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POTENTIAL RISKS IN INTEREST RATE RISK DEPOSIT MODELS IN THE BANKING SECTOR AND PROPOSED BEHAVIOURAL MODELLING

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ABSTRACT

In today's environment of fluctuating interest rate prospects, it is timely to discuss in detail certain issues inherent in banks' interest rate risk management, with particular emphasis on nonmaturing deposit balances. Experience indicates that banks currently employ a variety of approaches. The objective of this analysis is to identify an optimal methodological framework for interest rate risk modelling, focusing on the interest rate risk embedded in sight deposit products, building upon established risk management principles. The study seeks to highlight the limitations and systematic biases of widely used modelling techniques to enable the future application of more accurate methodologies. This need is further reinforced by the volatile interest rate environment, which has prompted stricter regulation, limited modelling flexibility, and increased demand for standardisation in the field. In modelling non-maturity deposits, based on the constant balancesheet assumption, the focus will be on the perpetuity approach and the deposit rate elasticity. The analysis covers not only effects on the net interest income (NII) but also on the economic value of assets and liabilities (EVE), while also offering a critique of replicatingportfolio approaches. The study aims to provide useable results for risk management professionals, with the hope of contributing to sectoral stability during periods of financial stresses.[2]

JEL codes: G2, G3, G4, G5, E0, E3, E4, E5, E6, E7, C0

Keywords: banking book interest rate risk, IRRBB, banking sector, non-maturity deposits, sight deposits, current account deposits, interest rate risk modelling, perpetuity, interest-rate elasticity, interest-rate sensitivity, pass-through rate, EVE, NII, NMD

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1 INTRODUCTION

The proper identification and management of interest rate risks are of paramount importance for banks as part of their core activities, which might easily lead one to assume that this field already relies exclusively on highly matured methodologies. This is true in many respects, however, the handling of more complex products arising from optionalities is still characterised by substantial simplifications and by methodological approaches that have, over time, somewhat gone astray. Both regulation and market practice naturally require certain simplifications to ensure that all institutions can apply the framework in a practical manner and that robust, comparable indicators are available – objectives that must be recognised alongside the criticisms raised. Developments in the field can be observed in the expansion of computational capacity and in software support, yet this has also resulted in users – similarly to what can be observed with statistical software – becoming somewhat distanced from the more direct use and understanding of the underlying theory. Consequently, some confusion can be discerned in the practical application of the theoretical relationships between the run-off approach, the role of repricing time and the assumption of a constant balance sheet. The aim of this study is to present and build upon theoretic fundamentals a new behavioural modelling framework for the interest rate risk modelling of non-maturity deposits, which is more appropriate than today's widespread practices. This framework adopts a perpetuity-based perspective while placing the repricing delay and the given interest rate elasticity at its centre. The following chapters alternate between professional context and theoretical derivation.

2 REGULATORY AND PROFESSIONAL BACKGROUND

2.1 Development of regulation

The methodology for interest rate risk in the banking book (IRRBB) remained relatively unregulated for a long time by both the Basel Committee and the European Banking Authority (EBA), not by accident. Institutions operate in highly heterogeneous circumstances not only regionally, but also in terms of size, lifecycle stage, activities and strategic orientation; moreover, aside from the crises of the recent past, this risk factor had a more limited direct impact. In recent years, however, this has changed, and the topic has received increasing attention.

In this context, the term "Banking Book" refers to all bank positions other than those held in the Trading Book, where market risk positions are consciously undertaken in a typically limited and isolated manner. Interest rate risk, in brief, means that the value of a given position and the associated income may fluctuate – and may generate losses – depending on changes in the interest rate environment.

Prior to 2016, the focus was on repricing mismatch indicators by tenors (gap) and on present value stress calculations of products, with certain stress metrics being subject to limitations (regulator of Hungary standard stress being 200-basis-point for EVE-type). At the same time, the methodologies applied by large banks were diverse and, compared with the regulation, more advanced, for example in the use of Monte Carlo techniques and various stress scenarios (see also Kalfmann, 2008, for further regulatory background).

The topic subsequently came to the forefront with the Basel Committee on Banking Supervision's (BCBS/BIS[3]) detailed methodological guidance entitled "Interest rate risk in the banking book" (BIS 2016), which was essentially adopted in the EU through the European Banking Authority's "Guidelines on the management of interest rate risk arising from non-trading book activities" (EBA 2018). In these methodologies, the supervisory approach is based on assessing the effects of six new standardised stress scenarios, encompassing both economic value and net interest income stress variants. The clear objective is to set out a traceable, implementable and uniform methodological expectation for institutions, one which at the same time reduces the room of the institutional modelling and the application of alternative approaches (e.g. Monte Carlo simulation; see Roób Péter, 2011).

Following these developments, the supervisory authorities of the EU Member States, including the MNB (National Bank of Hungary), placed increased emphasis on facilitating the introduction of the new methodologies, a process strongly propelled by the pronounced volatility of the global interest rate environment after the 2020 COVID crisis. The MNB has also set out progressively expanding expectations and recommendations in its ICAAP-ILAAP-BMA Manual (MNB 2021, 2022, 2023, 2024), which, from 2021 onwards, already recommends the establishment of a maturity-structure model for sight deposits.

The original Basel regulatory principle was broadly that institutions should have the option to choose between simpler, more robust, potentially more conservative solutions adapted to their circumstances that may imply higher capital requirements, and more complex, more accurate methodologies that require substantially more data, longer time series and greater resources, with the latter giving room for internal modelling and encouraging methodological sophistication. The level of modelling was therefore not typically imposed by legislation but rather incentivised, offering institutions genuine options. Experience shows that banks employed a wide range of approaches. Recently, however, standardisation appears to

3 Committee of the Bank for International Settlements (BIS).

be gaining the upper hand: the European Banking Authority (EBA), and through it the European supervisory authorities, are striving for greater uniformity, which has resulted in the emergence of centrally selected and mandated methodologies and in a reduction in methodological diversity. Consequently, the correctness of the chosen methodology has become particularly important in order to avoid systematic modelling risks.

Products whose expected cash flow (CF)[4] cannot be predetermined and calculated in advance inherently create uncertainty. Fundamentally, almost all risk types can be traced back to the unpredictability of the cash flow of a given balance-sheet item. Where the CF is uncertain, interest rate sensitivity characteristics will likewise be uncertain, and the risk will shift to this area as well. In such cases, institutions' individual approaches may range from the application of simpler and generally more cautious, conservative assumptions to more complex modelling solutions.

Non-maturity deposits particularly fall into this category, but term deposits may also be included owing to the dynamics of early withdrawals and placement volumes, which, given today's low balances, may even exceed the volatility of non-maturity deposit balances, as illustrated in Figures 1-4 for various periods. At the same time, deposit balances represent a very substantial share of the liability side of the balance sheet of traditional commercial banks, thus, they may play a significant role in offsetting the interest rate sensitivity of asset-side lending products. For this reason, it is essential that banks' management of interest rate risk needs to be grounded in the projection of genuinely expected processes and risks.

To explore the interest rate risks of deposits, it is necessary to return to the definitional foundations of interest rate risk and to build upon these, as set out in the derivation below. At first glance, the issues discussed may seem rather simple and obvious, particularly when compared with more complex models. However, practice shows that fundamental conceptual differences have emerged within the profession, which may significantly distort even more sophisticated approaches. This justifies a more detailed discussion of these questions and suggests that an attempt should be made to reconnect them to the basic objectives of risk management.

2.2 The theoretical foundations of the methodologies

The primary aim of interest rate risk modelling is to assess the potential economic value (EVE, Economic Value of Equity) and income (NII, Net Interest Income) impacts arising from shifts in interest rate levels. These impacts may give rise to

4 Cash flow (CF) denotes the set of future cash movements by time and amount.

hedging actions (e.g. entering into an IRS[5]), or even the establishment of capital buffers for any remaining potential losses, the latter also reflecting supervisory expectations and incentives towards the development of more comprehensively hedged portfolios.

In EVE stress tests, one must begin from their fundamental objective: to examine the fair valuation of all balance sheet items in Banking Book under changes in the yield environment, irrespective of their accounting valuation method. In essence, this constitutes a partial differential calculation based on theoretical pricing formulas, which generally rely on the Discounted Cash Flow Method (DCF) (Száz, 2003; Damodaran, 2005; Kalfmann, 2008).

The assumption of an unchanged balance sheet structure for the institution is a natural corollary of this approach, aiming to isolate interest rate risk effects, especially as rapid interest rate shocks typically leave no practical time for restructuring. The standard supervisory interest rate shocks are, by design, of this nature (EBA 2018).

Another general underlying assumption is that both the contractual rate of floating-rate positions and the discount rate change to such an extent that, following the repricing period, their effects cancel each other out. This is a robust and transparent view, consistent with the very purpose of repricing.

In general modelling practice (including the EBA and BIS standard method recommendations; BIS 2016), the scheduling of principal to the repricing time accords with this understanding, and can be further refined by modelling individual fixed cash flow elements. Thus, the effective repricing is the earlier of the payment and the repricing time, and principal is to be allocated to the repricing time. Deriving from this approach – namely the scheduling of principal to the repricing time and the truncation of cash flows thereafter (i.e. applying only for floating-rate components, excluding fixed spreads) – there follows a further equivalent assumption: in the fair valuation of a given instrument, expected future contractual interest rates are taken to correspond to the forward yields[6] of the yield curve[7] as its projection. Only the general use of forward rates yields the cumulative cancelling effect on valuation – stemming partly from the contrac-

5 IRS: Interest Rate Swap, a derivative transaction used to exchange fixed cash flows for floating ones.

6 Forward yield: the yield applicable between two future dates t_1 and t_2 which ensures that applying the spot yield to t_1 and then the forward yield to t_2 produces the same overall return as the t_2 spot yield.

7 Yield curve: the term-structure of expected returns in a given financial market as a function of maturity (tenor).

tual interest rate, and partly from discount factors derived from the spot (zero-coupon) curve – resulting in a net zero impact over this period.

