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## Riding the rate wave: interest rate and run risks in euro area banks during the 2022-2023 monetary cycle

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**Abstract**

This paper examines how the ECB's 2022–2023 interest-rate hikes affected euro-area banks' economic net worth and vulnerability to deposit runs. Drawing on granular, confidential data for 139 banks, we estimate each bank's economic net worth and find that unrealised losses on loans and bonds averaged around 30 per cent of equity. By September 2023, however, roughly half of these losses had been offset by gains from the deposit franchise and interest-rate swaps. We develop a theoretical framework linking banks' economic net worth and deposit-rate setting to depositor behaviour and run incentives. Further results indicate that banks with larger unrealised losses raised their deposit rates by less - a pattern we interpret as banks leveraging a more valuable deposit franchise to fund longer-duration assets. Although euro-area banks as a whole avoided widespread runs, several institutions nonetheless carried substantial mark-to-market losses, suggesting latent fragilities.

**Keywords:** Interest rate risk, bank runs, monetary policy, asset valuations, euro area banking system.

**JEL codes:** G21, E43, E58, G28

# 1 Non-Technical Summary

This paper investigates the implications of the European Central Bank's significant tightening of monetary policy throughout 2022-2023 on the financial stability of banking institutions in the euro area, with a particular focus on their economic net worth and susceptibility to deposit runs. The period under review was characterised by a rapid and substantial escalation in interest rates, representing a fundamental shift from the preceding era of low, or even negative, rates. This transition exposed banks to increased interest rate risk, primarily through the devaluation of fixed-rate asset portfolios accumulated during periods of lower yields.

Employing granular, confidential data encompassing 139 euro area banks, this paper undertakes a detailed estimation of each institution's economic net worth. Our approach moves beyond standard accounting metrics to provide a more accurate assessment of banks' underlying financial positions by marking to market their interest-rate-sensitive assets, notably loan portfolios and bond holdings. The analysis reveals that, on average, our sample of euro area banks experienced unrealised losses on their loan and bond portfolios equivalent to approximately 30 per cent of their pre-hike equity. These mark-to-market losses represent a considerable erosion of economic value, even if not immediately crystallised in reported profits or regulatory capital.

We estimate that, by September 2023, roughly half of these estimated unrealised losses had been offset by two hedging mechanisms. First, gains accrued from the 'deposit franchise' – the economic benefit derived from funding assets with relatively low-cost, less rate-sensitive retail and corporate deposits – proved substantial. Second, the utilisation of interest-rate swaps provided an explicit hedge against adverse rate movements for many institutions.

To illustrate the relationship between these balance sheet revaluations and deposit run risk we develop a theoretical framework that connects a bank's economic net worth and its deposit-rate setting strategies to the behaviour of depositors and their incentives to withdraw funds. Regression findings linked to this framework indicate a discernible pattern: banks encumbered with larger unrealised losses tended to increase their deposit rates to a lesser extent. This behaviour is interpreted as these banks ex-ante leveraging a more valuable deposit franchise, characterised by less rate-sensitive depositors, to fund longer-duration assets. Such actions are in line with conventional asset and liability management theory as banks seek to align the duration of their assets with their liabilities, however, these actions expose banks to cliff-edge bank runs as their longer-duration assets increase the likelihood they become insolvent on a mark-to-market basis.

Notwithstanding the substantial mark-to-market pressures and the isolated banking stresses observed internationally, the euro area banking system as a whole did not experience widespread deposit runs or systemic failures during this monetary tightening cycle. This resilience can be attributed to a combination of factors, including the aforementioned hedging effects of the deposit franchise and derivatives, alongside different structural characteristics of euro area bank balance sheets and depositor behaviour compared to other jurisdictions.

In conclusion, while the euro area banking sector demonstrated considerable resilience during the 2022-2023 period of rising interest rates, this paper uncovers vulnerabilities with several institutions carrying substantial mark-to-market losses. This suggests latent fragilities within the system that warrant monitoring in future rate hike episodes, particularly concerning banks' reliance on the stability of their deposit base in the face of considerable economic net worth depletion. These findings demonstrate the importance of assessing economic, rather than purely accounting-based, measures of bank solvency and risk.

## 2 Introduction

The rapid and pronounced rise in global interest rates beginning in 2022 posed a significant challenge to banking systems worldwide. After years of low or even negative rates, central banks moved aggressively to combat inflation, fundamentally altering the operating environment for financial institutions. This shift exposed banks to heightened interest rate risk, primarily through the devaluation of fixed-rate asset portfolios accumulated during the low-yield era. The frailty of this situation was starkly illustrated in early 2023 by the turmoil among US regional banks - exemplified by the failure of Silicon Valley Bank (SVB) - where substantial unrealised losses combined with depositor flight triggered insolvency.

By contrast, euro-area banks faced broadly similar monetary tightening from the European Central Bank yet avoided the kind of widespread runs and failures seen in the United States. This resilience invites a closer look at potential insulating factors, such as structural differences in banks' balance sheets, more effective hedging strategies, distinct depositor behaviour, or a combination thereof. Understanding why euro-area banks fared differently is crucial for evaluating financial stability and shaping policy responses.

It is important to reconcile this focus on potential economic vulnerability with the observation that, during this same period, many euro area banks reported significantly improved Returns on Equity (ROE), often reflected in positive equity market performance. Indeed, such heterogeneity in response to rate changes is characteristic of the euro area banking system; Hoffmann et al. (2019), examining an earlier period using granular data and a hypothetical rate rise, found that contrary to conventional wisdom, approximately half of the banks in their sample actually saw their net worth increase with rising interest rates, reflecting specific liability structures, advantageous loan fixation characteristics (driven by cross-country differences), and effective hedging strategies.

This apparent paradox – strong reported profitability coexisting with underlying economic net worth depletion – stems largely from the divergence between standard accounting reporting practices and economic valuations. While rising rates allowed euro area banks to benefit from widening spreads between repricing assets and slower-adjusting 'sticky' deposit costs – boosting current flow profitability – they simultaneously eroded the stock value of existing fixed-rate assets on a mark-to-market basis. Much of this asset devaluation remains 'hidden' as unrealised losses within portfolios held at amortised cost, thus not immediately impacting reported regulatory capital or book equity. Therefore, while reported profits improved in the short term for many, the underlying economic net worth, representing a truer measure of the bank's capacity to absorb losses, declined significantly across the system. Understanding this latent vulnerability, masked by favourable flow dynamics and accounting conventions, is crucial for a comprehensive assessment of bank resilience, representing a core motivation for this paper's focus on economic valuation.

In this paper, using granular confidential data we evaluate how the 2022–2023 interest rate hikes affected the financial health and stability of a large cross-section of euro-area banks, including both Significant Institutions (SIs) and Less Significant Institutions (LSIs). Moving beyond accounting measures, we estimate banks' economic net worth by marking to market their interest-rate-sensitive holdings - specifically bond portfolios and loans. We then measure two key hedging mechanisms: the deposit franchise, reflecting the economic value of low-cost, sticky deposits, and the use of Interest Rate Swap (IRS) derivatives.

Our analysis builds on a simple theoretical framework, in which depositor behaviour and banks' rate-setting choices jointly influence run risk. In this framework, solvency concerns, rather than illiquidity, drive the likelihood of runs by uninsured depositors. We introduce the concept of a minimum deposit rate required by depositors - reflecting outside options, depositor inertia, and perceived solvency - and compare it to the rate a bank can realistically offer given its balance-sheet constraints. Using granular, confidential ECB data, we then quantify the revaluation of banks' assets at three points during the tightening cycle (September 2022, March 2023, and September 2023). We find substantial heterogeneity in interest rate risk exposure. While unrealised losses were, on average, around 30% of pre-hike equity in September 2023, the combined deposit franchise and interest rate swaps hedged almost half of these mark-to-market losses.

Regression analysis indicates that banks with larger unrealised losses benefitted from a larger deposit franchise (keeping deposit rates low). We posit that this stems from ex-ante reliance on 'sticky' deposits whereby banks availing of a larger deposit franchise take on greater duration risk in their assets, in line with findings by Drechsler et al., (2021) and

Kulkarni et al. (2022) for U.S. and Indian banks. Differences in market competition and business models also shaped banks deposit-rate adjustments. Crucially, despite latent vulnerabilities, there were no large-scale deposit runs among euro-area banks during this period, suggesting that a combination of shorter duration assets, hedging and depositor inertia helped avert the type of large-scale deposit runs witnessed in U.S. regional banks in 2023.

The paper proceeds as follows: Section 3 includes a broad discussion of the literature. Section 4 presents the theoretical framework for bank runs under rising rates. Section 5 describes our unique dataset and the empirical methods used to estimate mark-to-market euro area banks balance sheets. Section 6 discusses the main results from the empirical exercise including an assessment of banks' run vulnerabilities. Section 7 includes a regression explaining banks' adjustments of deposit rates over the rate cycle, tied to the theoretical framework in Section 4. Finally, Section 8 concludes.

# 3 Literature review

The rapid and pronounced rise in global interest rates initiated in 2022 fundamentally altered the operating environment for banks worldwide, renewing focus on their management of interest rate risk (IRR). Our paper contributes to several strands of literature examining bank behaviour and stability in the face of interest rate fluctuations, particularly concerning the valuation of assets and liabilities, the role of hedging mechanisms, and the determinants of financial fragility in the euro area.

A foundational concept in banking literature is that banks engage in maturity transformation, typically funding longer-duration assets with shorter-duration liabilities, primarily deposits (Diamond and Dybvig, 1983). Traditionally, this maturity mismatch is thought to expose banks to IRR, whereby rising interest rates decrease bank net worth as the present value of assets falls more than that of liabilities. Empirical studies often find a negative relationship between interest rate increases and bank equity valuations, particularly in the U.S. context (Flannery and James, 1984; Lumpkin and O'Brien, 1997; English et al., 2018), suggesting markets perceive rising rates as detrimental to bank value. However, other studies measuring IRR through net worth sensitivity find considerable heterogeneity. Notably, Hoffmann et al. (2019), using granular supervisory data for euro area banks, find that approximately half the banks in their sample actually see their economic net worth increase with rising interest rates. This heterogeneity is strongly linked to national differences in mortgage market structures (predominance of fixed vs. variable-rate loans) and banks' liability composition, suggesting the traditional view of universal vulnerability is overly simplistic, at least in the euro area.

The 2022-2023 interest rate cycle brought the impact of IRR to center stage, particularly through the lens of unrealised losses on banks' securities portfolios accumulated during the preceding low-yield era. These losses significantly diverged from reported accounting profits, highlighting the crucial distinction between accounting measures and economic valuation (Acharya and Ryan, 2016). While rising rates boosted net interest margins (NIMs) for many banks, improving reported profitability, the simultaneous mark-to-market devaluation of fixed-rate assets eroded their underlying economic net worth. Standard accounting practices, particularly the classification of assets as Amortised Cost (AC) versus Fair-Valued (FV), allow significant portions of these losses to remain 'hidden' from regulatory capital and book equity calculations for many banks (Marsh and Laliberte, 2023; Granja et al. (2024). Marsh and Laliberte (2023) document how these unrealised losses, even if not immediately recognised in capital, can impair bank behaviour by reducing liquidity (due to reluctance to sell securities at a loss), increasing funding costs, constraining loan growth, and dampening M&A activity.

The potential for large unrealised losses to impair solvency creates fertile ground for bank runs. Recent analyses of the 2023 U.S. banking turmoil emphasise depositors' concerns about bank solvency, driven by the recognition of these losses, as a key trigger for runs (Jiang et al., 2024; Drechsler et al., 2024). This contrasts with canonical bank run models that primarily emphasize asset illiquidity and coordination failures among depositors (Diamond and Dybvig, 1983; Allen and Gale, 1998). The recent failures align more closely with models where runs are driven by fundamentals or information about bank solvency (Goldstein and Pauzner, 2005; Egan et al., 2017). Jiang et al. (2024) empirically demonstrate the critical role of high uninsured deposit leverage combined with significant mark-to-market losses in explaining the run on Silicon Valley Bank (SVB) and identifying other vulnerable U.S. banks. They estimated system-wide mark-to-market asset declines of 1.7−2.1 trillion, highlighting the magnitude of the shock and the significant exposure of U.S. banks to interest rate risk.

Given these risks, banks employ various strategies to manage IRR. Two key mechanisms are the deposit franchise and explicit hedging with derivatives like Interest Rate Swaps (IRS). The role of the deposit franchise - the value derived from funding assets with low-cost, 'sticky' deposits - is a subject of significant academic debate. One influential view, developed by Drechsler, Savov, and Schnabl (DSS), posits that the deposit franchise allows banks to effectively hedge IRR through maturity transformation (Drechsler et al., 2021). They argue banks possess market power in retail deposit markets - following Drechsler et al., 2017 - allowing them to maintain low deposit rates with limited sensitivity ('beta') to market rates (Hannan and Berger, 1991; Neumark and Sharpe, 1992). This market power, combined with substantial fixed operating costs incurred to maintain the franchise, makes the deposit franchise function like an implicit interest rate swap where the bank pays fixed (operating costs) and receives floating (the deposit spread). To hedge the resulting negative duration of their liabilities (including the franchise value), banks optimally hold long-duration fixed-rate assets. This framework suggests banks' NIMs and overall profitability should be relatively stable and insensitive to interest rate fluctuations, a finding supported by their analysis of aggregate U.S. data (Drechsler et al., 2021).

However, this view of the deposit franchise as a perfect hedge faces challenges. First, the 'deposits channel' (Drechsler et al., 2017) implies that as banks widen deposit spreads when market rates rise, some depositors will move funds to higher-yielding alternatives, notably (in the U.S. case) Money Market Funds (MMFs), eroding the deposit base (Xiao, 2020; Aldasoro and Doerr, 2023). Second, recent theoretical work introduces the concept of 'deposit franchise runs' (Drechsler et al., 2024). Since the franchise value depends on deposits staying with the bank, it is inherently runnable, especially by uninsured depositors (Iyer et al., 2013). This run risk is amplified when interest rates are high because the franchise value itself is larger, making its potential loss more damaging to solvency. Critically, DeMarzo et al. (2024) challenge the core DSS (2021) assumption, arguing that low deposit betas do not necessarily imply negative duration for the franchise value. They model the deposit spread as akin to a zero-duration floating-rate bond and argue that the franchise value's duration is primarily driven by fixed lending spreads net of operating costs, which typically results in a positive duration. Consequently, rising rates decrease franchise value, exacerbating rather than offsetting mark-to-market losses on assets. This alternative perspective implies a greater need for hedging using alternative means, such as the use of interest rate swap derivatives (IRS).

