dynamics is rather close to anelastic relaxations; thus, the models designed for physical relaxation processes analysis may be applied to study the demand deposits.

According to Hawkins and Arnold [9], the above-mentioned postulates for relaxation model could be formalized as follows:

$$\tilde{r}^{p} = c + Jr^{m}; \tag{1}$$

$$\Delta r_{n}^{p} = \sum_{i=0}^{N}[a_{i}r_{n-i}^{m} + b_{i}r_{n-i+1}^{p}]. \tag{2}$$

Here, equation (1) reflects the first and the third postulates – namely, the existence of equilibrium relationship between the equilibrium rate on demand deposits $(\tilde{r}^{p})$ and the market rate (r^{m}). J is the share of deposits that the regulatory reserve requirements allow investing.

Equation (2) presents the idea of the second postulate about time lag needed for equilibrium response to be achieved, and is built in the form of partial adjustment model with time-dependent notation: $r_{n}^{p} = r^{p}(t_{n})$.

It can be noticed that the three postulates formulated and the equilibrium relationship (1) closely resemble the relationship between stress and tension formulated in Hooke's law of elasticity:

$$\sigma = J\varepsilon. \tag{3}$$

Here the demand deposit rate would stand for tensile strain (ε), and the market rate would play the role of stress (σ). So, the constant c may reflect the changes in deposit rate produced by different factors ("stresses").

Further, the differential relationship describing relaxation dynamics may be applied:

$$\frac{\mathrm{d}r^p}{\mathrm{d}t} + \eta(r^p - c) = J_\upsilon \frac{\mathrm{d}r^m}{\mathrm{d}t} + \eta \cdot J_R \cdot r^m. \quad (4)$$

Here η denotes the rate, at which the deposit rate relaxes to the equilibrium level, J_υ stands for the fraction of response that occurs immediately after stress, and J_R is the coefficient for lagged response (at any future time after the stress). Thus, the change in the deposit rate with respect to time is related to the current deposit and market rates, and to the change in market rate with respect to time.

Equation (4) can be integrated to get the expression for time-dependent deposit rate. Denoting $\delta J = [J_R - J_\upsilon]$:

$$r^p(t) = c + (J_\upsilon + \delta J[1 - \mathrm{e}^{-\eta t}])r^m. \quad (5)$$

Of here, the decomposition of the response into instant part (J_υ) and time-dependent part (proportional to δJ) may be obtained:

$$J(t) = J_\upsilon + \delta J[1 - \mathrm{e}^{-\eta t}]. \quad (6)$$

Boltzmann superposition principle allows rewriting the response function and the time-dependent deposit rate expression, as given in (5) and (6), for the higher orders of the relaxation differential equation, as follows:

$$J(t)J_\upsilon + \sum_{i=1}^{N} \delta J^{(1)}[1 - \mathrm{e}^{-\eta(1)t}] \quad (7)$$

$$r^p(t) - c = \sum_{i=1}^{M} r_i^m J(t - \tau_i). \quad (8)$$

Here N denotes the order of differential terms included into the relaxation equation, and at the same time the number of relaxation terms. Equation (8) allows determining the demand deposits rate for known history of market rate movements r_i^m at the consecutive time periods: $\tau_1, \tau_2, ..., \tau_M$.

Hawkins and Arnold [9], and Poorman [8] state that application of the proposed model to the rates on separate deposit products, such as money market deposit accounts, allowed tracking the respective product rates rather well. This provided the conclusion that "product rates respond to market rates as if via anelastic relaxations" [9]. Therefore, the use of described model provides the theoretical description for transmission mechanism in rate setting for demand deposits and the corresponding factor relationships, and enables calculation of demand deposits rate (and further, duration, based on the assessed rate).

4. Conclusions

The review of existing studies on non-maturing deposits valuation reveals the existence of several approaches to the problem, but each of them has its own advantages and drawbacks. The majority of existing models do not conform to real-life behavior of decision-making agents and market dynamics, proposing only approximate solutions instead of a consistent framework.

Still, the application of physical models may facilitate the creation of a theory underlying the demand deposit movements. This paper reports on the prospective for use of relaxation phenomenon and the related physical models to analyze the demand deposits valuation, allowing to view demand deposits valuation from another angle and to build a consistent framework for their further study.

The anelastic model described can be used in internal risk-management practices by commercial banks, as well as by supervisory institutions for the purposes of banking regulatory policy development.

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