A brief methodological remark is warranted: despite the embedding of this in IRRBB and in fair valuation logic, the interpretation of the forward yield curve as a forecast (the expectations hypothesis, Lutz, F.A.–Lutz, V.C., 1951) is not universally accepted in economics. The forward curve may shift rapidly and assume atypical shapes during periods of turbulence, and certain tenor segments may behave as partially distinct market products.

Throughout this analysis, spot curves are understood as zero-coupon curves, representing the market-implied yield for a single cash flow at a given tenor – often not directly observable and themselves the result of model estimation (the BUBOR[8] is a zero-coupon curve, longer interbank yields require modelling).

This classical interest rate risk management perspective, together with the unchanged balance sheet assumption is the origin of the EU regulation's recommendation of the run-off approach[9] (EBA 2018), in order to avoid distortions from expectations about future portfolio restructuring – distortions not intrinsically related to interest rate risk. Under a constant balance sheet assumption, the maximum repricing horizon is generally the maturity date, since the assumption posits that an identical transaction will be renewed thereafter, replacing the previous one – yet such a new transaction has no interest rate risk effect, as it is priced at inception to the prevailing rate environment.

In NII modelling – that is, in estimating the expected annual net interest income impact due to an interest rate shock – discounting plays no role. Only the cumulative effect on cash flows arising from changes in contractual rates is relevant over the next one-year horizon. These effects, at transaction level, also depend on the repricing period, since the instrument's interest income will shift only following the repricing-induced adjustment.

These are, therefore, the underlying principles and objectives to be followed. The unchanged balance sheet assumption is also recommended by the MNB, with a single exception: accounting for flows between term deposits and non-maturity deposits. However, at the aggregate level, the assumption of constant total deposit volumes is retained (MNB 2021, 2022, 2023, 2024).

8 BUBOR: Budapest Interbank Offered Rate.

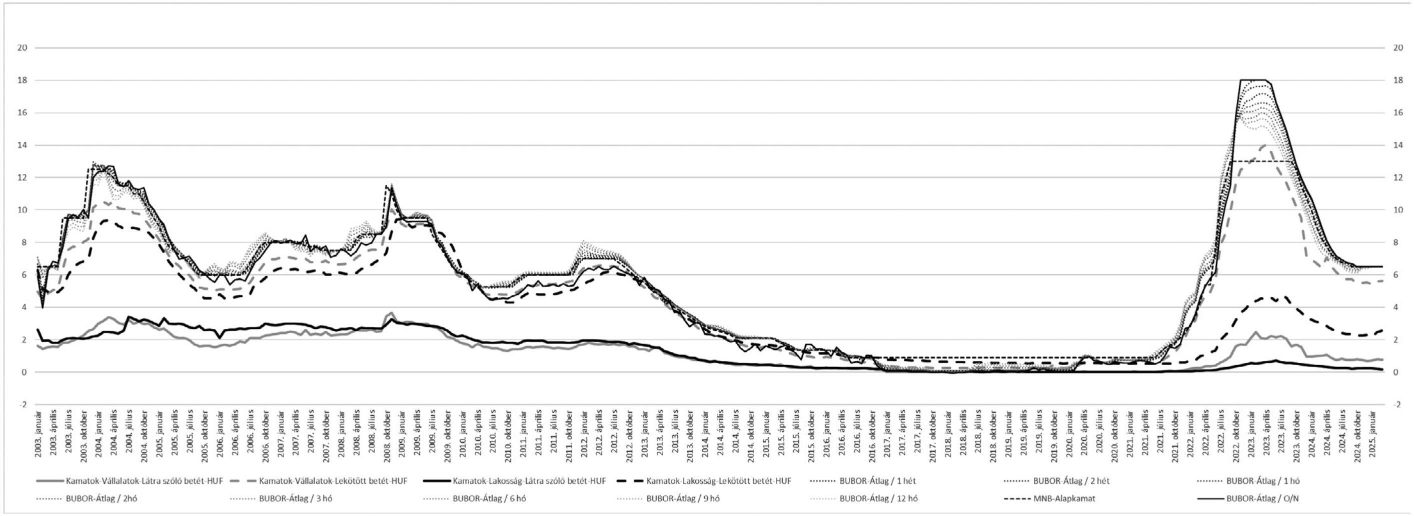
9 Run-off approach: the non-modelling of cash flows from future renewals, often mistakenly interpreted as contradicting the constant balance sheet assumption.

3 INTEREST SENSITIVITY OF NON-MATURITY DEPOSITS

Sight deposits are products without maturity whose interest-rate sensitivity is observably low, functioning, in effect, as a "leverage" multiplier in the price-formation process of the contractual interest rate[10]. This can be approximated, in simplified form, by the ratio of long-term interest-rate levels. The figures below illustrate interest rate and volume developments in the Hungarian banking sector, broken down into retail and corporate business segments for Hungarian Forint deposits (*Figures 1 and 2*), followed by separate tables for Euro deposits (Figures 3 and 4).

10 A proximate concept for EBA purposes is the "pass-through rate", used for identifying core and non-core balances.

Figure 1
Hungarian Forint deposit interest rates of the Hungarian banking sector, broken down into retail and corporate segments, and prevailing money market yields

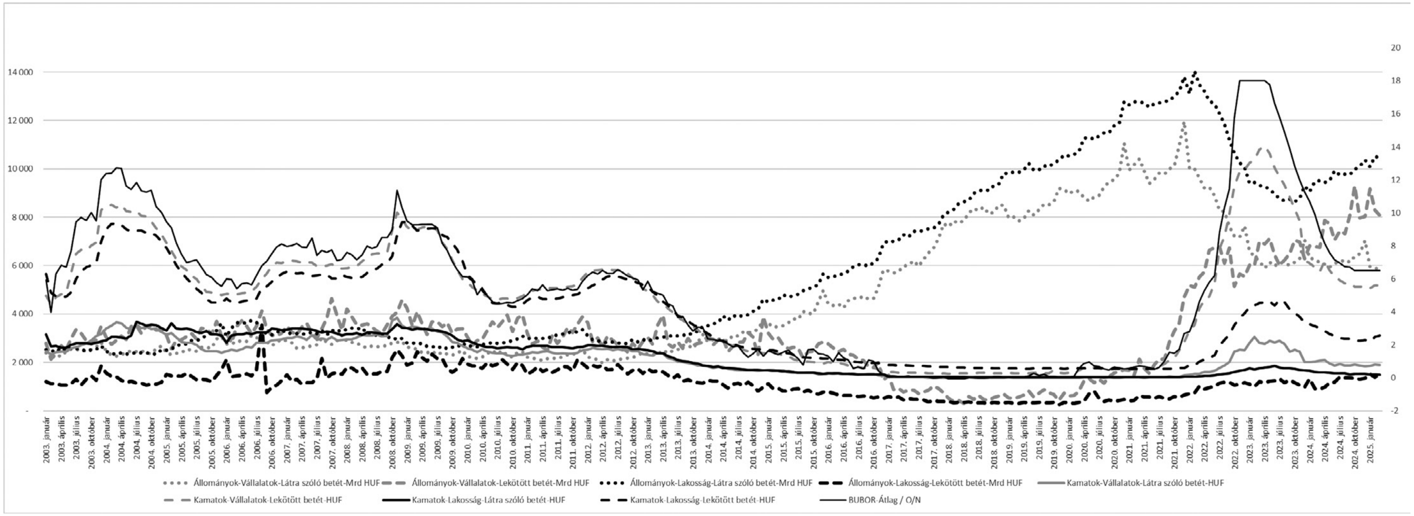


Source: MNB public statistics, public money market yield data[11]

11 Source: public statistics from the National Bank of Hungary (MNB), public market yield data, BUBOR: https://www.mnb.hu/monetaris-politika/penzpiaci-informaciok/referenciamutato-jegyzesi-bizottsag/bubor, Base rate: https://www.mnb.hu/Jegybanki_alapkamat_alakulasa.

Figure 2

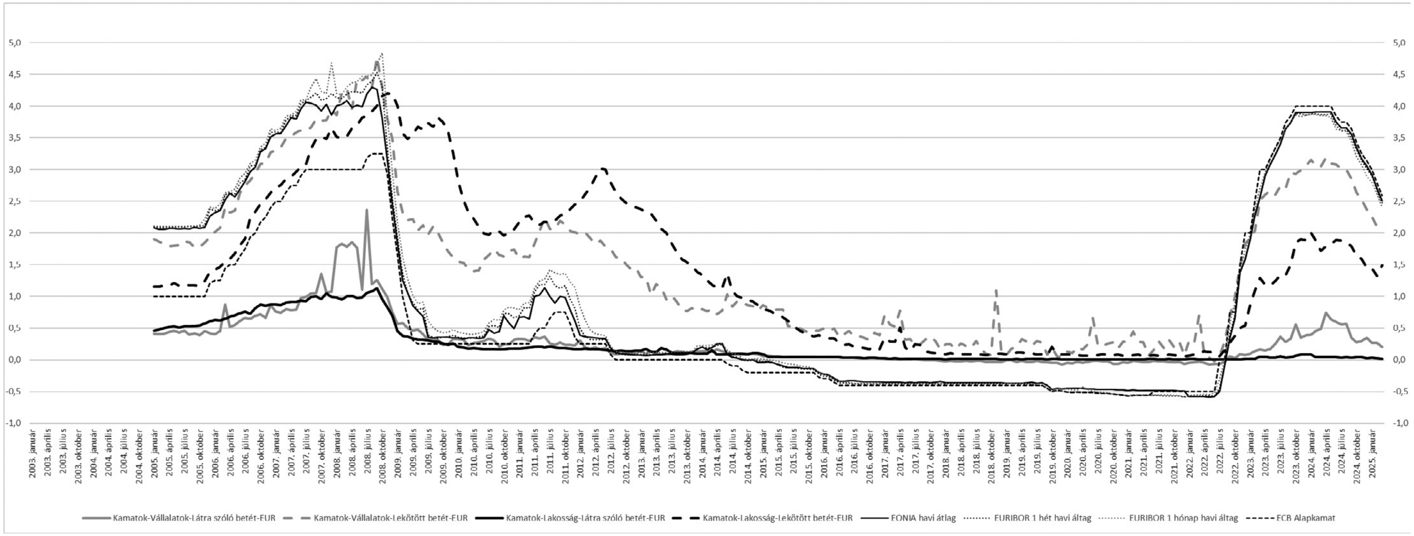
Hungarian banking sector Hungarian Forint deposit volumes adjusted to present value using the CPI, broken down by retail and corporate segments (left axis, billion HUF), alongside the main prevailing money market yields (right axis, %)