However, the effectiveness of explicit hedging using IRS is also debated. While widely used, recent studies using granular U.S. data suggest their net impact on hedging aggregate bank balance sheet IRR may be limited on average, despite large gross notional positions (Begenau et al., 2015; McPhail et al., 2023); see also Rampini et al. (2017) for related theory. Instead, swaps appear crucial for transferring risk between banks and facilitating client demands (e.g., transforming corporate floating-rate loans into fixed-rate exposures). This contrasts somewhat with evidence from the euro area, where Hoffmann et al. (2019) found IRS hedged approximately 25% of on-balance sheet IRR exposure using 2015 data, and findings from the ECB Financial Stability Review (2022) pointed at an increase in swap usage between 2019-2021, suggesting potentially more active hedging compared to the U.S. average, though likely still incomplete. Hedging practices may also differ systematically across regions, with banks in emerging market economies often relying more on direct matching of asset-liability repricing gaps rather than derivatives (Caballero et al. 2023).

Depositor uncertainty and information acquisition play crucial roles in run dynamics. He and Manela (2016) model runs triggered by rumours where depositors face uncertainty about bank liquidity and acquire noisy signals. This information acquisition creates belief heterogeneity, leading to endogenous withdrawal speeds driven by depositors' "fear-of-bad-signal-agents". Their work highlights how private information acquisition can destabilise solvent-but-illiquid banks. Importantly, they also show that public provision of solvency information can mitigate runs by crowding out private efforts to acquire liquidity information. This paper develops a simple, though complementary, theoretical framework focusing on depositor uncertainty about banks economic net worth interacting with depositor inertia. Our framework, like theirs, explores how uncertainty affects run thresholds, but emphasises the stabilising role of depositor inertia.

Our paper situates itself within this broad literature by focusing specifically on the euro area banking system's experience during the 2022-2023 tightening cycle. While facing similar pressures as U.S. banks, the euro area system exhibited greater resilience. Building on Hoffmann et al. (2019), we investigate the sources of heterogeneity in IRR exposure and resilience within the euro area during this specific stress episode. We move beyond accounting metrics to estimate the economic net worth of a large sample of euro area banks, quantifying the magnitude of unrealised losses and, crucially, assessing the offsetting capacity provided by both the deposit franchise (valued considering its potential benefits and risks) and explicit IRS hedging. Our approach differs from Hoffmann et al. (2019) by analysing an actual, high-magnitude rate hike cycle rather than a hypothetical scenario, allowing us to capture dynamic hedging behaviour and observe the behaviour of depositors following large-scale rapid rate hikes. Furthermore, we link our empirical estimates of net worth vulnerability and hedging to a theoretical framework of bank run risk driven by the interplay between depositor incentives and bank profitability constraints, potentially exacerbated by unrealised losses. By empirically analysing the determinants of deposit rate changes in this context – linking them to unrealised losses, deposit composition, and market competition – we aim to shed light on the mechanisms that contributed to the euro area banking system's resilience during this period of stress, contributing to the broader collective understanding of bank interest rate risk management and financial stability in the euro area.

In the following section, we develop a simple theoretical framework to demonstrate the impact of rising interest rates on a bank's net worth, and how this interacts with depositor incentives to withdraw funds.

# 4 Theoretical framework for bank runs

A useful starting point is to consider a bank whose balance sheet comprises a portfolio of long-term assets funded by short-term, withdrawable deposits. Let the face value of the bank's assets at time $t$ be denoted by $A_t$, and let $L_t$ represent its deposit liabilities. The bank's accounting net worth at any point in time $t$ is then simply defined as $NW_t = A_t - L_t$. Since a large portion of bank assets are typically held at amortised cost, the economic value of fixed-rate assets can fluctuate significantly more than their recorded accounting value. To capture this, it is helpful to define the bank's "economic" net worth explicitly as $NW_t^{\text{econ}} = A_t^{\text{marked}} - L_t$, where $A_t^{\text{marked}}$ represents the mark-to-market value of the banks' assets, including unrealised gains or losses resulting from changes in market yields.

A feature of many banks is their ability to pay deposit rates that lie below prevailing market interest rates. This gap between market rates and bank deposit rates creates a stream of quasi-rents, referred to as the "deposit franchise" value. Formally, if the short-term market interest rate at time $t$ is $r_{\text{m},t}$ and the bank pays its depositors $r_{\text{dep},t}$, the differential $r_{\text{m},t}$ - $r_{\text{dep},t}$ yields the present value of the deposit franchise:

$$DF = \sum_{t=1}^{T} \frac{D_t(r_{m,t} - r_{dep,t} - c)}{(1 + r_{m,t})^t}, \tag{1}$$

where $D_t$ denotes the level of deposits at time $t$, $c$ is a per-unit operating cost of managing deposits, and $T$ is the duration of deposits. When depositors are relatively unresponsive to rate increases - often described as deposit "stickiness" or a low deposit beta - the bank can keep $r_{\text{dep,t}}$ well below $r_{\text{m,t}}$. Since deposits make up the majority of most euro area banks liabilities, such banks may receive a substantial income from the deposit franchise in a high rate environment.

The bank's exposure to interest rate risk can be understood through the lens of duration. Let $Dur(A)$ represent the duration of the bank's asset portfolio. Fixed-rate assets have a *positive* duration, since they don't reprice immediately, their value declines as rates increase. Deposits, particularly when sticky, typically have a *negative* duration, because they increase in value as market rates rise. Therefore, a bank's overall duration gap is defined as:

$$DG = Dur(A) - \alpha Dur(L), \tag{2}$$

where $\alpha$ is an adjustment factor that captures the degree of deposit rate pass-through. When deposit rate pass-through is low (meaning deposit rates respond minimally to increases in market rates), $\alpha$ becomes large, enhancing the negative duration characteristic of deposits. Consequently, banks that expect continued low pass-through can strategically extend the duration of their asset portfolios in the knowledge that depositors will provide a natural hedge against rising yields.

Prior research by Drechsler et al. (2021) finds that U.S. banks with historically low deposit betas hold longer-duration, fixed-rate assets to match the slow repricing of deposits, and Kulkarni et al. (2022) document similar patterns for Indian banks. The negative duration property of sticky deposits can therefore hedge the interest rate risk of a positive duration asset portfolio. In other words, a larger deposit franchise effectively insulates the bank's net interest margin under normal conditions by offsetting the pass-through of rates on assets with a similarly low pass-through on liabilities.

In the following paragraphs we introduce a framework for thinking about depositors' run incentives, and demonstrate that banks tendency to utilise their deposit franchise to extend the duration of their assets may also increase the risk of sudden withdrawals under extreme levels of unrealised loss (in line with Drechsler et al. (2024)).

### Depositor incentives and deposit rate setting

The effectiveness of deposits as a hedge against rising interest rates is contingent on depositor retention (Drechsler et al. (2024)). Therefore, we now use a simple theoretical framework to capture the incentives of depositors when deciding whether to retain or withdraw their deposits at the bank. For simplicity, we assume that a bank's depositors are split between those with uninsured deposits and those with insured deposits. All depositors compare the expected payoff from staying to the expected payoff from withdrawing and investing elsewhere. In the case of uninsured depositors, if the bank remains solvent, we assume a depositor's payoff from staying is $1 + r_{\text{dep}} + \gamma$, where $r$ is the annual deposit rate and $\gamma \geq 0$ captures non-monetary utility, such as convenience or inertia-related switching costs. In the event of bank failure, an uninsured depositor receives $1 - \lambda + \gamma$, where $\lambda$ is the expected fractional loss incurred on uninsured deposits. Formally, the expected payoff for an uninsured depositor staying in the bank is:

$$E[\text{Payoff Stay}] = P(\text{Solvent})(1 + r_{\text{dep}} + \gamma) + P(\text{Insolvent})(1 - \lambda + \gamma), \tag{3}$$

while an outside risk-free option yields $1 + r_{\text{alt}}$. The depositor stays if $E[\text{Payoff Stay}] \geq 1 + r_{\text{alt}}$, which can be rearranged to yield a minimum deposit rate necessary to prevent withdrawals as:

$$r_{\text{dep}}^{\text{min}} = \frac{(r_{\text{alt}} - \gamma) + \lambda P(\text{Insolvent})}{(1 - P(\text{Insolvent}))} \tag{4}$$

An increase in $\lambda$, $P(Insolvent)$, or the alternative yield $r_{\text{alt}}$ raises $r_{\text{dep}}^{\text{min}}$. Conversely, larger depositor inertia, $\gamma$, reduces the required rate.

Banks, on the other hand, are constrained by the necessity to maintain profitability above a certain critical threshold, $\Pi_{\text{min}}$. As deposit rates rise, banks face compression of their net interest margins. Thus, banks have a clear incentive to limit increases in deposit rates, particularly when higher rates cause them to approach this profitability threshold. This threshold therefore establishes an upper-bound on the deposit rate the bank can feasibly offer, defined here as $r_{\text{dep}}^{\text{max}}$. To avoid a run while remaining viable, the bank will only offer a deposit rate that satisfies the following condition $r_{\text{dep}}^{\text{min}} \leq r_{\text{dep}} \leq r_{\text{dep}}^{\text{max}}$. When this condition holds, the bank remains in a "no-run" equilibrium. However, if depositors' minimum required rate exceeds the bank's maximum feasible rate, i.e., $r_{\text{dep}}^{\text{min}} > r_{\text{dep}}^{\text{max}}$, the bank cannot adequately compensate depositors, creating conditions conducive to a deposit run.

Banks with longer-duration fixed assets may receive lower interest income when market rates rise as these assets are slow to reprice, hence their $r_{\text{dep}}^{\text{max}}$ may be lower. However, so long as they are sufficiently hedged with sticky deposits, $r_{\text{dep}}^{\text{min}}$ should remain sufficiently low to avoid runs. In the following section we demonstrate these dynamics using stylised simulations and hypothetical assumptions on parameter values, including a demonstration of the circumstances under which even sticky depositors have incentive to run.

## 4.1 Run threshold simulations

In this section, we numerically illustrate how the minimum deposit rate required by depositors, $r_{\text{dep}}^{\text{min}}$, and the maximum feasible deposit rate that the bank can offer, $r_{\text{dep}}^{\text{max}}$, evolve as a bank's economic net worth deteriorates. In doing so we aim to provide a simple framework that will be useful to conceptualise the vulnerabilities faced by euro area banks in the latest rate hike, given our estimates of their economic net worth. Building on parameters introduced in the previous section, we now also introduce the concept of depositor uncertainty about the bank's true economic net worth, ($\sigma_{ENW}$), with a similar interpretation as that used in He and Manela (2016).

To simulate $r_{\text{dep}}^{\text{min}}$ and $r_{\text{dep}}^{\text{max}}$ under varying levels of economic net worth, we must include depositors' beliefs concerning the bank's mark-to-market solvency, represented by the probability of insolvency, $P(Insolvency)$. Since banks do not typically disclose unrealised losses, uninsured depositors must estimate $P(Insolvent)$ based on available information, subject to uncertainty. For simplicity we assume the probability of insolvency perceived by uninsured depositors is based on a standard normal distribution as follows:

$$P(\text{Insolvent}) = \phi\left(-\frac{\Delta ENW}{\sigma_{ENW}}\right) \tag{5}$$

where $\Delta ENW$ represents the percentage change in economic net worth relative to the bank's initial equity, and $\sigma_{ENW}$ is the standard deviation of depositors' estimate of this change, scaled by the share of the bank's pre-rate hike equity. In other words, if $\sigma_{ENW} = 20\%$, depositors' assessments of the banks depletion in economic net worth are dispersed around the true value with a standard deviation of 20 percentage points relative to the level of pre-rate hike equity.

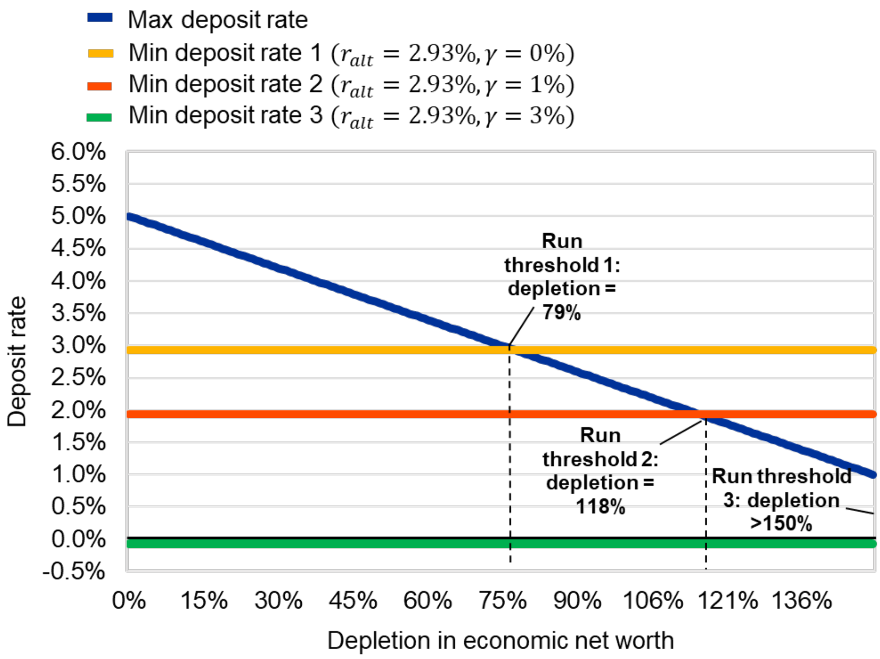
We first analyse insured depositors before subsequently considering uninsured depositors. Detailed assumptions underlying all numerical simulations are provided in Appendix Table 7.

### Insured depositors

We begin by examining insured depositors, whose deposits and contractual interest payments are fully protected, rendering them indifferent to the bank's economic net worth and insolvency risk. However, insured depositors remain aware of alternative investment returns ($r_{\text{alt}}$) and have non-monetary incentives to keep deposits at their bank (captured by the inertia parameter $\gamma$). Additionally, as outlined in the previous section, banks experiencing a significant depletion of economic net worth face relatively tighter constraints in their ability to raise deposit rates.

These dynamics are clearly illustrated in Figure 1. For this simulation, we set the alternative investment return ($r_{\text{alt}}$) at 2.93%, corresponding to the peak weekly average yield on a German 10-year government bond in 2023, and vary the level of $\gamma$.