Source: MNB public statistics, public money market yield data[12]

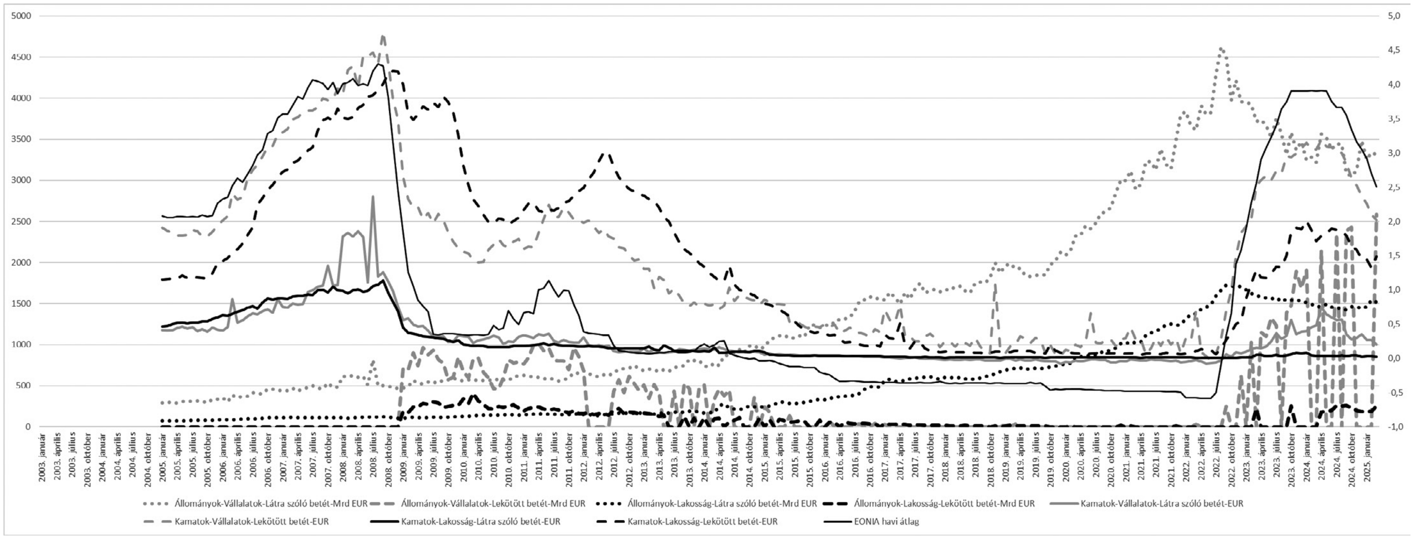
12 *Source*: Public statistics from the National Bank of Hungary (MNB), public market yield data, Volumes: https://www.mnb.hu/statisztika/statisztikai-adatok-informaciok/adatok-idosorok/xi-deviza-penz-es-tokepiac , BUBOR: https://www.mnb.hu/monetaris-politika/penzpiaci-informaciok/referenciamutato-jegyzesi-bizottsag/bubor. Base rate: https://www.mnb.hu/Jegybanki_alapkamat_alakulasa, CPI: Central Statistical Office (KSH).

Figure 3
Euro deposit interest rates of the Hungarian banking sector, broken down into retail and corporate segments, and prevailing money market yields



Source: MNB public statistics, public money market yield data (EONIA, EURIBOR), CPI: HICP/Eurostat

Figure 4
Hungarian banking sector Euro deposit volumes adjusted to present value using the CPI, broken down by retail and corporate segments (left axis, billion EUR), alongside the main prevailing money market yields (right axis, %)



Source: National Bank of Hungary (MNB), ECB public statistics, public market yield data (EONIA, EURIBOR), Volumes: https://www.mnb.hu/statisztika/statisztikai-adatok-informaciok/adatok-idosorok/xi-deviza-penz-es-tokepiac , CPI: HICP/Eurostat.

Just as with price elasticity, interest-rate elasticity of two variables refers to the expected rate of their change rates.

In the case of deposits, the principles dictate that we should consider the fair valuation methodology. Accounting valuation typically focuses on the notional value without discounting, as in the assessment of a company's own equity or in more complex corporate valuations.

When discussing the issue of the non-maturity deposit category, it may appear straightforward to conclude that the problem lies in the absence of maturity, and that the goal is to supplement this with an appropriate model. From an interest rate risk perspective, however, this is a significant misconception. It is important to emphasize that the problem is not caused directly by this characteristic of these products, but only indirectly: the root cause lies in the institutional pricing practices that have developed in the course of mass managing the individual volumes of deposits with varying placement and withdrawal times. Interest rate risk fundamentally resides in the repricing period. Pricing of non-maturity deposits is typically not tied is a pre-defined manner to yield environment, and even if it is linked to a given reference rate, the spread can be adjusted at any time by the institution. Consequently, these portfolios typically reprice uniformly according to the bank's discretionary decisions, making the institution's repricing practices and behavioural patterns the critical factors.

Thus, the product has two key fundamental characteristics:

1) the depositor's option to withdraw the non-maturity deposit at any time,
2) the bank's option to modify the interest rate of the non-maturity deposit at any time (legally subject to a slight delay[13]).

In a fair valuation perspective, the expected income is generally assessed through cash flow projection and discounting using the DCF method. Even if additional cash flow modelling steps or probabilistic branches are employed, discounting remains a common feature in the assessment of future cash movements, reflecting interest rate risk through yield variability. Moreover, a typical interest rate risk component in interest-bearing products is the variable-rate cash flow element.

13 The bank's reaction time also includes internal decision-making processes. In Hungary, current legislation additionally requires a 15-day period between announcing a change in non-maturity deposit rates and its implementation.

General formula in the DCF method (Száz, 2003; Damodaran, 2005):

$$PV = \sum_{t=1}^{n} \frac{CF_t}{(1 + r_t)^t} \tag{1}$$

where: PV: Present Value,
CF_t: payment due in t time,
t: remaining maturity of CF elements,
r_t: expected yield for the given maturity.

For non-maturity deposits, however, the cash flow behaves as a strongly probabilistic variable, since the client holds an option to withdraw the principal immediately and to terminate the transaction, even partially.

The institution uses its option of the interest rate pricing to adjust it to the market rates, aligning with its competitive position, which, due to the competitive environment in the banking sector, is expected to converge toward sectoral levels.

Accordingly to these observations, we can consider an interest cash flow whose interest is linked with a given elasticity to interbank rates (e.g., overnight[14]), while the timing of principal repayment at maturity can only be described by a probability distribution. In such case as a principle, each possible outcome can then be weighted by its probability of occurrence.

If, however, one evaluates a portfolio instead of individual deposits, where product features such as repricing are approximately homogeneous within the portfolio, the relevant consideration becomes the total balance level, in which individual transactions that are replaced are irrelevant. ***Under a constant balance-sheet assumption, this leads to the perpetuity valuation methodology.***

It appears that the industry has so far avoided treating non-maturity deposits as perpetuities, presumably due to their intangible nature, the need for bespoke formulas, and confusion arising mainly from approaches aimed at compensating for the typical absence of maturity, which has diverted attention from the significance of the repricing time.

14 In other words: the overnight rate, which is practically a one-day interest rate.

The general formula for the present value of a perpetuity with fixed cash flow elements and fixed yield (Luenberger, 2009) is:

$$PV = \frac{C}{r} \quad (2)$$

where: PV: present value,
C: amount of recurring payment in the CF[15]
r: expected yield (typically the longest tenor on the yield curve).

Interest-rate sensitivity is determined primarily by the repricing time rather than the estimated maturity of the instruments. When the interest-rate elasticity equals one, the sensitivity calculation principle described earlier for interest rate risk also applies here. That is, regardless of the dispersion of actual maturities, cash flows could be truncated and principal scheduled according to the expected repricing time. The resulting calculation of the scheduled CF differential between stressed and current discount rates therefore provides the fair value differential of the product. In this framework, one could apply the annuity formula up to the repricing time for interest CFs, and then schedule the total principal using the DCF method for the same repricing time. However, this remains an imprecise approach still.

Two additional, previously mentioned factors must be taken into account, which modify this theoretical approach:

a) the effect of general leverage in interest rates, or in other words, the impact of interest-rate elasticity *differing from one,*

b) the volume inflow and outflow of term deposits, which should be considered even under rapid shocks due to their potential speed of occurrence.

The impact of interest-rate elasticity can be observed clearly in aggregate public data for the banking sector. By examining pricing practices, we adopt the simplifying assumption that non-maturity deposit rates are treated homogeneously within the portfolio under study. In practice, this assumption can typically be applied at the level of individual product, client group, and currency combinations, having uniform parameters such as interest-rate elasticity, repricing period, and sensitivity to flows into term deposits. These sub-portfolios will henceforth be referred to simply as "products".

15 Note that in later formulas, "C" may stand for the principal using the common notation of the formulae in question!

Interest-rate elasticity is further treated as a general characteristic in the sense that it is assumed independent of interest rate levels, a necessary simplification given the large shocks under investigation[16]. From the assumption of uniform interest-rate elasticity, the interest-rate elasticity factor acts as a multiplicative term between the two variables.

As an additional simplification, the portfolio is considered immediately restructured upon occurrence of the shock, reflecting an assumed rapid reaction and reallocation among deposit types. Under this assumption, the portfolio exposure must be adjusted to reflect the restructured balances prior to calculations.

Henceforth, the deposit portfolio can be treated at the portfolio level as a perpetuity, where interest CFs are determined using the relevant interest-rate elasticity multiplier.

To apply the approach, the pricing formula must be expressed and then its variation examined under interest rate shock scenarios. The calculation must separate the impact during the repricing period from the impact thereafter, where the effect of the contractual interest rates and discounting differs across the CF elements.

4 ANALYSIS OF THE CORE / NON-CORE BREAKDOWN OF THE BIS APPROACH

Let us now consider the above in comparison with supervisory guidance, focusing first on the "core" / "non-core" breakdown.

If one adopts the strongly simplified view – which cannot be significantly justified by pricing observations – that the effect of interest-rate sensitivity is not homogeneous at the portfolio level but results from the combined effect of different transactions, in which only two extremes exist, i.e., a fully flexible portfolio segment, the non-core, and a completely inflexible segment, the core, where the inflexible portion is entirely insensitive to transaction interest rates (BIS 2016), it must be noted that this is not equivalent to identifying fixed-rate items, whose cash flows can be scheduled and truncated according to maturity, because any new transaction initiated at the end of the original one will also be interest-insensitive and will not reprice. Therefore, the fair valuation of the inflexible segment depends only on the discount rate in relation to the interest-rate environment, and the

16 The Hungarian supervisory expectation, expected to take effect in 2026, specifies parallel shifts of the Forint yield curve: a total range of 800 bp across shocks of ±400 bp (MNB, 2024). Previously, the shock range was ±300 bp, and before the Basel 2016 recommendations, ±200 bp.

cash flow can be treated as a perpetuity from a pricing perspective under a constant balance-sheet assumption. The flexible segment of the portfolio would, of course, clearly be schedulable according to repricing times, however, the shortest repricing period is typically used, again as an overly simplistic assumption.

In reality, interest-rate sensitivity is more homogeneous at the product level but varies across products, rather than emerging as the combined effect of two portfolio extremes. Thus, the aforementioned breakdown may only be interpreted theoretically across products or transactions, representing an excessively simplified view that assumes solely fully flexible and completely inflexible components.

The simplified core / non-core interpretation can be reconciled to a limited extent with the approach examined in the present analysis at the product-portfolio level, which primarily applies to the flexible segment, which exhibits an elasticity factor close to one, varying across products. The valuation of the completely inflexible segment, however, appears appropriate only under the perpetuity approach, which is typically not applied in repricing calculations by either supervisory authorities or institutions.

It is also worth noting that the development of this approach took place during the period of very low and relatively stable interest rates preceding the post-COVID economic crisis, when the role of interest rates appeared less significant.

A more advanced use of the core / non-core breakdown may replace the rigidly *flexible/completely inflexible* segmentation with a *fully flexible/less flexible* distinction and align it with the approach discussed in this analysis. In practice, both application and supervisory interpretation appear to be shifting in this direction.

The BIS recommendation – possibly influenced by previously low interest rates in Western Europe, often close to zero – proposes a methodology based on the assumption that core and non-core balances can be identified. However, it presumes that the maturity of the core balances can be estimated, which in practice is suggested for use in assigning repricing-time categories. According to the principles outlined in this analysis and the characteristics of the products, this is fundamentally a flawed approach, primarily because, under the constant balance-sheet assumption, the renewal of non-maturity deposits – which occurs as individual items mature – does not correspond to a repricing event, since the repricing of non-maturity balances typically occurs at the portfolio level rather than the transaction level, and is generally defined by banks in their public product notices. Therefore, maturities generally have no direct connection to repricing, and repricing must be analysed separately to determine when, with what delay, and to what extent it occurs under given shocks. The objective is not to assign an artificial maturity distribution to items without maturity.

At the portfolio level, the extremely segregated, heterogeneous nonmaturity deposit repricing process according to the extreme repricing times described above does not characterise the Hungarian sector and is not observable in this form; consequently, it is not appropriate to apply it as such. It cannot be observed that, under shocks, significant segments would reprice only after several years or never. Heterogeneity appears at the product level in the interest-rate sensitivity and repricing (or delay) values, as illustrated in Figures 1–4.

For the nonmaturity deposit product, it is not characteristic that a depositor would receive a new interest rate if they withdrew and then redeposited funds at any later time, since the conditions are not individualised or tied to specific cash movements but are general.

Apparent misinterpretation may arise solely from the observation that in certain portfolio segments repricing occurs only rarely, sometimes only every few years. This does not necessarily support a similarly long repricing lag, as it may merely reflect the tracking precision and rounded step intervals in the follow-up adjustments, and it depends entirely on the magnitude of shocks that occurred during the period under review, which may not have triggered any repricing. For example, if an institution only adjusts its rate when the transaction interest differs by 200 basis points from 35% of the BUBOR ON reference value, but no such event has occurred for years, this does not imply that it would not react more quickly under a significant shock. Standard shocks are considered sufficiently substantial, and conclusions must be drawn on this basis. This interpretive issue has been mitigated by recent interest-rate shocks, but it existed when the regulation was first being developed.

The core / non-core separation as a simplified model carries inherent risks, particularly if

a) the identification of the core segment is excessive,
b) assuming a completely interest-insensitive stable portfolio and
c) scheduling the stable portion using a maturity-based approach
d) over excessively long repricing horizons

for interest-rate risk calculations. Such an application may lead to unjustifiably inflated estimates of liability-side interest-rate risk offsets, which can result in underhedging of assets. Points b) and c) reflect general methodological errors, while the magnitude of points a) and d) depends on the modelling approach, though they are *characteristic; this is evidenced by the European Banking Authority subsequently imposing upper regulatory limits on these elements*[17].

Building on maturity can extend repricing over several years, whereas in reality it is often observed around 0.5–1 year under shocks (see figures and the author's modelling experience).

Overestimated liability-side repricing times can therefore cause portfolio-level position shifts, under-hedging of fixed asset-side transactions, and potential losses in the event of upward interest-rate shifts or shocks, particularly if the shift is persistent.

It should also be noted that the BIS approach to core identification recommends considering two factors jointly: the characteristic of remaining stably with the institution and the non-repricing property (BIS 2016, Article 112, p. 26). Even in this case, it remains questionable why an item would reprice at longer "renewals", as maturity continues to have no repricing role. Furthermore, using these two characteristics can easily create confusion in modelling, as not all segments simultaneously exhibit both interest insensitivity and stable volume; rather, their degree and pattern typically differ, particularly observable at higher interest rates.

Overall, the core / non-core breakdown perspective appears to be applicable only as a strong simplification at product-, client-, currency-, or narrowly defined portfolio levels, where interest rate-insensitive and interest rate-sensitive balances can be clearly distinguished. However, the generally moderate interest-rate sensitivity phenomenon should not be treated as the result of these factors, but rather, as discussed further below, in relation to the flexible portfolio segments.

Due to the perpetuity behaviour of non-maturity deposits, it is generally worth noting that, for a fixed perpetuity, using a duration-based (tenor average), first-order (discount) interest-rate sensitivity as an approximation for stress testing the position's present value is not appropriate. This is because the magnitude of a stress shift is generally high relative to the discount rate, in a perpetuity, it is proportional to K rather than 1 + K, and if K is small, the distortion is even greater (as one approximates using the tangent of a hyperbola). Consequently, discount-rate sensitivity is significantly nonlinear. If, for example, a core / non-core model application leads to such a task, a higher-order approximation should at least be employed, but the most accurate approach remains to calculate by the actual PV difference formula rather than relying on sensitivities.

17 The upper limit for maturity-based scheduling is five years (!), and for the core ratio 90%, although lower limits apply to certain segments.

The portion considered stable and entirely interest-insensitive typically relates to noninterest-bearing items or items with negligible interest, which are mostly transactional or convenience balances. In this case, ignoring interest, there is nothing left under the perpetuity approach – no interest, no principal – and therefore no interest-rate sensitivity, simplifying its treatment substantially. However, this also means that it provides no liability-side offset for interest-rate risk. From an interest-rate risk perspective, such balances can therefore be treated similarly to interest-insensitive equity elements, which are generally excluded from modelling.

Therefore, for simplifying the modelling through categorisation, it is more appropriate to divide the non-maturity deposit portfolio into the following five main categories rather than the previous two, typically based on product, client segment, currency, or other defining characteristics:

A. *sub-portfolio with floating interest rates*
   – sub-portfolio that has officially floating rate, although banks may adjust the negative spread component with a given tracking period, so behavioural characteristics should also be examined here,
B. *sub-portfolio considered fully interest rate-sensitive*
   – sub-portfolio exhibiting behaviour similar to floating rate products but requiring behavioural modelling for repricing-time or delay parameters,
C. *sub-portfolio with a given degree of interest* elasticity,
   – where the interest elasticity must also be defined beyond the parameters above
D. *sub-portfolio completely interest-insensitive with fixed interest*
   – which requires a perpetuity representation and formula-based stress simulation rather than duration-based methods; such sub-portfolios likely do not exist in practice or constitute only a small portion,
E. *sub-portfolio completely interest-insensitive with zero or negligible interest* (e.g., between 0 and 0.1%)
   – which should be excluded from modelling and may represent a significant share due to transactional balances.

5 METHODOLOGICAL REMARKS ON REQUIRED PARAMETER ESTIMATIONS

5.1 The importance of institution-specific modelling capabilities and modelling freedom

The aim of this study is to establish a methodological framework, not to enforce the use of specific methodological details or particular calculation results. Modelling freedom is important to ensure that institutions retain the ability and incentive to capture key processes more accurately and in a manner tailored to their own data sets and tools.

Sector-level conclusions or measurements must, of course, always be adapted to the specific institution, potentially incorporating expert adjustments. A fundamental principle is that, where available, an institution's own historical data series should be primarily analysed and considered, with sectoral time series used to a lesser extent. This is significant because, as noted in the earlier analysis, institutions have considerable discretion in pricing non-maturity deposits and may establish their own strategies; accordingly, repricing generally does not derive directly from the contractual parameters of transactions. Therefore, it should be regarded as a necessary behavioural modelling component, or an embedded option, with adjustments potentially required due to institution-specific characteristics. Institutional behaviour is generally influenced by the institution's position in product pricing competition, which may relate to its size and market share, as well as to the interest-rate sensitivity of its depositors and the extent to which they move their deposits between institutions or investment markets in response to pricing.