**Figure 1: Relationship between minimum and maximum deposit rates and run regions for insured deposits under varying assumptions for $\gamma$**




*Notes:* Parameter values and assumptions are documented in Appendix Table 7. All calculations were performed using MATLAB.

In Figure 1, the downward-sloping blue line represents the maximum deposit rate ($r_{\text{dep}}^{\text{max}}$), highlighting its negative relationship with the extent of economic net worth depletion. When the depletion in economic net worth exceeds 100%, the bank is in a position of negative economic net worth as the mark-to-market value of their assets is lower than that of their liabilities. When depositor inertia is absent ($\gamma = 0$, yellow line), insured depositors derive no additional non-monetary value from maintaining their deposits at the bank. Consequently, these depositors will withdraw as soon as the bank is unable to match the alternative outside option (i.e., when $r_{\text{alt}} = r_{\text{dep}}^{\text{min}} > r_{\text{dep}}^{\text{max}}$). This scenario is indicated as 'Run threshold 1', which in our simulations occurs when the bank's economic net worth has declined by approximately 79%.

Conversely, positive values of depositor stickiness ensure deposits remain stable even when the bank's offered deposit rate is lower than the available outside option. The orange and green lines in Figure 1 illustrate this situation. Specifically, in the scenario represented by the green line, depositor inertia ($\gamma = 3\%$) exceeds the outside alternative yield (2.93%). In this scenario, insured depositors even accept slightly negative deposit rates ($\gamma - r_{\text{alt}} = -0.07\%$), despite the outside option offering a higher financial return. This outcome demonstrates the importance of depositor inertia in mitigating run risks for banks facing challenging economic conditions or deteriorating net worth positions.

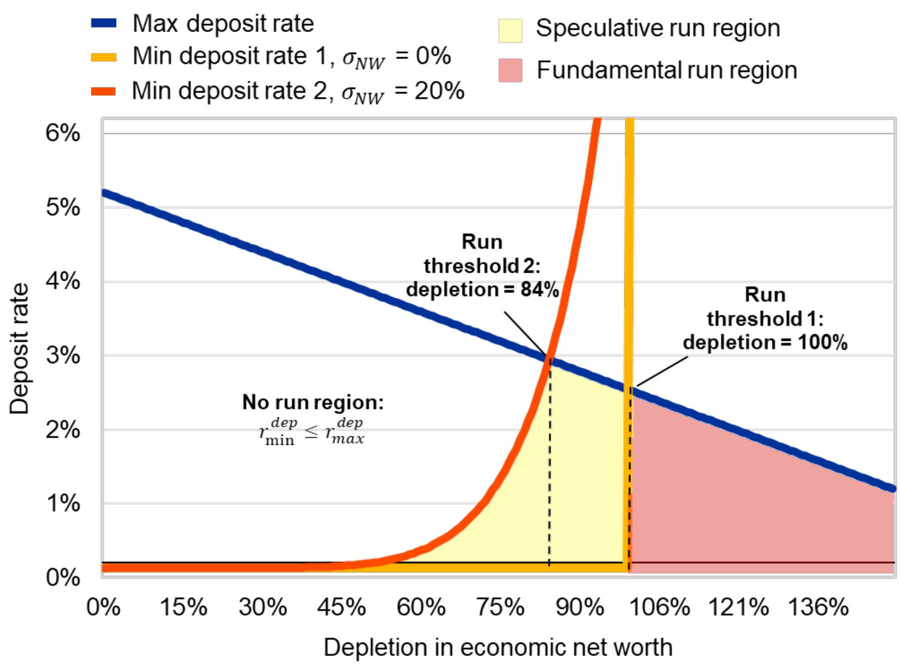
Linking these simulations to findings in the literature (e.g., Drechsler et al. (2021)), banks that have extended the duration of their assets due to having sufficiently sticky deposits are in a position resembling the green line. Such banks are unlikely to see insured depositors run despite the larger unrealised losses on their long-duration assets reducing the maximum deposit rate they can offer.

### Uninsured depositors

Next, we consider the behaviour of uninsured depositors, who face potential losses if the bank fails. Unlike insured depositors, uninsured depositors consider the probability of their bank being insolvent, $P(Insolvent)$, when determining whether to withdraw their funds. Using the standard normal probability framework described above, uninsured depositors estimate the percentage change in the bank's economic net worth with uncertainty, denoted by the standard deviation $\sigma_{ENW}$, expressed relative to the bank's initial equity.

Figure 2 provides simulations illustrating how the minimum deposit rate required by uninsured depositors ($r_{\text{dep}}^{\text{min}}$) and the maximum feasible rate offered by the bank ($r_{\text{dep}}^{\text{max}}$) evolve under different assumptions regarding depositor uncertainty ($\sigma_{ENW}$). Here, for both deposit rate scenarios, we hold fixed the alternative outside investment yield ($r_{\text{alt}}$) at 2.93%, and depositor inertia ($\gamma$) at 3%, implying uninsured depositors would accept even a slightly negative deposit rate when *P(Insolvency)* is near 0.

**Figure 2: Relationship between minimum and maximum deposit rates and run regions for uninsured deposits under varying assumptions for $\sigma_{ENW}$**




*Notes:* Parameter values and assumptions are documented in Appendix Table 7. All calculations were performed using MATLAB.

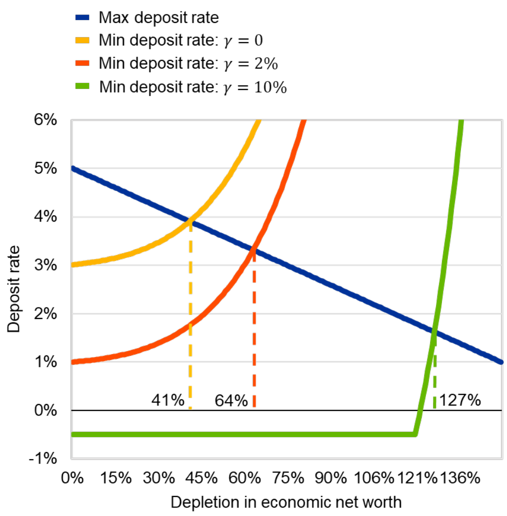
In Figure 2, the scenario depicted by the yellow line assumes perfect information ($\sigma = 0$), indicating depositors are certain about the bank's economic net worth. Under these conditions, a run occurs only when the bank's economic net worth depletion reaches 100% (*Run threshold 1*), at which point the bank is insolvent on a mark-to-market basis, and all uninsured depositors know that the bank is unable to repay them in full based on the market value of its assets. At this point, there is no feasible level of $r_{\text{dep}}$ that would incentivise them to remain.

By contrast, the scenario represented by the red line incorporates depositor uncertainty ($\sigma > 0$). In this case, uncertainty leads depositors to require higher compensation to retain their funds, even if the bank remains fundamentally solvent. This creates conditions for a *speculative* run (*Run threshold 2*) where, in the absence of full information on the bank's true economic net worth, uninsured depositors withdraw despite the bank being in a position of positive economic net worth. Such a scenario aligns with He and Manela (2016) where depositor uncertainty can precipitate runs on banks that are otherwise fundamentally solvent.

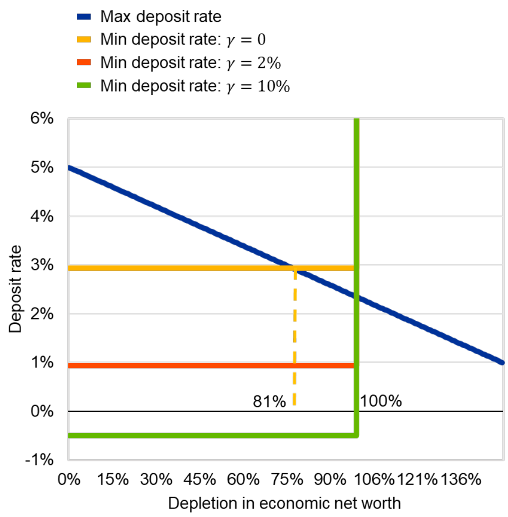
Next we illustrate a scenario whereby despite having negative economic net worth, a deposit run may be delayed, or avoided entirely. This situation resembles the case of Silicon Valley Bank (SVB) in late 2022. Although SVB was insolvent on a mark-to-market basis by September 2022, at this time uninsured depositors were largely unaware of the extent of unrealised losses on the bank's asset book. A run did eventually occur in March 2023, when the bank's weak financial position became broadly recognised, and rapid withdrawals ensued.[1] Within our framework, such dynamics are captured by a high level of depositor inertia ($\gamma$) coinciding with declining levels of depositor uncertainty ($\sigma_{ENW}$).

In Figure 3a and Figure 3b, we repeat the simulations varying the parameters $\gamma$ and $\sigma_{ENW}$. All other parameter values continue to align with previous simulations (see Appendix Table 7).

**Figure 3: Uninsured deposits' behaviour - reduction in uncertainty, $\sigma_{ENW}$, about the bank's economic net worth under various assumptions for $\gamma$**




(a) $\sigma_{ENW} = 40\%$




(b) $\sigma_{ENW} = 0\%$

*Notes:* Parameter values are identical to those in Figure 2, except for adjustments to $\sigma_{ENW}$ and $\gamma$. All calculations were performed using MATLAB.

[1] In September 2022, the bank had \$15.9 billion of unrealised losses largely held in its bond portfolios, compared to \$11.8 billion of tangible common equity. As news of the bank's financial position spread across social media, led by venture capitalists and informed investors, the uncertainty about the bank's position reduced.

**Panel (a): High uncertainty** ($\sigma_{ENW} = 40\%$)

Under conditions of high uncertainty, Figure 3a demonstrates that depositor stickiness strongly influences run thresholds. With low stickiness ($\gamma = 0\%$ or $2\%$), depositors require increasingly higher deposit rates to remain with the bank as economic net worth deteriorates, triggering speculative runs at relatively modest depletion levels (41% and 64% in these simulations). Conversely, when stickiness is substantial ($\gamma > 10\%$), depositors tolerate lower deposit rates for much longer, delaying the run threshold to a significantly deeper negative economic net worth position (at $-127\%$). This illustrates how depositor stickiness can substantially mitigate run risk even under pronounced uncertainty.[2]

**Panel (b): No uncertainty** ($\sigma_{ENW} = 0\%$)

In Figure 3b, we eliminate uncertainty entirely, meaning depositors have full knowledge of the bank's economic net worth. In this scenario, uninsured depositors withdraw funds immediately, triggering a fundamental run exactly when economic net worth depletion reaches 100%, regardless of the level of deposit inertia ($\gamma$). As discussed above, this rapid shift from high to low uncertainty bears similarity to the situation experienced by SVB from September 2022 to March 2023, as depositors' uncertainty dissipated and awareness of the bank's position became clear, prompting a first mover advantage to remove funds as depositors understood that the bank's position was broadly acknowledged.

This comparative analysis highlights the roles of depositor uncertainty and inertia in shaping bank run dynamics. For uninsured depositors, higher uncertainty can either hasten or delay runs depending on the degree of depositor inertia. Depositors lacking additional non-monetary incentives (low $\gamma$) react swiftly to increased insolvency probabilities under uncertainty, thereby triggering early speculative runs. In contrast, high levels of depositor inertia combined with uncertainty about the banks mark-to-market financial position may not result in a run despite the bank being fundamentally insolvent on a mark-to-market basis.

[2] Here we also put a floor on $r_{\min}$ at 0.5%, to account for the lower bound on deposit rates, where we assume a non-linear relationship as deposit rates become negative. This assumption captures the fact that depositors are less willing to pay to keep deposits at the bank. In any case, this assumption is for added realism and relaxing it does not change the estimated run threshold.

The latter scenario demonstrates the inherent risk a bank takes on when relying too heavily on its deposit franchise to hedge long-duration assets, without other hedges in place (such as interest rate swaps). Where uninsured depositors are made aware of the extensive erosion of their bank's economic net worth, exceeding the book value of its assets, the bank is unable to offer them a sufficient deposit rate to prevent a run. The riskiness of a bank's over-reliance on the deposit franchise is covered extensively in Drechsler et al. (2024).

In the following sections we turn to the empirical analysis of the paper, covering first our dataset, followed by the approach to estimate the present values of each selected balance sheet item.

# 5 Data and empirical estimation

The extensive set of granular data available to us provides several advantages over existing papers in the literature. For bonds, we utilise confidential ECB securities data, which provide detailed information on both the face value and market value of holdings at the bank level and on a security-by-security basis. This enables us to directly track changes in the market value of individual bonds held by individual banks in our sample. For household loans (including mortgages and other lending) we combine two datasets: the ECB Individual Balance Sheet Items (IBSI) dataset for data on the volumes of loans by type, and the ECB Individual Interest Rate Statistics (IMIR) dataset for data on lending rates. These datasets contain bank-level data, are available for all banks in our dataset, and provide information on loan volumes and lending rates by sector, portfolio, and split by duration. We compliment these data with data from confidential household survey data compiled by the European Systemic Risk Board (ESRB) which includes additional country-level information on loan and interest rate fixation durations. For non-household loans, we use AnaCredit, a confidential loan-level dataset containing detailed information on individual loans from banks in the euro area[3]. To calculate the deposit franchise, we also utilise IBSI and IMIR data, which provide monthly information on banks' deposit rates and volumes vis-‘a-vis households and non-financial corporates. We combine these

[3]AnaCredit data are not available for households.

bank-level data with country-level averages of the share of banks uninsured deposits due to the lack of bank-level data on uninsured deposit volumes. Finally, for derivatives, we use European Market Infrastructure Regulation (EMIR) data, which includes granular instrument-level information such as the entities involved in the trade, product and underlying information, notional amounts, daily contract values, and margins. Table 1 summarises our data sources. In the following sections we provide further information on how these various datasets are used in our empirical analysis.