The use of an institution's own data for modelling may be limited by, for example, a very short historical series for products with identical parameters, highly volatile volumes (due to non-interest-driven incentives), business strategy, or the absence of suitable historical series for relevant shocks (e.g., for older shocks).

5.2 Analytical focus on stress periods

With regard to the estimation of repricing-time and balance-change parameters, it should be noted that, since standard shocks are of significant magnitude, historical regression analyses should preferably be restricted specifically to major shock periods and examined in isolation, as processes may differ considerably under stress for fundamental reasons. For this purpose, a delayed-variable linear regression with zero intercept is appropriately applicable, in which the optimal lag identifies the repricing delay and the beta coefficient represents interest-rate sensitivity. The zero intercept (alpha) is a fundamental requirement arising from the need for a general interest-rate elasticity value that is independent of the general level of interest rates.

Even when the analysis focuses on shocks, expert assessment and adjustment may be required to account for any atypical characteristics of the particular shocks, which may result in reactions lower or higher than average. For example, periods of turbulence caused by non-economic factors, such as the shutdowns during the COVID pandemic, may have been considered temporary by the market and institutions, while simultaneously generating high savings and deposit levels, leading to slightly dampened institutional responses.

Focusing on shocks in the calibration of risk parameters is not an unusual practice, for instance, this is reflected in the commonly Trading-Book related Stress Value at Risk (SVaR) methodology (BIS 2016).

5.3 Asymmetry of repricing delays for non-maturity deposits

Analyses[18] have also indicated, and this can be observed in Figures 1–4, that repricing times exhibit significant asymmetry depending on the direction of the shock. This is fundamentally explainable by the effect on banks' income positions, which in turn influences their pricing policies.

The BIS/EBA model does not address this asymmetry, nevertheless, incorporating it is an ideal objective for achieving more realistic estimates.

The basic idea is that this can be implemented by calibrating models separately for stress-period observations distinguished by shock direction. It should be recognised, however, that this introduces significant methodological challenges. Simple models, as well as more complex toolkits, can only be applied with considerable caution and, preferably, with expert adjustments.

Within significant stress periods, when examining isolated up- and downswings, a straightforward linear regression approach faces obvious statistical challenges, notably non-stationarity in addition to the problems posed by shorter time series. It is important to emphasise that the current objective is solely to determine asymmetric variable lag times, while ensuring alignment with the delay values of a symmetric model so that the lags are in the same direction and bracket the symmetric measure. Fundamentally, the goal is to identify the changes in trends, which requires analysing time windows surrounding the change points rather

18 The author has measured and utilised these parameters in professional work; however, presenting the results is not the objective of this analysis. Outcomes depend on the parametric or expert identification of historical stress periods. Asymmetric repricing delays were also noted by Maes and Timmermans (2005) for savings deposit types in the Belgian banking sector.

than solely the up- and downswings. Very short time series should be avoided, and minimal trend influence should be sought at the series' edges wherever possible. However, identifying stress periods of sufficient magnitude and speed within the time series is already challenging. By focusing on change events in the trend, difference variables can be analysed to identify the delay factor, which is a common method to address non-stationarity. Besides, we should not forget, that in the main regression model, the differenc variable itself is not what we need for measuring linear interest-rate elasticity. Selecting appropriate time windows presents another significant, related issue: strong trends or missing data at the edges can strongly influence the main trend and the average levels of the variable when shifting the window, which may affect the parameter measuring the fit.

Regarding asymmetric lagged variables, it is worth mentioning the Asymmetric Price Transmission (APT) theory[19], which has been widely studied and offers elements that can be applied to further analyse the issue. Beyond time-series analysis methods, the economic context can also be aligned: interest rates represent the price of money, mediated by the bank between the interbank market and its clients. A more recent approach for examining this issue is the nonlinear autoregressive distributed lag model[20] (NARDL). However, in such complex methodologies, there is generally no built-in focus on explicitly identifying and analysing significant shocks in a particular direction, and behaviour differing by direction is typically inferred mechanically from time-series decomposition, splitting by the sign of movements. This can fragment the shock trajectory due to smaller fluctuations, whereas fundamentally it should be interpreted as a continuous process. When applied as stress-focused analyses, the same issues arise regarding window shifting and non-stationarity within stress segments.

5.4 Identifying the yield environment affecting repricing of non-maturity deposits

Regarding the examination of the yield environment, it should be noted that overnight rates exhibit smoother behaviour than central bank policy rates, while generally moving in tandem with them and serving as a reference for deposit pricing. Correlations with other short-tenor rates can also be examined, but stronger relationships are typically observed with shorter tenors.[21] It should be

19 An overview is given by Meyer and Cramon-Taubadel (2002).

20 Described by Shin, Y.–Yu, B.–Greenwood-Nimmo, M. (2014).

21 The author has measured and utilised these parameters in professional work; however, presenting the results is not the objective of this analysis.

noted that during periods of pronounced stress (e.g., 2022–2024), when inverted yield curve appears, statistical measurements may show stronger dependencies on longer maturities. This is primarily and temporarily caused by the smaller fluctuations of longer yields and the proximity of the low interest-rate path of non-maturity deposits with low interest-rate sensitivity, and does not necessarily reflect a fundamental causal relationship.

This topic also relates to the replicating portfolio approach, a widely used modelling technique. Its underlying idea is similarly based on the co-movement of non-maturity deposit rates with a combination of interbank deposit rates. However, this approach has methodological problems, which will be discussed in detail later.

5.5 Empirical insights

In *Figures 5 and 6*, we plot the retail and corporate non-maturity deposit rates as a function of the overnight BUBOR rate over a long 20-year period (January 2005–March 2025). The figures show both a simple linear regression and a regression through the origin based on the fundamental assumptions discussed.

Figure 5
Hungarian retail interest rates as a function of BUBOR ON (January 2005–March 2025; slope intersecting the origin: 0,18765, r^2: 0,5749, p-value <2,2e-16)

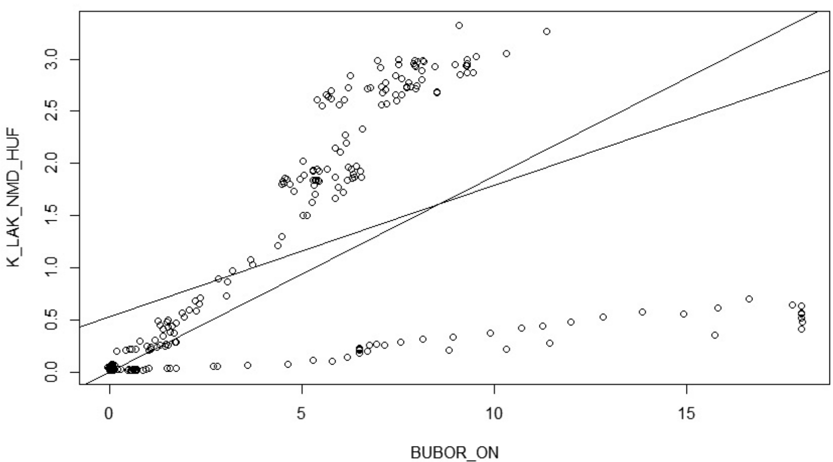
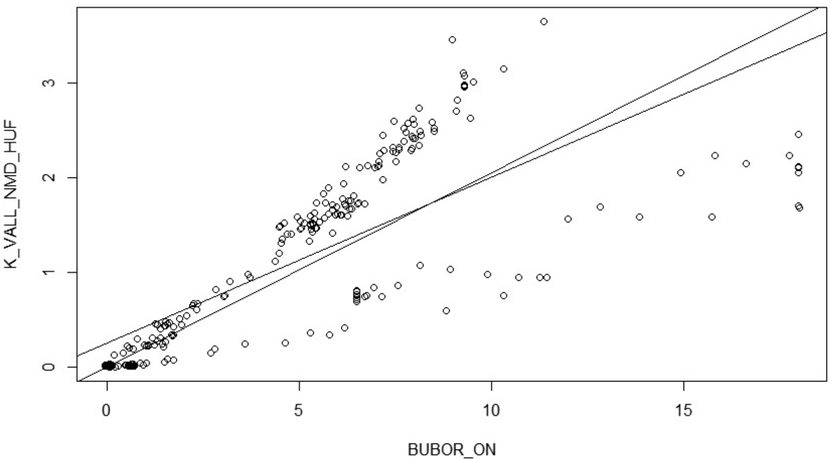


Figure 6
Hungarian corporate interest rates as a function of BUBOR ON (January 2005–March 2025; slope intersecting the origin: 0,204921, r^2: 0,8159, p-value<2,2e-16)

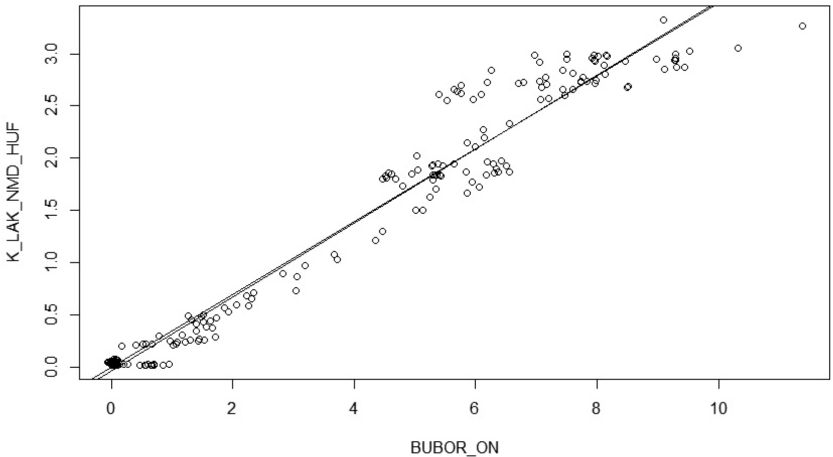


Source: author's compilation

The figures immediately show that the points are arranged in several groups, indicating the unique behaviour of various crises. If we consider them together, we get quite different slopes than separately, as the correlation of the segments points more realistically towards the origin. Thus, by aggregating and averaging the interest-rate sensitivity estimates from the crisis-specific analyses, we may arrive at different results than when analysing the combined sample, particularly if the fundamental assumption of intersecting the origin is abandoned.