**Table 1: Data Sources**

| Item | Source | Key Information |
|---|---|---|
| Key balance sheet information | Orbis (BankFocus) | Consolidated balance sheet data for 139 banks, including 58 Significant Institutions (SIs) and 81 Less Significant Institutions (LSIs). |
| Debt securities (holdings and issuances) | ECB Security Holdings Statistics Group and Sector (SHS-G and SHS-S) | SHS-G and SHS-S include security-level data, covering euro area holders and global issuers for 98.5% of debt, equity, and investment fund holdings of euro area institutions. SHS-G contains a sample of 109 (as of 2022Q4) large banks with detailed bank-security level information. |
| Loan and deposits data | AnaCredit, ECB Individual Balance Sheet Items (IBSI), ECB Individual MFI Interest Rate Statistics (IMIR), and ECB/ESRB Mortgage Questionnaire | AnaCredit includes loan-level information for all euro area banks. IBSI and IMIR provide detailed monthly data on certain balance sheet items on an unconsolidated basis. The ECB/ESRB mortgage questionnaire is a bi-annual detailed survey on mortgage lending completed by all national central banks in the euro area. |
| Interest rate swap derivatives | European Market Infrastructure Regulation (EMIR) data | EMIR is a regulatory dataset on derivative trades with detailed daily information on contracts, valuations, and the counterparties involved. |

Our sample of banks includes 58 Significant Institutions (SIs) and 81 all Less Significant Institutions (LSIs). The institutional significance refers to the systemic importance of the bank and aligns with the classification of the ECB Single Supervisory Mechanism (SSM) following rules by the European Banking Authority (EBA). The sample is composed of all supervised banks in the euro area for which we had sufficient data coverage. Since institutional asset and liability management is likely to be undertaken at the level of the Global Ultimate Owner (GUO) we used consolidated data and excluded any banks that were not designated as the GUO, which removed subsidiaries of non-euro area banks.[4]

Tables 2, 3, and 4 summarise our sample of banks split by supervisory category, business model and country. Our final sample accounts for 63 per cent of the total assets of the euro area financial system. On a count basis, the sample is dominated by retail and consumer credit lenders (79). However, since these banks tend to be more limited in their activities, and given that many are LSIs, they constitute just 7.1 per cent of the total assets of the sample. On the other hand, 16 G-SIBs and investment banks constitute 76 per cent of the total assets of the sample.

[4]One exception here is where the bank was owned by a foreign non-bank financial institution, where we assume the bank still operates as a ring-fenced entity from the perspective of managment of interest rate risk.

Table 2: Sample of banks by supervisory category

| Supervisory Category | Total Assets (€Bn) | Count | Average Size (€Bn) | Smallest (€Bn) | Largest (€Bn) |
|---|---|---|---|---|---|
| Significant Institutions | 16,913 | 58 | 292 | 4 | 2,634 |
| Less Significant Institutions | 521 | 81 | 6 | 0.2 | 28 |

Table 3: Sample of banks by business model

| Business Model | Total Assets (€Bn) | Count | Average Size (€Bn) | Smallest (€Bn) | Largest (€Bn) |
|---|---|---|---|---|---|
| Retail and consumer credit lenders | 1,233 | 79 | 16 | 0.2 | 116 |
| Diversified and corporate lenders | 2,873 | 44 | 65 | 0.3 | 307 |
| GSIBs, universal and investment banks | 13,329 | 16 | 833 | 2.8 | 2,634 |

Table 4: Sample of banks - by country

| Country | Total Assets (€Bn) | Count | Average Size (€Bn) |
|---|---|---|---|
| AT | 562 | 8 | 70 |
| BE | 255 | 3 | 85 |
| CY | 22 | 3 | 7 |
| DE | 3,405 | 35 | 97 |
| EE | 11 | 5 | 2 |
| ES | 3,711 | 23 | 161 |
| FI | 603 | 5 | 121 |
| FR | 4,258 | 5 | 852 |
| GR | 84 | 1 | 84 |
| IE | 28 | 1 | 28 |
| IT | 2,961 | 23 | 129 |
| LT | 15 | 2 | 8 |
| LU | 57 | 3 | 19 |
| LV | 12 | 4 | 3 |
| MT | 23 | 3 | 8 |
| NL | 1,127 | 4 | 282 |
| PT | 208 | 4 | 52 |
| SI | 25 | 3 | 8 |
| SK | 69 | 4 | 17 |

## 5.1 Estimating net worth

In this section we detail our approach estimating banks' economic net worth, which involves present value calculations of interest rate sensitive balance sheet items. We focus our analysis on loans, debt securities, deposits, and derivatives. Other balance sheet items - such as equity investments and investment fund shares - are influenced by a broader set of factors, including market sentiment, economic growth prospects, and bank performance, which dilute their direct relationship with interest rate changes. In line with comparable studies (Jiang et al. 2024, Drechsler et al. 2024), we chose not to include bond liabilities, since any valuation effects on bond liabilities are unlikely to deter uninsured depositors from withdrawing their funds in the short-term.[5]

We chose three periods over the rate hike period in which to measure banks' economic net worth: September 2022, March 2023 – amid the U.S. regional bank failures – and September 2023, when euro area government bond yields reached their peak. Estimating economic net worth at multiple dates across the cycle allows us to consider the evolution of offsetting effects (including interest rate swaps and the accumulated value of the deposit franchise) and banks' behavioural responses (such as shifting assets between accounting categories and purchasing higher yielding bonds).

Two approaches are commonly taken to estimate present values – directly observing market prices on similar instruments, or through the calculation of a discounted cash flow. The use of market price data is more straightforward than implementing a discounted cash flow as it requires fewer assumptions and implicitly reflects the collective beliefs of investors on the value of specific assets. However, the ability to effectively employ market prices for this task varies by instrument. It is relatively straightforward to use market data to calculate valuation impacts on bond and equity instruments (at least where these instruments are publicly traded in sufficiently liquid markets), but it is more difficult to do so for loan portfolios. A market price approach was used by Jiang et al. (2024) to value banks' real estate loan portfolios in the U.S. The authors used variation in the prices of Exchange Traded Funds (ETFs) tracking residential and non-residential

[5]The reduction in the market value of bond liabilities cannot be readily converted into cash to meet liquidity needs during a deposit run, as the bank cannot compel bondholders to accept early repayment at discounted prices.

mortgage-backed securities (MBS) combined with ETFs on U.S. treasury bonds to adjust for loan durations, as reported by banks in their regulatory call reports. However, ETF prices can be influenced by broader market sentiment and liquidity factors unrelated to the underlying loans and may include a mix of securitised loans with different risk profiles and durations that do not match the conventional loans typically held by banks, resulting in an inaccurate reflection of the actual risks and value of the banks' real estate portfolios. In any case, for our purposes, there does not currently exist a European ETF index tracking MBS with underlying loans originating in euro area countries. Our approach combines banks' reported market prices for bonds with a simple discounted cash flow approach for loans. For the deposit franchise and interest rate swap derivatives, our interest is backward looking – we use observed deposits data since the start of the rate hike, as well as the exchanged contract values on interest rate swaps between counterparties.

#### Bond holdings

In this section, we outline the methodology employed to mark-to-market the bond holdings of our sample of euro area banks. We include all types of debt securities, including those issued by other banks, corporates and government, and those held on both a fair-valued and amortised cost basis. Fair-valued prices on bonds held at amortised cost are not recognised on banks' balance sheets but are included in the calculation of liquidity coverage ratios and affect the space needed to obtain secured funding, including from the ECB. For this reason, their market prices are reported to the ECB on a confidential basis and used in our analysis. The ECB's Security Holdings Statistics data (SHS) are produced on two dimensions: at group and sector level. Each dataset provides security-level data, including information on the face value and observed market prices. The group-level dataset (SHS-G) contains bank-level data for 109 (as of 2022Q4) banks in the euro area, while the sector-level dataset (SHS-S) contains sector-level data for the main economic sectors in the economy, including banks. In our case, 86 banks have data in the SHS-G dataset, while for the remaining 53 banks (all LSIs), we rely on SHS-S at the country level. Our approach to the latter involves applying the reported change in market value relative to face value for bank bond holdings at the country level, to the holdings of individual banks.[6]

While SHS datasets include both the nominal/face and market value of bonds, they do not include the purchase price by the bank. Therefore, if the bank did not acquire the bond at origination, but did so on the secondary market, there may be a discrepancy between the reported nominal value in SHS (the face value of the bond at issuance) and the banks reported book value (market value at purchase date). This applies to bonds held at amortised cost only, since changes in prices of bonds held at fair value are reflected on banks' balance sheets. To counter this issue, we assume that the market value of banks' amortised cost bonds was equal to their book value prior to the shift in interest rates expectations.[7] Expectations of rising interest rates began to manifest at the longer end of the yield curve as early as the fourth quarter of 2021, therefore we focus on the change in bond prices from Q4 2021 up to the peak in bond yields observed in the third quarter of 2023.

Figure 4 plots the average revaluations of the bond holdings for our sample of banks. Figures are expressed as a share of banks' pre-rate-hike equity, so they can be interpreted as the change in net worth due to revaluations on interest-rate-sensitive balance sheet items.[8]The figure shows that the market values of bonds held at amortised cost and bonds held at fair value together on average decreased by more than 11% of pre-rate hike equity by September 2023, when euro area bond yields reached a local peak. In our calculations, banks' bond purchases since 2022 have partially offset the valuation effects on their existing holdings, supporting the overall value of their portfolios.[9] In addition, banks also appear to have reallocated the accounting classifications of their bond holdings, from fair-valued to amortised cost, as shown in Figure 5. This is likely in effort to protect their value of equity, albeit increasing latent risks via unrealised or *'hidden'* losses.

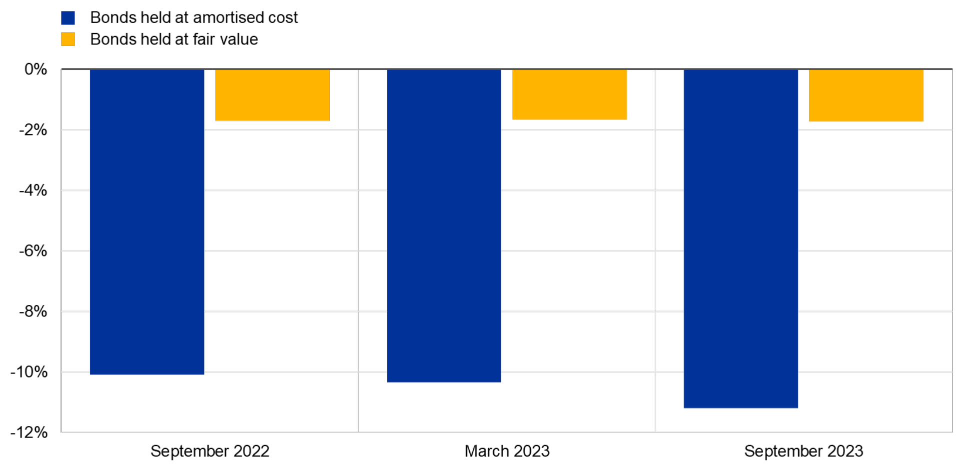
[6]For banks without data in SHS-G, in case the characteristics of their bond holdings differ substantially from that of the aggregate banking sector in their country (particularly relating to the average duration and issuer sector), their true valuations may differ from those used in our analysis. We are comforted by the fact that observed correlations on the ratio of market to nominal value of banks bond holdings among those reporting to SHS-G are very high, at 98 per cent.

[7]We believe this is a reasonable assumption given that bond yields remained low and stable for the 8 years preceding the 2022–2023 rate hike cycle.

[8]We use each bank's reported equity at end-2021, prior to the shift in market interest rate expectations, to avoid any fair-value adjustments that might have been applied to banks' balance sheet equity in 2022.

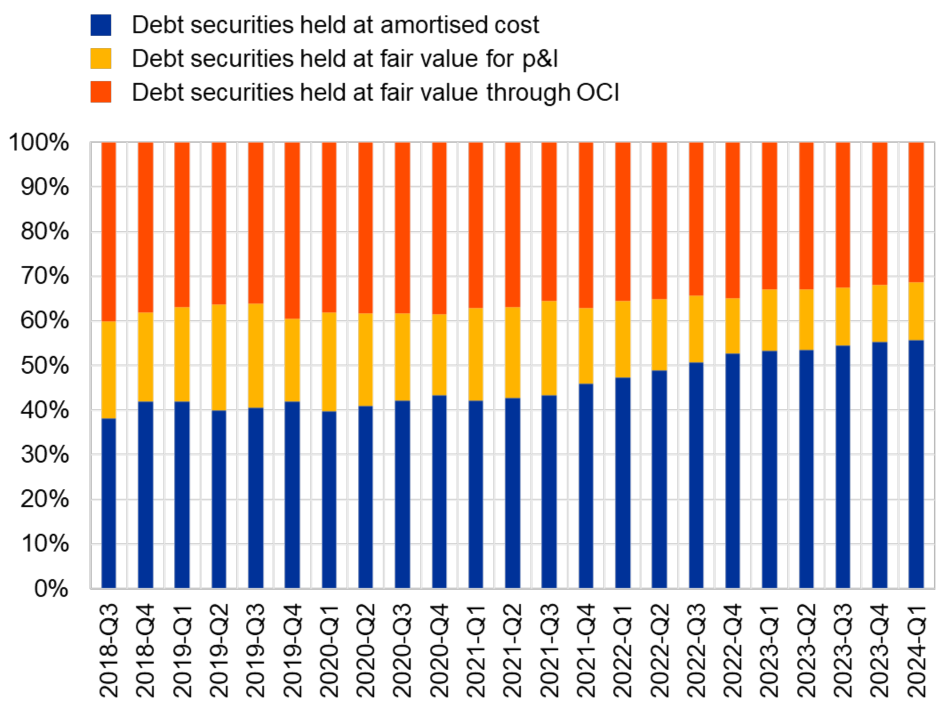
[9]According to our calculations, the positive offsetting value of bonds purchases was on average approximately 2% of equity by September 2023

**Figure 4: Change in valuations on banks bond holdings throughout the rate hike**




*Notes:* The y-axis shows the average bond revaluations as a share of pre-rate hike equity *Source:* ECB Securities Holdings Statistics - Group (SHS-G) and Sector (SHS-S).

**Figure 5: Accounting classification of bonds held by euro area banks**




*Notes:* In this figure we use the aggregate face value of bonds held by euro area banks with data available in SHS-G. *Source:* ECB Securities Holdings Statistics - Group (SHS-G) and Sector (SHS-S).

### Loan portfolios

We take the January 2022 loan book of each bank and split it into three portfolios: household mortgages, household other loans, and Non-Financial Corporation (NFC) loans.[10] For each portfolio, we record its total principal $L$, average coupon rate $\bar{r}$, and a weighted-average remaining interest rate fixation period $T$. Over these $T$ months, the portfolio continues to pay interest at $\bar{r}$. After $T$ months we assume the loans reprice to align with market conditions.[11] We value the resulting monthly cash flows under four distinct yield-curve snapshots (January 2022, September 2022, March 2023, and September 2023), letting $r_t^d$ denote the monthly discount rate in scenario $d$. The present value in scenario $d$ is:

$$NPV_d = \sum_{t=0}^{T-1} \frac{\text{CF}_t}{\left(q + r_t^d\right)^t}. \tag{6}$$

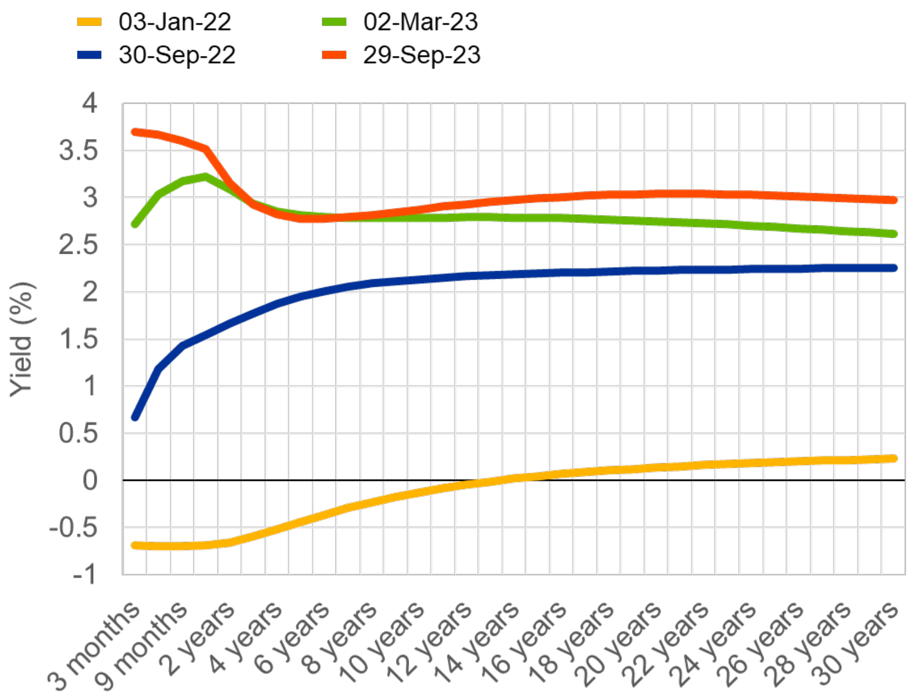
With $CF_t$ representing principal repayment and interest. Because the same loan terms $L$,$\bar{r}$, and $T$ are held fixed, any reduction in $NPV_d$ relative to $NPV_{\text{Jan22}}$ arises solely from the shift in the AAA yield curve at each subsequent date. Figure 6 shows the yield curves used for the discounting, at different dates. Longer fixation portfolios experience a greater present value decline, because they remain locked at the old rate for more months before repricing. There is a wide dispersion in average fixation duration on mortgages across euro area countries, ranging from an average of 6.3 years in Belgium, to less than 6 months in Latvia, highlighting the substantial cross-country differences in interest rate risk exposure on euro area banks loan portfolios.[12] Figure 7 shows the average decrease in value for loan books of euro area banks, split by loan category, at September 2022, March 2023 and September 2023. Losses on mortgage loans were the most substantial, and together with loans to NFCs and other loans to households losses, loan revaluations amounted to more than 15% of pre-rate hike equity by September 2023.

[10]We include all loans to households and non-financial institutions, which represent over 70 per cent of euro area banks total loan exposure. The remaining loan exposures of euro area banks include other banks (18 per cent), other types of financial institution (10 per cent), and loans to government (2 per cent). Loans extended to banks and other financial institutions typically feature shorter fixation periods and therefore are less prone to valuation effects due to interest rate risk.

[11]Given this assumption and given we are interested in the delta, comparing comparing $NPV_d$ to $NPV_{\text{Jan22}}$, no further discounted cashflow calculation is necessary after the fixation period is expired.

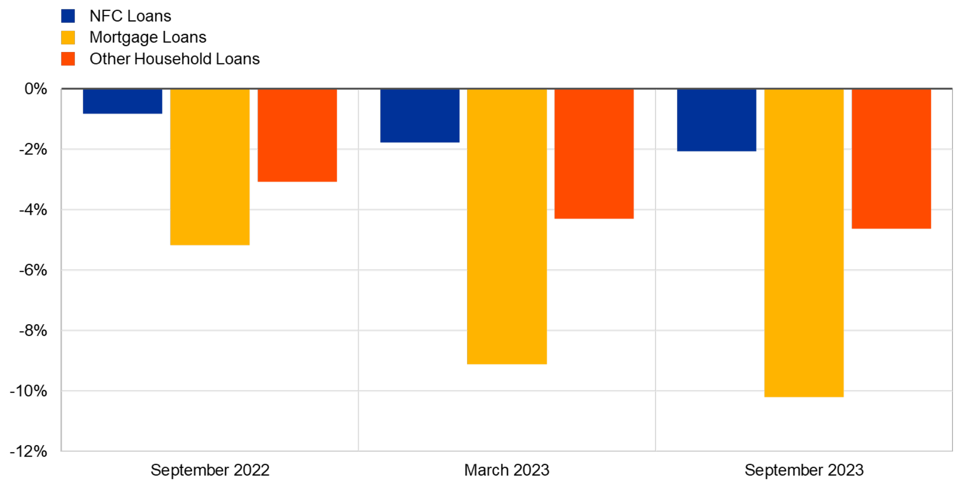
[12]For a breakdown of country-level fixation durations, see Appendix Figure 16.

**Figure 6: Yield curve on euro area AAA government bonds - selected dates**




*Notes:* We chose the yield curve at the beginning of the month of March 2023, since long-term rates shifted down sharply in mid-March following the collapse of SVB. *Source:* ECB Statistical Data Warehouse - yield curve data.

**Figure 7: Change in valuations on banks loan books throughout the rate hike**




*Notes:* The y-axis shows the average loan revaluations as a share of pre-rate hike equity. *Source:* AnaCredit, iBSI, iMIR.

### The deposit franchise and interest rate swap derivatives

We proceed to calculate the contribution from realised gains and losses due to the deposit franchise and the change in net contract value of interest rate swap derivatives over the rate hike period. We estimate the deposit franchise following Equation (1), which calculates the discounted value of the gap between market rates and weighted-average deposit rates for all deposit types (overnight and term) and all deposit counterparty sectors.[13] In our setting, in Equation (1), $t$ extends from the start of the rate-hike period to the reference date at which $NW_t^{\text{econ}}$ is measured. Since we are concerned with depositors' run incentives, this makes the important assumption that depositors consider the bank's realised cumulative franchise income, rather than a bank's hypothetical future income from the deposit franchise when deciding whether to run.[14] The pass-through of ECB policy rates to deposit rates has been more limited compared to tightening periods, as shown in Figure 8, which may be associated with higher levels of excess reserves in the system due to the substantial quantitative easing that took place in the years preceding the 2022–2023 interest rate rises(Messer and Niepmann, 2023).

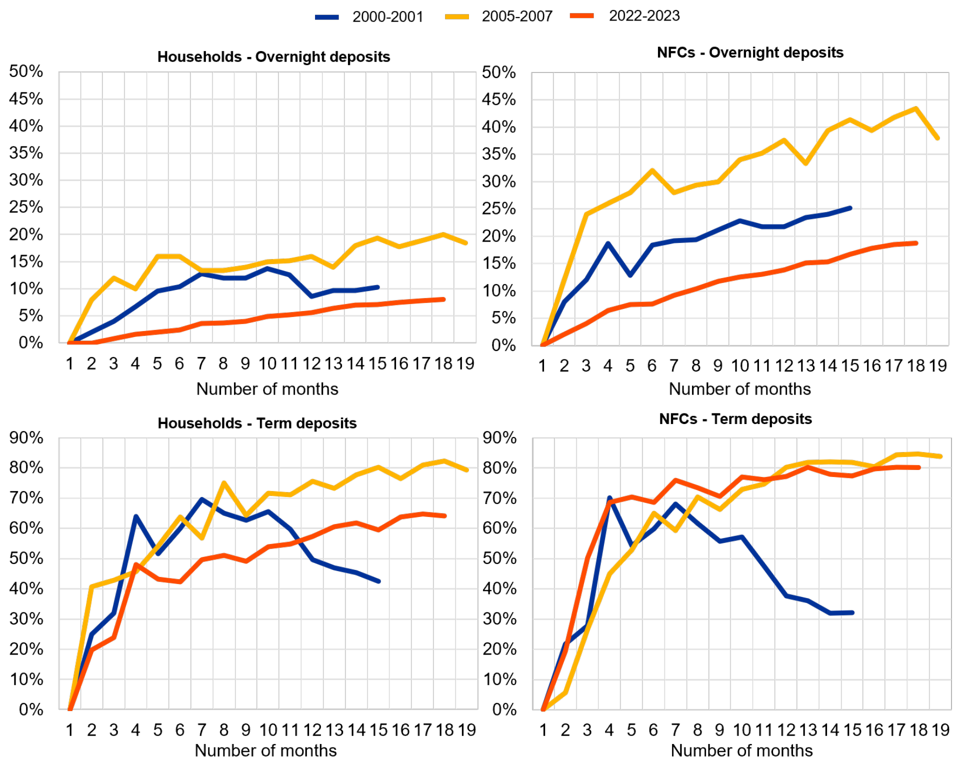
In our calculation of the deposit franchise, we assume a fixed cost covering administrative and operating expenses of 1% for all deposit types. This assumption is based on the average reported fixed costs by a large euro area commercial bank of 0.94, but is also in line with assumptions made in other similar papers.[15] For deposit volumes, we use detailed bank-sector-type level data from IBSI and for rates we use IMIR data at the same level. While the majority of our sample have observations in IMIR, some banks were missing from the IMIR dataset despite all banks being present in the IBSI dataset. For these cases, we used country-level averages of deposit rates at the sector-type level, applied to deposit volumes at the bank-sector-type level from the IBSI dataset.

[13] Since the data on monthly deposit rates covers household and NFC deposits only, we apply the deposit rates of NFCs to deposit volumes of other sectors when calculating the deposit franchise for these sectors (predominately non-bank financial institutions). The overall impact of this is small given the comparatively minor share these other sectors have in total deposits.

[14] Following Drechsler et al. (2021), the deposit franchise resembles an interest rate swap where the value of the fixed leg (operating costs) decreases relative to that of the floating leg (the spread between the market rate and the deposit rate paid by the bank) as interest rates rise.

[15] Santander 2024 Institutional Presentation and Drechsler et al. 2017.

**Figure 8: Cumulative pass-though of the ECB Deposit Facility Rate (DFR) to deposit rates of euro area banks in selected rate hike periods.**




*Notes:* The figure shows, since the beginning of each rate hike period, the cumulative change in the weighted average deposit rate divided by the cumulative change in the ECB Deposit Facility Rate.

*Source:* ECB Individual Interest Rate Statistics (IMIR) and ECB SDW.

### Interest rate swap derivatives

To assess the impact of interest rate changes on banks' net worth through their derivative positions, we consider changes in the net contract value of their interest rate swap positions. Specifically, we consider the difference between the average net contract value from the fourth quarter of 2021 and the average monthly values in September 2022, March 2023, and September 2023.[16] This method allows us to measure how fluctuations in interest rates have affected the banks' derivative portfolios over time. By using the actual changes in net contract value we implicitly include any behavioural responses by the bank in adjusting derivative positions dynamically over the rate hike, which is an advantage over studies that calculate hypothetical changes in derivative values based on banks' static

[16]Since the data are daily, monthly positions are an average across all days in the respective month

derivative positions.

We use European Market Infrastructure Regulation (EMIR) data, which includes detailed information such as the entities involved in the trade, product and underlying information, notional amounts, daily contract valuation, and margins, as well as various asset class-specific variables.

The change in a bank's net contract value on interest rate derivatives is simply calculated as:

$$\Delta\text{Net Contract Value} = \text{Net Contract Value}_{\text{d}} - \text{Net Contract Value}_{\text{2021Q4}} \quad (7)$$

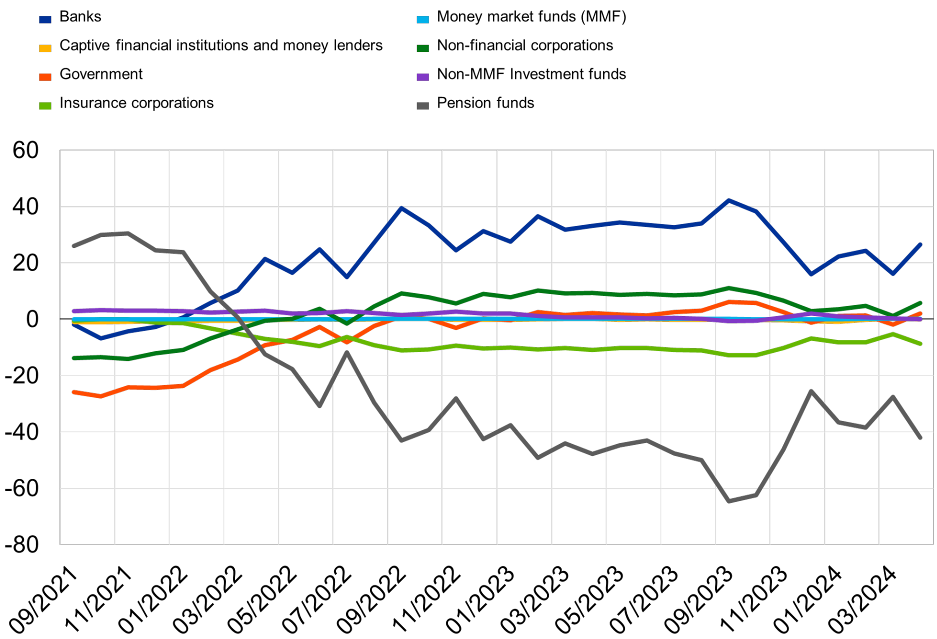
where $d$ is the reference date – either September 2022, March 2023, or September 2023. By calculating these changes, we capture the realised gains or losses on interest rate swap positions attributable to movements in market interest rates. This approach reflects the evolving market conditions and their direct effect on the valuation of the banks' derivative instruments during the specified periods, as well as the subsequent impact on their accounting net worth through the P&L.