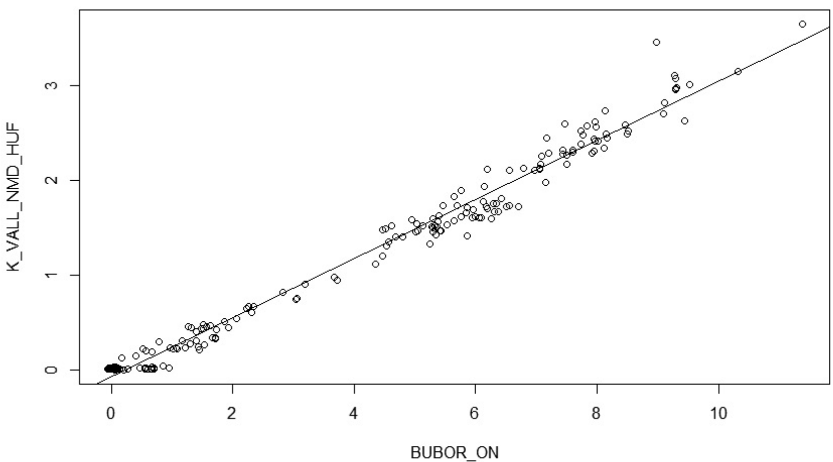
Considering the same figures but omitting the post-COVID stress period, it becomes apparent that this period indeed accounts for most of the observed segmentation:

Figure 7
Hungarian retail interest rates as a function of BUBOR ON (January 2005–March 2025; slope intersecting the origin: 0,348527, r²: 0,9817, p-value<2,2e-16)



Source: author's compilation

Figure 8
Hungarian retail interest rates as a function of BUBOR ON (January 2005–March 2025; slope intersecting the origin: 0,301061, r²: 0,9917, p-value<2,2e-16)



Source: author's compilation

Thus, the pre-COVID period provides an opportunity for robust, statistically significant measurements of interest-rate elasticity, as indicated by the slope, even though this simple example does not focus on other crisis periods or additional statistical parameters. Statistics, however, are not our goal but a tool, and fundamentally, the experience from all crises must be incorporated into the modelling in some manner – whether through expert adjustments, weighted averages of elasticity, or other techniques.

Consequently, this brief analysis also highlights the presence of a general interest-rate elasticity factor that is mainly independent of the level of interest rates, although it may vary across different types of crises.

6 THE PERPETUITY-BASED FORMULA FOR MODELLING NON-MATURITY DEPOSITS

Returning to the required computational methodology, we generally apply the interest-rate elasticity multiplier assumption. Thus, we assume that the contractual rates of a given sub-portfolio follow the relevant interbank benchmark rates – typically overnight or other short-term rates – with a uniform repricing lag and a proportional multiplier, which may vary by the direction of the change and by portfolio segment.

As explained earlier, owing to this multiplier, the DCF method cannot be straightforwardly simplified: the cash-flow evaluation cannot be omitted for the post-repricing components, as the impact of the contractual interest-rate change does not exactly offset the effect of the change in the discount rate. Consequently, returning to the fundamental objectives, we must estimate differences in fair value under a constant-balance-sheet assumption, for the time being.

In the simple case of non-maturity deposit volumes with stable interest-rate elasticity, the following occurs until the repricing time: the discount rate changes immediately, while the contractual rate changes only at the repricing time. Thus, by default, according to the cash-flow formulation, the product behaves as a fully fixed-rate item during the first period, meaning that there are no flexible and inflexible components.

For the post-repricing period, the perpetuity of the contractual rate – determined by the interest-rate elasticity multiplier – must be discounted using the yield curve under the constant balance sheet assumption.

At this point, it should be noted that this is not valid if the product has contractual floating interest by its public product notice and, according to the model, the institution's general repricing lag exceeds the next repricing date specified in the notice. In such cases, the closer repricing date may be applied, however, the magnitude of interest-rate sensitivity arising from the subsequent adjustment of the spread relative to the reference rate must be taken into account, to the extent that it is observable. In these situations, repricing may be modelled in two steps, since the repricing specified in the product notice may be followed by a later spread adjustment when the institution reacts to the shock. These cases will not be addressed further here.

Since the yield curve is typically not flat, the interest-rate risk effect of non-maturity volumes can, in theoretical terms, be examined in three phases during shock testing, as set out below, assuming that yields beyond the end of the curve are treated as constant.[22]

1) Until the repricing date, the instrument typically behaves as a fixed-rate transaction, with no change in the cash flows.
2) In the period following the repricing date, the cash flows should be specified taking into account the interest-rate elasticity multiplier. In this case, however, the calculation is not uniform due to differences in yield levels along the yield curve; therefore, up to the observation point corresponding to the longest tenor of the yield curve, an appropriate approach is to specify and discount the cash flow by elements. In this case, the contractual rate must be adjusted using the derived forward yields as reference, multiplied by the interest-rate elasticity factor, since future rate movements are likewise expected to follow the prevailing yield environment. In line with the general approach established earlier, this future path can be projected on the basis of forward rates calculated between the points of the curve corresponding to the relevant interest-rate periods. The cumulative effect differs between the contractual rate and the discount factor because of the interest-rate elasticity multiplier.
3) Beyond the longest tenor observation point of the yield curve, the calculation can be simplified by applying the perpetuity formula, which must, of course, be further discounted from that point onwards using the period-specific discount factor in order to obtain a present value.

However, the multi-stage specification of cash flow calculations may be regarded as a computational complexity.

Let us now examine the change in the value of a simple perpetuity for a given interest-rate elasticity multiplier, assuming a flat yield curve in the examined seg-

22 This is a commonly applied modelling assumption in valuation exercises.

ment beyond a given tenor (T). Such case is the 3) above, i.e. the segment following the longest tenor of the observed yield curve.

The present value of a perpetuity can be expressed as the product of principal and the interest rate level:

$$PV = \frac{C \cdot k}{r_T \cdot (1 + r_T)^T} \tag{3}$$

where: PV: present value,
C: principal outstanding,
k: contractual interest rate,
r_T: expected yield at tenor T,
T: the starting time for applying the perpetuity formula.

The term $(1 + r_T)^T$ discounts the future value to present value from the starting point of applying the perpetuity formula.

The interest rate "k" can be expressed by "L" leverage or interest-rate elasticity multiplier and by "r'_{dt}" as the expected future market rate, in the form $k = r'_{dt} \cdot L$, where r'_{dt} denotes the given dt tenor, that is, the forward rate period to which the non-maturity deposit portfolio is sensitive. Typically, this corresponds to overnight (ON, dt = 1 day) or another specified short tenor.

Since we have assumed that from the starting point of applying the formula (T) the expected yield level remains constant at r_T, it follows that over this period the r'_{dt} values of the short-term (dt) forward yields likewise take identical values, coinciding with r_T along the flat segment of the yield curve.

Thus, if the r'_{dt} forward yield coincides with the r_T yield, the perpetuity formula applicable to non-maturity deposits simplifies in an interesting way after substitution:

$$PV = \frac{C \cdot L}{(1 + r_T)^T} \tag{4}$$

where: PV: present value,
C: principal outstanding,
L: general interest-rate elasticity of the transaction,
r_T: expected yield on tenor T,
T: the starting time for applying the perpetuity formula.

It can be seen that, at this stage, the product is effectively not interest rate-sensitive at the cash-flow level over periods beyond the application tenor, but only sensitive for the discount factor at time T. Consequently, the mitigation of interest rate risk remains effective even under low interest-rate elasticity, albeit proportionally less, in line with lower rates. The present value is sensitive solely to the extent of interest-following ratio and to the discount factor corresponding to the beginning of the period. The L interest-rate elasticity can be generally assumed to be stable.

It is advisable to identify only the end of the yield curve for the T point, the perpetuity segment commencing from there can be considered to have a uniform expected yield and is calculable using the perpetuity formula, based on information on yields available at present. Thus, the flatness of the yield curve is assumed only for unobserved long-term yields, as a form of convergence, and over the long segment the slope of the yield curve is typically modest, reflecting a broadly similar market perception.

It should also be noted that the perpetuity formula is applicable only to tenors following repricing, not only for the sake of a uniform cash-flow representation but also because the repricing period of the portfolio is fundamentally shorter than the ideal period for assuming a constant yield, which is relevant only for long-term yields.

This formulation for the valuation of non-maturity deposits raises an important interpretive point: namely, that the interest rate risk exposure effectively reduces to the magnitude of the interest-rate-elastic share identified by the interest-rate-elasticity multiplier. For this share, the effect of the contractual rate and the discount factor neutralise one another after the start of the perpetual-annuity application period, in the same way as for other transactions with an elasticity of 1, once the repricing period has passed.

This means that the reduced capital exposure $C \times L$ may be expressed as a single cash-flow element at time T, corresponding to the start of the flat segment of the yield curve, while subsequent cash-flow elements may be omitted, and discounting is then performed at time T within the usual modelling framework.

This is thus an important result that simplifies modelling and is also well aligned with empirical observations.

It should also be emphasised that the unchanged cash flow up to the repricing date concerns the full cash-flow exposure as the cash flow is expressed, and not the reduced one. Although the interest rate applied here will also be lower than the market reference rate by virtue of the inherently lower interest-rate-sensitivity, the contractual cash flow plan written out should not be reduced. However, if the entire cash flow is to be treated under a reduced-capital approach, then the interest rate applied to the reduced capital in the fixed-rate period must be divided by the interest-rate-elasticity multiplier when the interest cash flow is expressed.

7 EXTENDING THE APPLICATION OF THE COMPUTATIONAL APPROACH

In sum, we have so far established that, under the assumptions of a constant balance-sheet and stable interest-rate elasticity, the cash-flow representation of a given volume of non-maturity deposits is reduced to a single term at the starting point of the flat segment of the yield curve, as if the capital exposure became due only in proportion to the interest-rate elasticity at that point – an outcome implied by the perpetuity formula.