It is also interesting to observe the counterparties across other economic sectors of banks' interest rate swap positions, which typically include insurance companies and pension funds. With their long-term liabilities, these entities usually prefer to receive fixed rates to match their expected outflows. Interest rate swaps allow these entities to align their interest rate exposures with their specific financial objectives, thereby facilitating a mutually beneficial transaction with the banks. Figure 9 shows the change in net contract value of various sectors in the euro area, including the banks in our sample. Over the period from 2021Q3 to 2023Q3, the net position of the banks in our sample grew by approximately €50 billion, as a result of the increase in market rates.[17] There is also a negative relationship between banks and insurance companies, suggesting insurers were behaving similarly to pension funds, although insurers positions appear much smaller. Finally, Figure 10 shows the average changes in value of both the deposit franchise and IRS

[17]The strong negative correlation between euro area pension funds' net contract value and that of banks in our sample confirms our prior expectation regarding the counterparties involved in transactions with banks, with pension funds losing over €90 billion in contract value since 2021Q3.

derivatives as a share of pre-rate hike equity across the reference dates. While the hedging contribution of derivatives is immediate, adjusting with the yield curve and increasing to a peak of just under 7% of pre-rate hike equity, the contribution of the deposit franchise grows over the rate hike. This is in line our approach of including the deposit franchise hedge on realised gains only, rather than their hypothetical future value.[18]

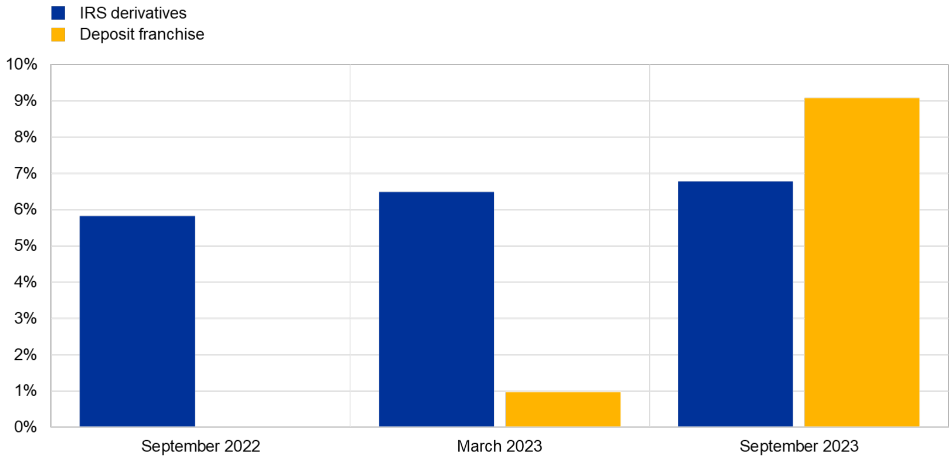
**Figure 9: Change in net contract value of interest rate swaps for sectors in the euro area**




*Notes:* : Net contract values are calculated at the institution level as the aggregate positive positions on interest rate swaps minus the aggregate negative positions. Net contract values are net at the sector level, so a gain in one bank will be offset by a loss in another in the figure. *Source:* European Market Infrastructure regulation (EMIR) data.

[18]As previously mentioned, this is akin to treating deposits like an interest rate swap.

**Figure 10: Change in net contract value of interest rate swaps and contribution from the deposit franchise**




*Notes:* : The y-axis shows the contributions from IRS derivatives and the deposit franchise as a share of pre-rate hike equity. *Source:* European Market Infrastructure regulation (EMIR) data, iMIR, iBSI, AnaCredit.

# 6 Results

In this section we present the results of our calculations for interest-rate induced asset revaluations, how they relate to deposit run vulnerabilities and the overall hedging behaviours of euro area banks. All results are expressed as a share of banks' pre-rate-hike equity, showing the contribution of each interest rate-sensitive balance sheet item to economic net worth. We begin by discussing our estimates of the change in economic net worth observed across euro area banks at two dates during the rate cycle, at March and September 2023, including anonymised bank-level results.

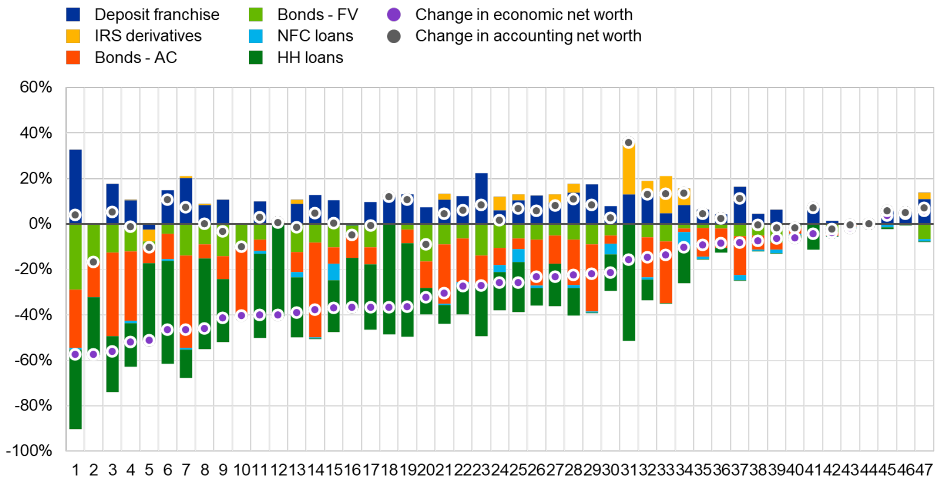
## 6.1 Overview of bank-level balance sheet revaluations

On average, the decline in economic net worth for all banks amounted to roughly 24% in March 2023 and 19% in September of the same year. Although unrealised losses reached their peak in September - mostly driven by a reduction in the value of household loans - the hedges provided by IRS derivatives and the deposit franchise offset the decline in asset valuations on average by 46%. Over the course of the rate hike - up to September 2023 - taking the average across all banks, the deposit franchise hedged 27% of asset revaluations, while IRS derivatives hedged the remaining 19%, a figure comparable, but slightly lower, than the 25% estimated by Hoffmann et al. (2019).

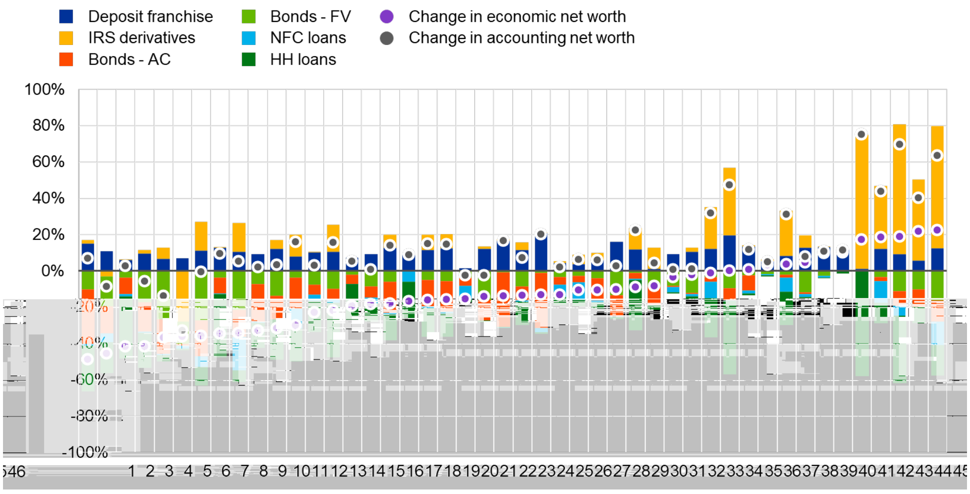
Figure 11 shows anonymised bank-level results on the revaluations of estimated balance sheet positions over the full rate hike to September 2023. Banks are split in terciles according to size (total assets) and ordered based on change in economic net worth, from the most negative to the most positive.

We find significant variation in the cross-sectional impact of interest rates on the economic net worth of euro area banks, suggesting a large degree of heterogeneity in interest rate risk exposure across euro area banks. About one-in-six banks in our sample increased its net worth throughout the latest rate hike, lower than the one-in-two figure estimated by Hoffmann et al. (2019), perhaps due to the larger interest rate shock experienced by banks in our paper. As pointed out by Hoffmann et al. (2019), these results indicate that banks do not completely match interest rate sensitivities on their assets and liabilities, as instead argued in the frameworks presented by Hellwig (1994) and Drechsler (2021). Intuitively in our results, smaller banks appear to have experienced the largest losses on their household mortgage portfolios, and appear to have more limited use of interest rate swap derivatives. Larger banks instead exhibited a higher degree of hedging activity through interest rate swap (IRS) derivatives, and experienced proportionally greater losses in their bond portfolios relative to smaller banks. We explore these results in more detail in the following sections.

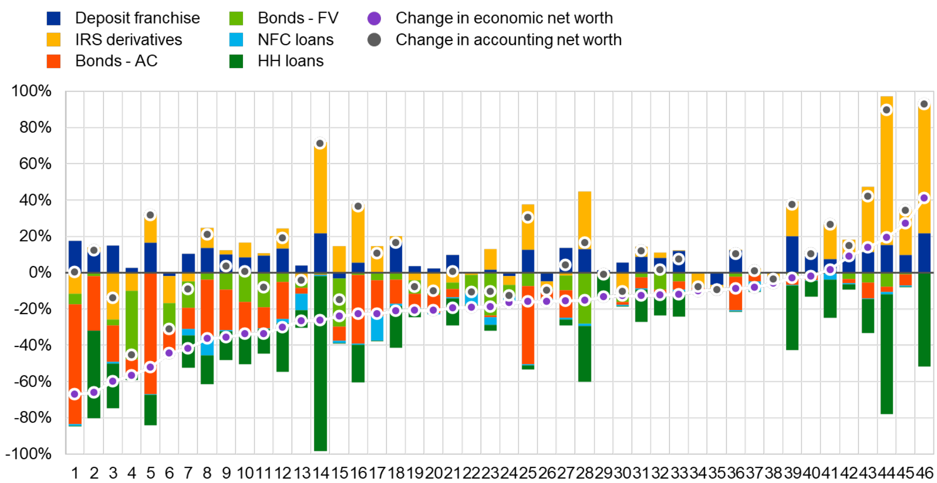
**Figure 11: Balance sheet revaluations as a share of pre-rate hike net worth, split by bank size**




(a) Small




(b) Medium

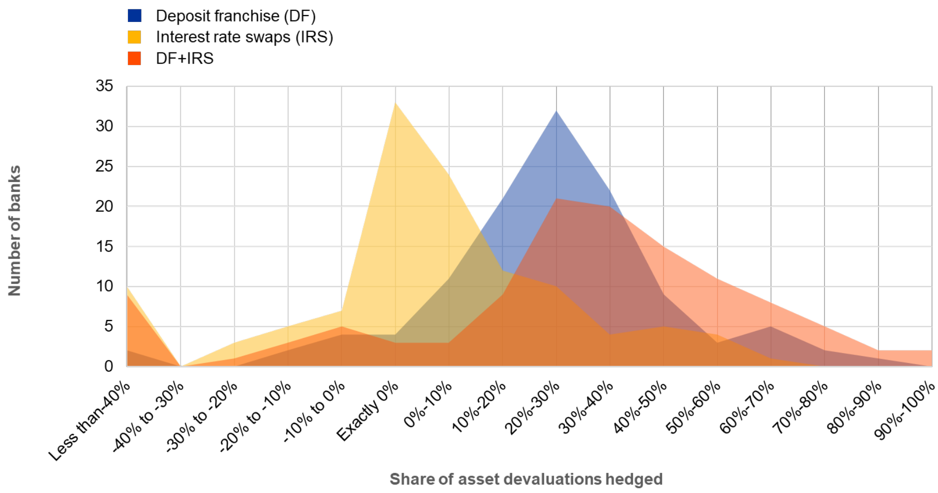



(c) Large

*Notes:* The figure shows revaluations for banks split by size tercile based on total assets in 2023. *Source:* Various, as discussed throughout the text.

Next we consider the hedging role played by the deposit franchise and interest rate swap derivatives. Figure 12 illustrates the extent to which the decline in asset values - unrealised losses plus valuation changes in fair-valued bonds - was offset by the deposit franchise and IRS derivatives, both individually and in combination, for banks that experienced a reduction in economic net worth by September 2023. The chart displays the number of banks whose hedging of asset revaluations - via the deposit franchise, IRS derivatives, or their combination - corresponds to each percentile bucket shown on the $x$-axis. For this set of banks, we find that the deposit franchise hedged between 10% and 40% of interest rate–induced asset revaluations in most cases, while IRS derivatives accounted for a hedge of between 0% and 30% of these revaluations for the majority of banks. When combined at the bank level, the deposit franchise and IRS derivatives jointly hedged between 10% and 70% of interest rate–induced asset revaluations for the majority of banks.

**Figure 12: Share of asset devaluations hedged by the deposit franchise and IRS derivatives at the bank level**




*Notes:* : The x-axis shows the share of asset devaluations hedged through both the deposit franchise and IRS derivatives. The y-axis shows the number of banks for each hedging bucket *Source:* Various, as discussed throughout the text & own calculations.

Our findings support the view that such mismatches in banks' balance sheets drive the demand for interest rate swaps as a hedging tool to reduce interest rate risk. This suggests that the exposure of euro area banks to interest rate risk is fundamentally different from that of U.S. banks, which instead have been found to make limited use of interest rate swap derivatives for hedging purposes (Begenau et al. (2015), McPhail et al. (2023)). As argued by Hoffmann et al. (2019), one potential explanation for this discrepancy lies in the degree of heterogeneity in loan-fixation conventions at the country level in the euro area, whereas US banks appear to have broadly similar maturity mismatches - largely shaped by the widespread use of long-term fixed-rate mortgages. This heterogeneity allows the financial system to absorb the hedging demands of those banks with larger duration gaps and create risk sharing through off-balance sheet exposures. As shown in our empirical section, we find pension funds to be the largest counterparty sector for banks' IRS positions throughout the latest rate hike.

Given the significant variation in the cross-section of our results, in the following subsection we consider how our estimates of unrealised losses and hedging positions relate to various bank-level characteristics. Specifically, we consider banks' business models, fixation durations of mortgage-portfolios[19], and bank size, and we assess how these impact banks' hedging positions and asset devaluations. We find that banks with longer fixation durations and those classified as retail and consumer credit lenders are associated with larger estimates of both unrealised losses and hedges.[20] Following this, we consider the vulnerability of our sample of banks to stylised deposit run scenarios, and finally we use regression analysis to predict the drivers of banks' deposit rates over the rate-hike period, linking to our theoretical framework.

## 6.2 Bank-level determinants of hedging behaviour and unrealised losses

Given the large cross-sectional variation we find in the exposure to interest rate risk measured by the decline in economic net worth, we proceed to investigate how various bank-level characteristics are associated with both unrealised losses and the contribution of hedging. We regress bank-level mortgage fixation durations, banks' business models and bank size (as the log of total assets) on both unrealised losses and hedges. Hedges are

[19] As discussed earlier in the paper, we estimate mortgage fixation durations at the bank-level, using iBSI and iMIR combined with ESRB confidential data on household mortgages.

[20] For descriptive purposes, Table 8 in the Appendix shows results aggregated by bank size, business model and mortgage fixation duration, presented in terms of averages and standard deviations across each group.

calculated as the contributions of the deposit franchise and IRS derivatives to economic net worth, while unrealised losses are equal to the contibutions of loan revaluations together with those relating to bonds held at amortised cost. They are both expressed as a share of equity, and calculated using the reference date of September 2023.

Table 5 presents our regression results. Across all regression specifications for hedges (*Hdg.*) and unrelised losses (*Unr. loss*) the coefficients of our predictors have the same direction, corroborating our hypothesis that banks with higher unrealised losses tend to hedge more. As expected, we find that banks with medium- and long-term mortgage fixation durations are associated with higher levels of both unrealised losses and hedging positions compared to those with short fixation durations. This corroborates the view that banks with longer-duration assets relied more heavily on the hedges provided by both the deposit franchise and IRS derivatives. Similarly, banks that are Retail/Consumer Lenders have larger unrealised losses (c. 16% larger as a share of pre-rate hike equity) and also tend to hedge more compared to G-SIBs (c. 18% larger hedge positions as a share of pre-rate hike equity), even after controlling for bank size. This is also true when comparing diversified/corporate banks to G-SIBs, although the coefficient on unrealised losses is not significant while the coefficient on hedging is significant (with diversified/corporate banks hedging c. 14% larger when compared to G-SIBs).

The coefficient for total assets in equation (5) is positive (although not particularly significant) suggesting that larger banks hedge more than smaller banks, which appears at first to contradict our findings that G-SIBs hedge less. For this reason, in the final two regression specifications (7) and (8), we introduce an interaction term between the centered log of assets and business model categories, to account for potential heterogeneity in the effect of firm size across business models.[21] The main effect of the log of assets (centered) is now more negative and statistically significant at the 5% level (– 3.1%), implying that among firms in the reference business model (G-SIBS), larger asset size is associated with a reduction in hedging, and - to a lesser extent - also to a reduction in unrealised losses. For Diversified/Corporate banks, the interaction coefficient is 4.7% (p = 1.17%). For Retail and Consumer Credit Lenders, the coefficient is even higher at 6.5% (p = 0.7%). In other words, for Diversified/Corporate and Retail/Consumer Lenders, a

[21] We center the log of assets for better interpretability of coefficients.

larger asset base is associated with more hedging activity, whereas for G-SIBs, larger size predicts more limited hedging.[22] In Appendix 17, we plot the predicted effect of bank size on hedges (equation 7) by different business models, indicating that the heterogeneous effect of business model on hedges, depends on bank size. We find the significance of this interaction term is driven by interest rate swap derivatives, rather than the deposit franchise. We find that smaller institutions engage less in effective hedging strategies with derivatives within both the Diversified/Corporate and Retail and Consumer Credit cohorts, in line with findings from the ECB Financial Stability Review (ECB, 2022; 2023). In contrast, the largest universal and G-SIB banks appear to have made less use of interest rate swap derivatives relative to their equity. Other studies have found that the extensive market access and diversified operations of G-SIBs may incentivise greater engagement in risk-bearing activities, potentially resulting in a reduced reliance on interest rate risk hedging strategies (Esposito, 2015).[23] Furthermore, their function as market makers, combined with the scale of exposures they may seek to hedge, might introduce frictions in their appetite and ability to find suitable counterparties in the interest rate swap market.

[22] This effects persists also after controlling for unrealised losses.

[23] See Ballester (2009) for the relationship between too-big-to-fail banks and moral hazard incentives to risk taking.

**Table 5: Regression Results: Bank-level characteristics and Hedges/Unrealised Losses (% Equity)**

| | (1) Hdg. | (2) Unr. loss | (3) Hdg. | (4) Unr. loss | (5) Hdg. | (6) Unr. loss | (7) Hdg. | (8) Unr. loss |
|---|---|---|---|---|---|---|---|---|
| Long | 0.0876* | 0.147*** | 0.107** | 0.171*** | 0.0917* | 0.165*** | 0.0956* | 0.162*** |
| | (0.0469) | (0.0464) | (0.0512) | (0.0485) | (0.0498) | (0.0482) | (0.0493) | (0.0485) |
| Medium | 0.0890*** | 0.151*** | 0.0919*** | 0.157*** | 0.0888*** | 0.156*** | 0.0958*** | 0.157*** |
| | (0.0275) | (0.0347) | (0.0280) | (0.0356) | (0.0275) | (0.0354) | (0.0270) | (0.0348) |
| Short | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (.) | (.) | (.) | (.) | (.) | (.) | (.) | (.) |
| Div./Corp. | | | 0.0872* | 0.0497 | 0.144** | 0.0732 | -0.0301 | -0.0542 |
| | | | (0.0508) | (0.0428) | (0.0681) | (0.0618) | (0.0707) | (0.0741) |
| Ret./Cons.Crdt | | | 0.100** | 0.125*** | 0.179** | 0.157** | 0.0168 | 0.0484 |
| | | | (0.0489) | (0.0430) | (0.0806) | (0.0747) | (0.0736) | (0.0785) |
| Uni/GSIB/IBk | | | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | (.) | (.) | (.) | (.) | (.) | (.) |
| log_assets | | | | | 0.0191* | 0.00788 | | |
| | | | | | (0.0108) | (0.0114) | | |
| log_assets_c | | | | | | | -0.0311** | -0.0299* |
| | | | | | | | (0.0146) | (0.0163) |
| Div/Cp×logAsC | | | | | | | 0.0470** | 0.0178 |
| | | | | | | | (0.0193) | (0.0190) |
| Ret/Cn×logAsC | | | | | | | 0.0652*** | 0.0660*** |
| | | | | | | | (0.0239) | (0.0245) |
| UniGB×logAsC | | | | | | | 0 | 0 |
| | | | | | | | (.) | (.) |
| Constant | 0.0936*** | 0.171*** | 0.00281 | 0.0752 | -0.370 | -0.0785 | 0.116* | 0.185*** |
| | (0.0167) | (0.0286) | (0.0482) | (0.0475) | (0.234) | (0.235) | (0.0639) | (0.0687) |
| R-squared | 0.0414 | 0.119 | 0.0659 | 0.175 | 0.0899 | 0.179 | 0.116 | 0.227 |
| MSE | 0.190 | 0.182 | 0.189 | 0.177 | 0.187 | 0.177 | 0.186 | 0.173 |

Standard errors in parentheses, robust to heteroskedasticity. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. N=139 for all models.

*Note:* Abbreviations defined as follows: Div./Corp. = Diversified/Corporate; Ret./Cons.Crdt = Retail and Consumer Credit Lenders; Uni/GSIB/IBk = Universal, G-SIBs, and Investment Banks; logAsC = log_assets_c, Div/Cp = Diversified/Corporate, Ret/Cn = Retail/Consumer, UniGB = Universal/GSIBs). Each column represents a separate regression model, with hedges (columns 1, 3, 5, and 7) and unrealised losses (columns 2, 4, 6, and 8) as dependent variables. Hedges are calculated as the contribution to economic net worth from the deposit franchise and IRS derivatives, while unrealised losses include revaluations from loans and bonds held at amortised cost. Both are expressed as a share of pre-rate hike equity, and calculated at September 2023. Independent variables include MTG duration categories, bank business models, bank size (log of total assets), and interaction terms between banks' bus. models and size. "Short" is attributed to banks with a remaining fixation duration of less than 2 years, "Medium" to banks between 2 and 5 years, and "Long" for banks above 5 years. Short Duration MTG and Universal, G-SIBs, and Investment Banks serve as reference categories. R-squared and Mean Squared Error (MSE) statistics are provided for each model.

## 6.3 Deposit run scenarios and unrealised losses

In this section, we provide an overview of the implications that asset revaluations have for vulnerabilities to potential deposit runs by uninsured depositors. Since we consider a bank to be mark-to-market insolvent when the market value of its equity capital is fully depleted (i.e., when its economic net worth becomes negative), a simple insolvency threshold $I_{i,t}$ for defining mark-to-market insolvency following a deposit run is given by

$$I_{i,t} = E_{i,t_0} + \Delta ENW_{i,t} - \theta_{i,t} D^u_{i,t}. \tag{8}$$

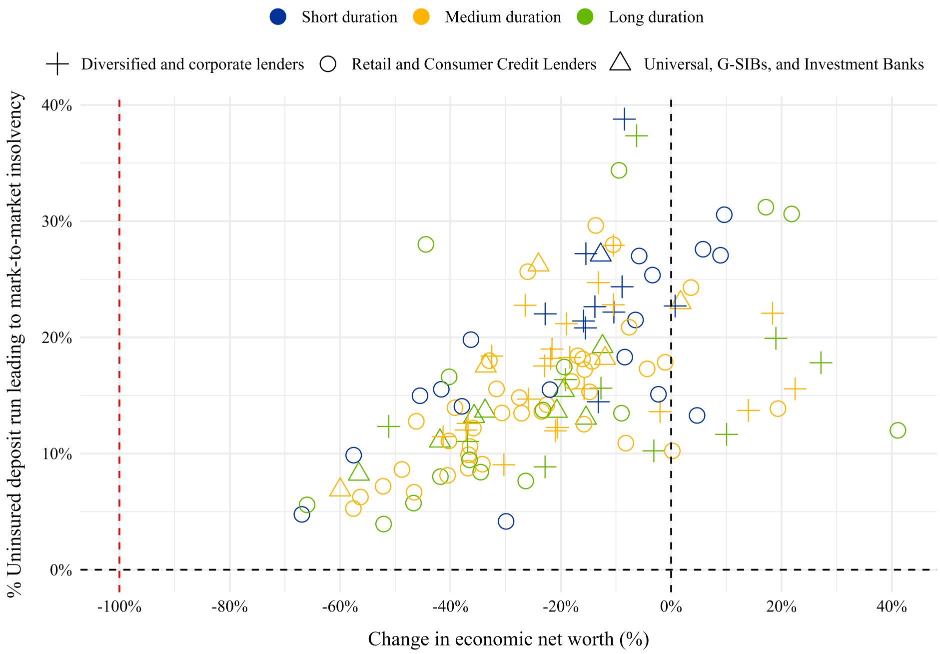
In this expression, $E_{i,t_0}$ denotes the pre-rate equity of bank $i$ at time $t_0$; $\Delta ENW_{i,t}$ is the change in economic net worth for bank $i$ at time $t$ induced by interest rate changes; $\theta_{i,t}$ represents the share of uninsured depositors running on the bank; and $D^u_{i,t}$ corresponds to the total amount of uninsured deposits at time $t$ for each bank.

In Figure 13 we illustrate bank-level vulnerability by plotting the change in economic net worth (x-axis) against the share of uninsured deposits that would need to run for a bank to become insolvent on a mark-to-market basis (y-axis). The y-axis is calculated as the ratio of economic net worth to the volume of uninsured deposits.[24] We do this exercise using our estimates for both September 2023 13a and March 2023 13b. Uninsured deposits were estimated using bank-level deposit volumes and country-level data on the share of uninsured deposits provided by the European Banking Authority (EBA).[25] As expected, across both reference dates, we find a positive relationship between the change in economic net worth and the share of uninsured depositors running on the bank which would lead the bank to mark-to-market insolvency. Euro area banks appeared most vulnerable to deposit runs in March 2023, where six banks would have become insolvent on a mark-to-market basis (y-axis $< 0$) were they to experience a 5% run of uninsured deposits, versus three banks in September 2023.

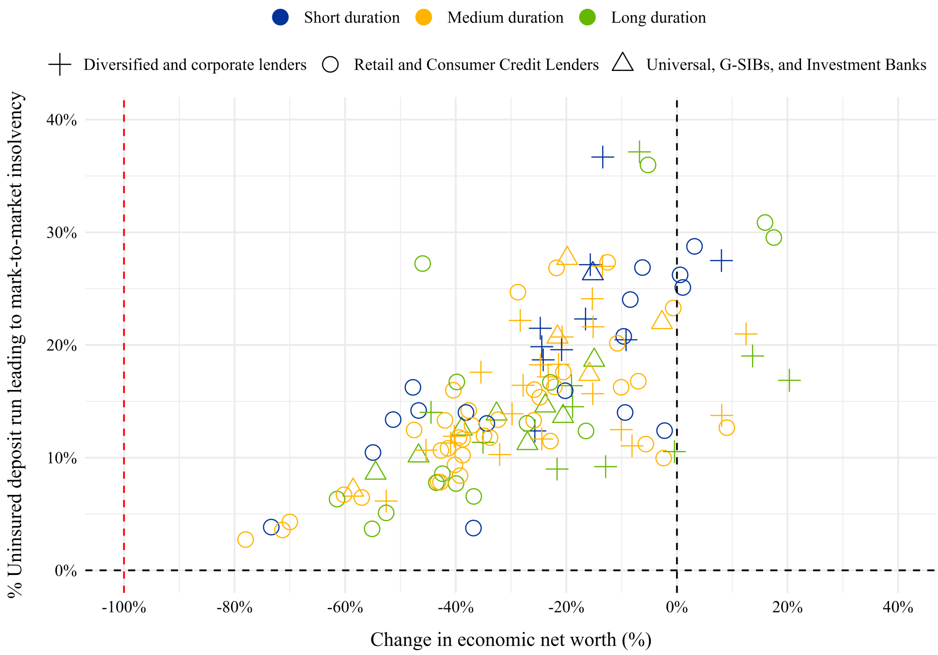
[24] To understand this, consider a bank with economic net worth at the reference date of 50 and uninsured deposits of 200. It would take a run of uninsured deposits of 25% to wipe out the remaining economic net worth of the bank.

[25] Figure 18 plots country-level figures.