This applies to the entire affected cash-flow horizon, jointly to both the flexible and non-flexible components, if the portfolio is viewed in such a theoretical decomposition.

7.1 The shock-dependent case of interest-rate elasticity

As long as the behaviour of interest-rate elasticity is assumed to be stable and its shock-sensitivity is not assumed to be relevant over longer tenors, the conclusion is sustainable. If empirical observations indicate that interest-rate elasticity becomes unstable under shocks, the methodology must be enhanced and interest-rate elasticity must be modelled, incorporating its effects. For this purpose, the application of the perpetuity formula with new parameters values will typically also be required, which does not render the current simplification substantially more complex, but merely implies that the (L) term becomes shock-dependent.

7.2 Simplifying the calculation between the repricing period and the perpetuity phase

Up to now we have not examined in detail the valuation between the repricing date and the point at which the yield curve becomes flat. The contractual interest rate for these cash-flow segments is also determined on the basis of the forward curve, which must be derived from the constructed yield curve in both the baseline and stressed scenarios estimations, and is generally tenor-dependent. When determining the interest cash flow, however, the interest-rate elasticity multiplier (L) must again be applied. Here too, the interest amount equals the forward reference yield multiplied by the elasticity (L), applied to the capital (C) at the relevant time (t). Its value under the DCF methodology may therefore be expressed as follows:

$$PV = \sum_{t=t_1}^{T-1} \frac{CF_t}{(1+r_t)^t} = \sum_{t=t_1}^{T-1} \frac{C \cdot r'_{dt,t} \cdot L}{(1+r_t)^t} = C \cdot L \cdot \sum_{t=t_1}^{T-1} \frac{r'_{dt,t}}{(1+r_t)^t} \tag{5}$$

where: PV: present value,
CF_t: payment due in t time,
t: remaining maturity for CF elements,
t_1: the time of the first repricing interest cash-flow element
T: the starting time of the application period of the perpetuity formula.
r_t: the yield expected for the given maturity
$r'_{dt,t}$: the forward yield at time t for the period dt, defined over the interval between t-dt and t.

It can be observed that, since no principal repayment is assumed at portfolio level under the constant balance-sheet assumption, the linearity of the formula for the interest-rate elasticity allows these elements to be factored out as multipliers from the terms to be aggregated, as the valuation formula is first-order sensitive to interest-rate elasticity. Consequently, a similar conclusion is reached in that the exposure value may be regarded as reduced in proportion to interest-rate elasticity. Thus, the compensating effect of floating interest rates will again operate on the remaining proportion of the exposure, between the contractual rate and the discount rate. In this respect, the formula functions in a manner analogous to the perpetuity formula.

In summary, the reduction of the principal amount in proportion to interest-rate elasticity may be considered as the measure of interest-rate exposure for tenors following the repricing period, and the instrument may therefore be treated as a floating-rate product having this reduced principal amount.

In EVE stress scenarios, it is appropriate to schedule the principal of the limited-elasticity non-maturity deposit portfolio simply according to the repricing time, while principal exposure must be adjusted using the interest-rate elasticity as a multiplier. Interest cash flows calculated on the full principal must be taken into account prior to the repricing period.

7.3 Managing stresses having long-term transition

In a long-term balance evolution model, one possible approach is to explicitly write the cash flows in detail by tenor up to the end of the projected changes (forward curve yields × interest-rate elasticity × magnitude of changes in scope). For the remaining time interval, the perpetuity approach may be applied, and the resulting ineffectiveness in the present-value difference justifies omitting the cash flows, while the leverage multiplier should still be applied. After repricing, the interest-rate elasticity component can also be factored out from these formulas, since in the specialised DCF formulation it appears linearly as a first-order multiplicative term again. However, the long-term evolution model does not conform to the classical standard supervisory shock approach, and therefore does not fully align with the realistic expectations for Basel and EU/EBA standard shocks, although there appears to be emerging supervisory openness in this regard.

7.4 Application to other products

Non-unity interest-rate sensitivity clearly also manifests in other products where floating interest is contractually specified. Under the constant balance-sheet assumption, a stable, renewable balance may likewise be treated as a perpetuity, even if it has a contractual maturity. In such cases, the repricing period is also clearly defined according to the applicable interest parameters. It is, however, important to examine the relationship between the transaction's reference rate and the shock-induced shifts, as this may alter or even offset the contractual interest-rate sensitivity.

7.5 Net interest income stress calculations

For NII stresses, the situation is much more straightforward. Here, the relevant period for changing interest income is within one year, which is correctly covered by the post-repricing period up to the one-year tenor. In general, the interest-rate elasticity multiplier must be applied to the exposure to provide an accurate estimate of the impact on interest income, as there is no discounting involved – only the proportional adjustment of the effect on contractual interest income.

Therefore, in NII stress scenarios, the exposure must also be adjusted by the interest-rate elasticity *multiplier, and the impact calculated for the period following repricing.*

8 CRITIQUE OF THE REPLICATING PORTFOLIO APPROACH

The replicating portfolio approach applied in the modelling of non-maturity deposits warrants attention because it is now not only widely used, but also referenced and recommended by supervisory authorities. The Basel Committee on Banking Supervision (BCBS), in its 2016 methodological guidance on interest rate risk in the banking book (BIS 2016), mentions the widespread use of this approach for nonmaturity deposits in the chapter on "Key Considerations and Assumptions". Subsequently, the National Bank of Hungary (MNB), as the national banking supervisor, has also recommended the use of the model (MNB 2021, 2022, 2023, 2024; Appendix 3: "Expectations for the Modelling of Nonmaturity deposits for Institutions, and the MNB's Own Benchmark Model for Banking Book Interest Rate Risk").

In the literature, the model is most frequently associated with the analysis by Maes and Timmermans (2005), which examined a type of savings deposit in the Belgian banking sector. Their study provides a clear description of the application technique of the model, however, they were not the originators of its underlying theory, but rather analysed it as an already established practice. It should be noted that the authors effectively summarised the fundamental characteristics of the non-maturing deposits and made observations regarding historical pricing behaviours (such as asymmetric repricing lags and interest-rate ratios) similar to those highlighted in this analysis. They also formulated numerous critical remarks regarding the methodology of the replicating portfolio approach. Notably, they advised caution when applying it for supervisory purposes. They further observed that alternative methodologies, such as Monte Carlo-based cash-flow simulation models, appear to have a stronger methodological foundation. The analysis demonstrates a careful examination of an inadequate model, of which own critics the professional community has paid relatively little attention to. Moreover, the fundamental derivation of the basic concept is lacking, and thus its flaws have not been thoroughly identified – possibly because the analysis focused on a solution already in practical use.

The most significant critical observations are summarised below.

a) *Lack of fundamental justification and the paradoxical logic*

The basic concept assumes that institutions' asset-optimisation and pricing processes result in the utilisation of funding in a manner, that it can be seen as equivalent to a combination of deposits with different maturities, thereby allowing the properties of such a structure – including the maturity profile – to be applied to nonmaturity deposits.

The existence of such a process, however, is not empirically supported. Banks typically do not place their assets in such interbank deposit structures, interbank deposits beyond a few months are rare. Instead, banks predominantly lend to clients due to asset-side margins, so the objective is not solely to minimise the margins and volatility on the deposit side. Furthermore, banks maintain substantial central-bank and other highly liquid short-term (overnight to one month) reserves for liquidity safety, and for longer-term holding purposes, they invest in liquid bond markets due to the high liquidity of these assets. The bond market is linked not to interbank expected yields but rather to government bond yields. Deposit pricing is often also driven by interbank rate competition, aligned with the institution's competitive position and the interest-rate sensitivity of its clients.

Practice does not support the assumption that, although the asset-side deposit placement process does not actually take place and the corresponding balance-sheet yields do not evolve accordingly, banks would nevertheless price on the basis of such a theoretical deposit portfolio.

The paradoxical nature of this logic lies in the fact that we seek to determine the interest rate risk characteristics of nonmaturity deposits precisely in order to enable institutions to build their risk management and hedging processes upon them, which in turn leads to a reconfiguration of the bank's balance-sheet structure. This model, however, presupposes the given and optimal functioning of these processes from the outset; consequently, if the model's outcome were to feed back into them, their assumed stability and optimality would be automatically called into question.

The authors of the cited analysis (Maes–Timmermans, 2005) themselves note that, for example, Monte Carlo–based cash flow output simulation models appear to be methodologically more sound (see, inter alia, the Conclusions section).

b) *Modelling the maturity structure instead of the repricing period*

From the above, it may be somewhat understandable that the assumed existence of term deposits leads to a focus on maturities; however, the historically observed behaviour of nonmaturity deposits does not support this theory. The approach systematically diverts attention from the interest-rate risk significance of the repricing period, shifting focus instead to "substituting" a maturity for deposits that are, by definition, "without maturity", as implied by their designation.

c) *Disregard of the uniform portfolio-level repricing option of the bank*

The uniform, portfolio-level repricing option of the banks through public product notices confers a floating-rate character on nonmaturity deposits at the product level, applied consistently across the portfolio, whereas the model aims at fixed-rate, segmented deposit modelling. In practice, banks are not constrained by the assumed maturities of the deposit structure, nor by those of loans, particularly when considering an interest rate reduction environment. Banks are able to reshape their repricing profile through their liquid assets and interest rate hedging transactions; the speed of this process may vary, depending, inter alia, on how rapidly they follow or even pre-empt the shock. Moreover, the asset-side repricing time may differ significantly across banks, reflecting deliberate business policy and interest rate risk management choices, and may allow a given institution to respond more rapidly.

d) *The model performs poorly under stress scenarios*

The authors of the referenced analysis (Maes–Timmermans, 2005) also demonstrate and explicitly identify as a shortcoming (for example, in the Conclusions section) the instability of the model during periods of stress. Yet this would precisely constitute the primary objective of such modelling. This also shows that the replicating portfolio model does not capture an existing stable underlying process.

e) *The model is unstable, and its results are sensitive to the optimisation objective function, the observation period, and parameter choices*

The same authors (Maes–Timmermans, 2005) also show and identify as a deficiency the model's sensitivity and instability with respect to parameterisation. This again suggests that the replicating portfolio model fails to represent a stable underlying process.

Practical application of the model shows[23] that during pronounced stress periods – when the yield curve becomes inverted over significant segments (for example, between 2022 and 2024) – optimisation based on the dispersion of margin deviations and the Sharpe ratio paradoxically steers the optimal portfolio composition towards the longest maturities. This occurs because, along the stress path, shorter tenors exhibit larger stress-induced fluctuations in the time series than both long-term yields and the typically lower-rate non-maturity deposits. In non-inverted yield curve environments, the model typically reaches its optimum at considerably shorter tenors. Consequently, the model reacts in an outsized and unstable manner to yield curve inversions, producing materially different results depending on the extent to which the selected modelling period is characterised by an inverted yield environment. The model thus tends to be unstable precisely during stress periods, delivering

23 In the course of the author's professional work, the relevant parameters were measured and used, however, their presentation does not form part of the present analysis.

results that diverge markedly from those obtained under non-stress optimisation – exactly when interest rate risk management seeks robust and reliable outputs for preparedness. This constitutes a significant limitation of the model and materially constrains the applicability of its results.

f) *The characteristics of specially regulated savings deposits are not fully comparable to those of nonmaturity deposits*

The referenced study (Maes–Timmermans, 2005) focuses on savings deposits within the Belgian banking sector that are supported by specific regulatory features. These products are unlikely to behave in a manner fully consistent with the definition of simple non-maturity deposits. They can be expected to carry higher interest rates and to be less strongly characterised by transactional and operational balances.

9 NOTES ON VOLUME MODELLING

So far, we have not addressed the real-world phenomenon whereby, in response to individual shocks, depositors can indeed quickly reallocate between non-maturity and term deposits. Modelling this process may be useful if its dependence on the interest rate environment can be demonstrated through appropriate modelling. However, it is worth noting the following points.

For modelling deposit flows, it does not appear sufficient to rely solely on the specification of standard interest rate scenarios as a condition, particularly under the instantaneous shock criterion of the EBA assessment. Deposit flows depend on a number of additional factors, not all of which are strictly related to shifts in the interest rate environment. The main such factors are:[24]

a) the time profile over which the yield curve shift occurs;

b) customer expectations regarding the long-term outcome of the shift, including their interest rate risk expectations, which are likely to influence term deposit decisions to a greater extent than the magnitude of the shift itself:

- additional shifts in the same direction over a period of time,
- reversion to previous levels (e.g., COVID),
- persistent shifts;

24 Maes and Timmermans (2005), in their examination of savings deposit types in the Belgian banking sector, also note in Section 2.3 the considerable difficulty of analysing purely interest rate environment correlation due to other external factors, such as alternative investment opportunities.

c) the actual proportion of interest rate change affecting non-maturity and term deposits (interest-rate sensitivity relationships);

d) the macroeconomic environment of the shift:

- the level of confidence in the banking sector,
- macroeconomic stability, the financial stability of customers, the extent to which people need to draw on their savings during a crisis,
- relative yield shifts in capital and bond markets (e.g., discounted government bonds, MÁP+, etc.).

For all these reasons, a sensitivity-based portfolio model approach, which examines the regression between the magnitude of an interest rate environment shock and the yield environment, can naturally only provide a highly simplified approximation. Accordingly, it is advisable to apply it conservatively and in a moderate manner, provided that the relationship can be demonstrated.

The factors affecting such volume changes can also have a significant impact on the institutional behaviour that determines the pricing of non-maturity deposits, as the bank can offset the outflow-supporting factors to the extent necessary through interest rate adjustments.

Recent observations of portfolio flows do not unequivocally support the assumption that, in the event of shocks, flows between term deposits and non-maturity deposits would necessarily be in exactly opposite directions and of equal magnitude (see *Figures 1–4*). This is likely due to other contemporaneous crisis effects and to the flow directions of term deposits across other money market segments in recent periods (term deposits – equities – investment funds – bonds – foreign currency, etc.). Nevertheless, in the case of purely interest rate risk effects – without changes in other crisis factors or in the relative returns of investment sectors – it remains reasonable to assume a constant balance-sheet perspective at the aggregate deposit level. This assumption is necessary to enable partial or ceteris paribus analysis of interest rate changes, isolating them from all other factors, as also recommended by the National Bank of Hungary in its ICAAP methodological manual.

Therefore, based on observations of deposit portfolio flows, it is advisable to proceed conservatively and, relative to the deposit movements observed during recent shocks, to identify and model only considerably smaller flow magnitudes that genuinely depend on the interest rate environment between non-maturity and term deposits, provided that the relationship can be demonstrated.

SUMMARY

This analysis raised criticisms regarding the following modelling phenomena and supervisory expectations:

a) In the modelling of non-maturity deposits, the focus on establishing a maturity is misplaced, as repricing should be the relevant consideration.
b) In the modelling of non-maturity deposits, the role of individual, transaction-level maturities or deposit rollover periods is not observable in practice at the portfolio level, due to the uniform pricing applied through public product notices.
c) The "run-off" approach (BIS, EBA, MNB), in connection with the above, is unsuitable for modelling deposits without maturities under the assumption of a constant balance sheet; instead, the perpetuity approach should be applied.
d) The applicability of the replicating portfolio approach is problematic due to the unproven assumption of an institutional optimisation relationship with deposit rates, the focus on maturity rather than repricing time, its unstable results, and its general inconsistency with observable shorter repricing periods.
e) The core / non-core approach is overly rigid and does not reflect the less binary nature of real-world products, which can in fact be characterised and segmented along multiple important parameters, such as interest-rate elasticity and repricing lag.
f) In supervisory practice, the interest-rate elasticity multiplier is not applied in EVE calculations, even though its necessity can be derived.

The most important conclusions of the analysis are reflected in the following modelling recommendations:

a) The use of observable repricing times and the historically observed repricing lags following shocks as institution-specific behavioural models, instead of inadequately justified models.
b) In both EVE and NII modelling, the interest-rate elasticity of non-maturity deposits should be taken into account, fundamentally as a multiplier of interest rate risk exposure. This can also be demonstrated in the case of EVE through a combined application of the perpetuity and DCF approaches.
c) Instead of the core / non-core approach, modelling should be based on product-level parameters, whereby genuinely interest-insensitive and non-interest-bearing elements cannot be treated as interest rate risk offsets on the liability side. A new categorisation based on these parameters is proposed, which also allows for simplification of modelling approaches within certain categories.

Among the visibly evolving and expanding supervisory regulations, significant deficiencies appear to persist, the unresolved nature of which introduces contradictions into the sophistication process, particularly with respect to increased stress levels and stricter supervisory conditions.

It must be clearly understood that, at the international level too, albeit to varying degrees across individual banks, an overestimation of the repricing times of non-maturity deposits due to flawed modelling can be found in the banking sector currently, as well as the overestimation of exposures not adjusted for interest-rate elasticity (primarily EVE) and of liability-side positions not adjusted for fully interest-insensitive segments. These all appear as falsely balancing factors for the asset side, resulting in erroneously longer repricing times of assets (more fixed-rate instruments, longer floating rate periods) and insufficient interest rate hedging (e.g., IRS) when optimising the banks' overall interest rate risk positions.

Until these issues are fully understood, there is little point in further refining supervisory stress levels, limits, and restrictions, as systematic distortions become embedded in the sector's risk management. This arises not only from the choice of centralised methodologies but also from the increasingly constrained operational flexibility of banks and the need to comply with stricter requirements, which compel compensatory adjustments.

When a modelling issue is identified for certain institutions, the situation is unlikely to be resolved instantaneously; transitional relief in terms of timing and limit compliance may also be necessary during the adjustment period. Supervisory authorities should support institutions in this process.

Consider the matter from a broader perspective. Most bank executives are well aware – and this is observable in banks' accounting performance – that in a high interest rate environment, the net interest income of most banks typically increases significantly due to rising interest margins. A substantial portion of this, however, actually derives from the negative margins on deposits rather than from positive margins on assets, which naturally vary across banks. Furthermore, deposit rates tend to rise more slowly and to a lesser extent under positive interest rate shocks, while they fall more rapidly in a declining rate environment. This is precisely the empirical manifestation of the combined effects of interest-rate elasticity and repricing lags.

So how does this work in practice? Under strict supervisory conditions, is there really such room for variation in interest income on supposedly fully hedged portfolios? Or are bank portfolios perhaps not as fully hedged as the IRRBB modelling suggests, particularly given the implicit pressure to reduce capital requirements? Unfortunately, the latter appears to be the case.

Perhaps the next step in the sophistication process should be for the industry to address this issue openly, which may also entail accepting a certain residual open position as an inherent feature of banking operations, rather than attempting to conceal it[25]. The IRS market alone is not necessarily able to meet all hedging requirements at acceptable transaction costs for every bank, so floating-rate assets should arguably be given greater focus.

As a cautionary example, the recent bank failures in the United States, such as the case of Silicon Valley Bank, are instructive, as analysed in detail by Júlia Király and András Mikolasek (2023). The root cause originated from interest rate risks in the bank book, as long-term fixed-rate bonds on the asset side suffered devaluation during the stress period of rising interest rates. This was observed by the bank's investors and depositors, triggering a bank run that led to a liquidity crisis and ultimately to the bank's failure.

In such a case, it would likely not be sufficient to reassure investors and depositors simply by showing that the institution models its deposit-side repricing behaviour in a way that it is not expected to raise rates for years – even if competitors do – assuming this would adequately offset the situation.

It is hoped that this analysis has promoted a more accurate measurement of interest rate risk, enabling more precise portfolio hedging and contributing to the development of banks' and supervisors' interest rate risk management routines, thereby supporting the stability of the banking sector even in turbulent and volatile interest rate environments.

25 Risk managers are generally reluctant to tolerate open positions; here, a trade-off emerges between EVE and NII hedging, where pursuing long-term EVE coverage may result in lower nominal NII coverage.

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