## Figure 13: Change in economic net worth and % of uninsured depositors running in order to make a bank mark-to-market insolvent




**(a) September 2023**



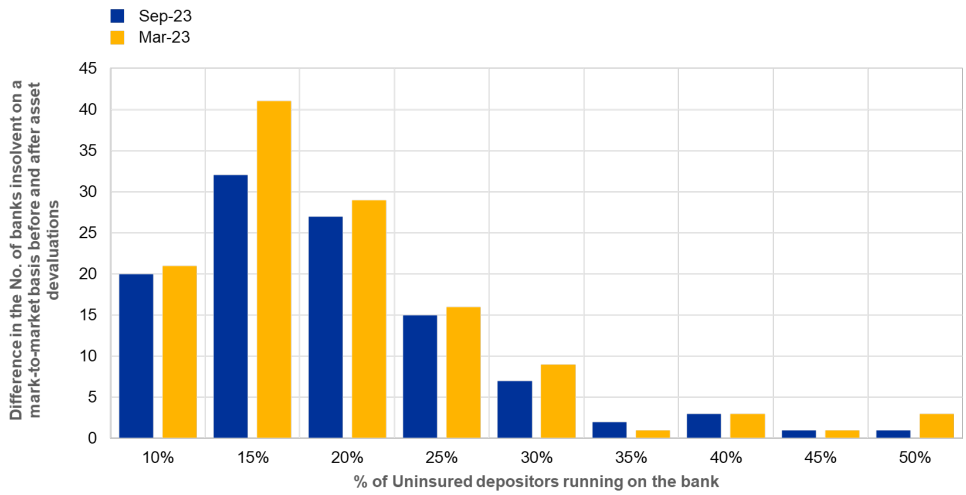

**(b) March 2023**

*Notes:* The figures show, on the x-axis, the change in economic net worth as of September 2023 as a fraction of banks pre-rate hike net worth. The y-axis shows the share of uninsured deposits outflows that would have caused the bank to be insolvent on a mark-to-market basis.

*Source:* Various, as discussed throughout the text & own calculations.

The greater vulnerability of banks to runs on uninsured deposits in March versus September 2023 occurs despite unrealised losses being larger in the latter month. It arises because offsetting gains on the deposit franchise and interest rate swap derivatives increased over time, and were only partially realised in March 2023. To further illustrate this mechanism and the relevance of asset revaluations for deposit run vulnerability, Figure 14 plots the change in the number of banks reaching mark-to-market insolvency in September 2023 and March 2023 compared to the pre-hike scenario for various run sensitivities. Results demonstrate that asset revaluations dramatically increase banks vulnerability to runs: under a 10% run of uninsured deposits, 20 (21) additional banks would became mark-to-market insolvent in September 2023 (March 2023) relative to the pre-hike position. It is important to note that these figures do not account for the systemic effect whereby depositors reallocate their funds from an insolvent bank to a solvent bank, nor do they incorporate depositors' stickiness or uncertainty - two key factors in our theoretical framework. In the following subsection, we attempt to tie our theoretical insights from Section 3 to observed adjustments in deposit rates by banks using regression analysis.

**Figure 14: Difference in the number of mark-to-market insolvent banks at September 2023 and March 23 vs. pre-rate hike, according to the share of uninsured depositors running on the bank**

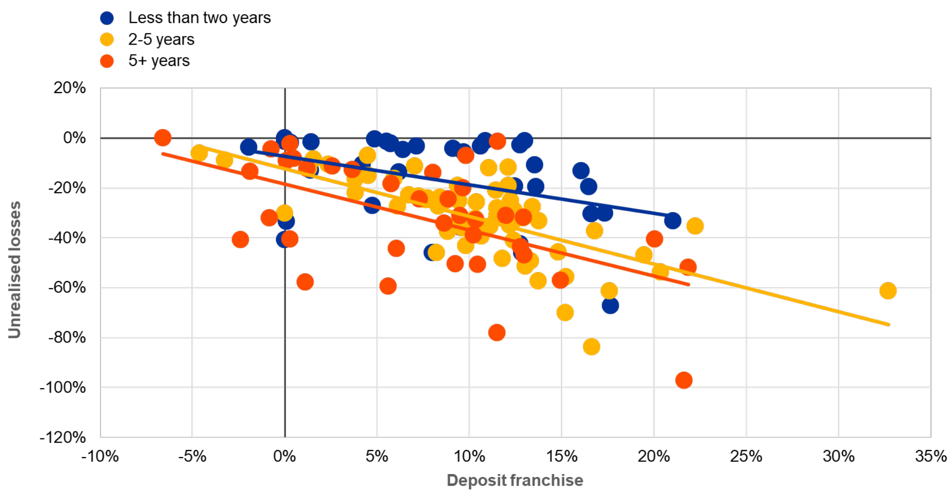



*Notes:* : The x-axis shows the share of uninsured deposits needed to reach mark-to-market insolvency, while the y-axis denotes the number of banks failing for a given share of uninsured deposits running on the bank. *Source:* Various, as discussed throughout the text & own calculations.

# 7 Regression analysis of deposit-rate changes

In this section we tie our empirical results to the theoretical framework of Section 3 by attempting to explain changes in deposit rates using bank and country-level variables. To begin, Figure 15 shows the correlation between the deposit franchise value and unrealised losses at September 2023 split by bank-level mortgage duration. We observe that banks with the largest realised gains from the deposit franchise over the rate hike period are also those that carried the largest unrealised losses on their assets. This pattern is in line with studies suggesting that banks deliberately match the long positive duration of fixed-rate assets with the negative duration of a sticky deposit base. This finding holds for banks across all bank-level mortgage fixation cohorts (short, medium, long), suggesting that although euro area banks are bound by national mortgage fixation practices, they still appear to match the gains on the deposit franchise to their unrealised losses (perhaps by acquiring longer-duration bonds or longer fixation loans relative to other domestic banks).

**Figure 15: Unrealised losses and deposit franchise**




*Notes:* : The x-axis shows the deposit franchise as a share of pre-rate hike equity. The y-axis shows unrealised losses as a share of pre-rate hike equity. Banks are split by bank-level mortgage fixation durations, according to the following brackets: <2 years = Short duration; 2-5 years = Medium duration; +5 years = Long duration *Source:* Various, as discussed throughout the text & own calculations.

By contrast, Appendix Figure 19 documents no systematic link between unrealised losses and the change in deposit volumes over the rate hike, confirming that euro-area banks deposit franchise was driven by adjustments in deposit rates, rather than deposit volumes. The stability of deposit volumes also reflects the fact that, according to our estimates, no bank in the sample experienced negative economic net worth.[26] Furthermore, it is likely that other factors discussed in our theoretical framework, such as high depositor stickiness ($\gamma$) and relatively low levels of depositor uncertainty ($\sigma_{ENW}$) regarding banks' true financial health, helped to keep more vulnerable banks away from a 'run equilibrium'.

This stability in deposit volumes afforded banks strategic leeway. First, banks with large unrealised losses had less pressure to raise deposit rates, helping to mitigate pressure on their margins during the tightening cycle. Second, it supports the notion, following Drechsler et al. (2021) and Kulkarni et al. (2022), that banks strategically manage asset duration risk, leveraging their understanding of deposit base sensitivity (influenced by factors like $\gamma$, alternative rates $r_{alt}$, and uncertainty $\sigma_{ENW}$) to use sticky deposits as a natural hedge. In this way, banks align their asset duration with the perceived stability and low rate-sensitivity of their deposit base, which is somewhat determined by factors outside of their control.[27] In theory, this strategic asset-liability management, aiming to match durations, can be further supplemented by the use of interest rate swap derivatives to hedge any residual duration gaps that arise from imperfect matching, which we test for by regression analysis in this section.

The following regression aims to explain banks' deposit pricing decisions. The explanatory variables are motivated by the channels formalised in the theoretical framework of Section 3. In line with Figure 15, we expect that unrealised losses will have a negative relationship with the change in banks' deposit rates, since banks that have extended the duration of their assets do so in the knowledge that their deposits are sufficiently sticky to provide an adequate hedge against these losses. In addition we include the share of household overnight deposits as a proxy for depositor inertia ($\gamma$) since households are found to display higher levels of inertia than other types of depositors. The share of uninsured deposits measures the fraction of deposits held by depositors who care about the probability of insolvency; as we demonstrate in the theoretical framework, their required compensation

[26] The levels of economic net worth depletion were on average far lower than other estimates released for the U.S. banking system.

[27] Including cultural factors, financial literacy, deposit composition, competitive forces and market power

rises when economic net worth is depleted. Domestic market power is proxied by the Herfindahl–Hirschman Index (HHI) and should allow banks to keep a wider spread between market and deposit rates.[28] Conversely, realised gains on interest-rate-swap (IRS) positions represent formal hedging of the residual duration gap and could, in principle, relax the need to contain deposit costs, or could be used to hedge duration risk in the absence of a sufficiently large deposit franchise. A higher non-performing-loan (NPL) ratio may limit the duration banks take on on their assets side or force a bank to economise further on the rate it pays, and may therefore be associated with a smaller increase in deposit rates. Finally, liquid-asset holdings, bank size, business-model dummies and the average remaining fixation period of mortgage loans are included as controls for funding-model heterogeneity and any further differences in asset–liability management across bank types.

Formally we estimate the change in each bank's average deposit rate between June 2022, the month preceding the first ECB increase in the deposit facility rate, and September 2023, when euro-area market rates reached their peak. Three complementary specifications are reported in Table 6. The baseline pools all observations and reports heteroskedasticity-consistent (HC) standard errors. Because some regressors vary only at the national level we replicate the baseline with standard errors clustered by country using the CR2 small-sample correction of Jackson (2020). In a third specification we include country fixed effects; doing so absorbs all level differences across jurisdictions, including the HHI and the uninsured deposit share, so these two variables are omitted.

Each of the three specifications largely align with our expectations. Firstly, a ten-percentage-point increase in unrealised losses relative to equity is associated with a roughly ten-basis-point smaller rise in the average deposit rate, corroborating the idea that banks which leverage the negative duration of stickier deposits to extend asset duration subsequently avail of that funding advantage when rates rise. Household overnight deposits exert a similarly strong dampening effect: a ten-percentage-point larger share is linked to a twenty-basis-point smaller rate change, in line with the prediction that a more inert depositor base accepts lower remuneration. By contrast, a higher fraction of uninsured deposits pushes rates up, indicating that banks must compensate more run-sensitive creditors when latent solvency risk increases, although this result is not significant in the version with clustered standard

[28] We take country-level HHI figures from the ECB Statistical Data Warehouse - Banking Structural Statistical Indicators (SSI).

**Table 6: Regression of deposit rate changes on bank characteristics**

| | Spec 1: Full (HC) | Spec 2: Full (Clust.) | Spec 3: Country FE (HC) |
|---|---|---|---|
| Constant | $1.07^{*}$ | $1.07^{**}$ | $2.07^{***}$ |
| | (0.64) | (0.53) | (0.58) |
| Unrealised loss / equity | $-1.04^{***}$ | $-1.04^{***}$ | $-0.86^{**}$ |
| | (0.26) | (0.32) | (0.34) |
| H'hold ON dep / total dep | $-2.08^{***}$ | $-2.08^{***}$ | $-2.24^{***}$ |
| | (0.25) | (0.18) | (0.30) |
| HHI | $-1.88^{*}$ | $-1.88^{**}$ | |
| | (1.06) | (0.87) | |
| IRS change / equity | 0.10 | 0.10 | 0.22 |
| | (0.20) | (0.17) | (0.20) |
| Uninsured dep / total dep | $1.13^{*}$ | 1.13 | |
| | (0.59) | (0.70) | |
| NPL ratio | $-2.49^{***}$ | $-2.49^{***}$ | $-1.91^{***}$ |
| | (0.70) | (0.60) | (0.71) |
| Liquid assets / total assets | −0.15 | −0.15 | −0.10 |
| | (0.27) | (0.32) | (0.38) |
| Log(assets) | 0.04 | $0.04^{**}$ | $0.04^{*}$ |
| | (0.03) | (0.02) | (0.03) |
| Bus. model: Diversified/corp | 0.11 | 0.11 | 0.04 |
| | (0.20) | (0.09) | (0.21) |
| Bus. model: Retail/consumer | $0.47^{**}$ | $0.47^{***}$ | 0.32 |
| | (0.21) | (0.11) | (0.24) |
| Fixation length: Medium | $-0.26^{**}$ | $-0.26^{**}$ | $-0.37^{**}$ |
| | (0.11) | (0.12) | (0.17) |
| Fixation length: Long | −0.25 | $-0.25^{*}$ | −0.21 |
| | (0.17) | (0.14) | (0.26) |
| $R^2$ | 0.66 | 0.66 | 0.73 |
| Adj. $R^2$ | 0.63 | 0.63 | 0.66 |
| Num. obs. | 137 | 137 | 137 |

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

**Note:** Heteroskedasticity-robust standard errors are reported in parentheses. Variance inflation factors (VIFs) were tested for multicollinearity and are presented in Appendix Table 9. H'hold ON Dep stands for household overnight deposits and is included as a ratio to total deposits. The base category for categorical variable Bus. model is *GSIBs and investment banks.* The base variable for Fixation length is *short.*

errors. Domestic market concentration is statistically significant in both specification 1 and 2 with a negative coefficient demonstrating that higher levels of concentration in domestic banking sectors enables banks to keep deposit rates lower, availing of their greater market power. Conversely, this result implies that banks operating in more competitive domestic banking sectors raised deposit rates by more, presumably to prevent depositors from leaving to alternate bank paying offering depositors a larger return.

Realised gains on interest-rate swaps are not statistically significant across any regression specification, implying that explicit derivative hedging does not substitute for, or crowd out, hedging using deposits. The coefficient on the NPL ratio is negative and significant, which is consistent with the notion that banks with lower-quality loan portfolios may be more reluctant to raise rates. Business-model dummies show that retail-oriented lenders increase rates by more than GSIBs even after controlling for funding mix, possibly as a result of the finding in Section 5.2 that large G-SIBs are less likely to use interest rate swap derivatives to offset interest rate risks, relying more on the deposit franchise. Finally, banks whose mortgage books reprice only slowly - the medium and long-fixation cohorts - raise deposit rates by less, providing further evidence of deliberate duration matching through the deposit franchise.

In sum, the empirical estimates mirror all three channels highlighted in the theoretical framework: banks that rely most on sticky retail funding to hedge duration risk adjust their deposit prices less; banks that face a larger run-sensitive uninsured deposit base adjust them more; and greater domestic competition puts upward pressure on deposit rates by increasing the alternative return available to depositors. These results are robust to alternative estimators and to the inclusion of country fixed effects, although the finding on uninsured deposits in not significant at conventional levels in the regression specification with clustered standard errors.

Despite these findings, evidence from this regression should not be read as proof that the deposit franchise constitutes a fail-safe hedge. As emphasised by Drechsler et al. (2024), the very stickiness that muted deposit rate pass-through turns into latent fragility when unrealised losses approach the scale of book equity. Because most banks in our sample left a non-trivial duration gap unhedged - as demonstrated by the sizable depletion of their economic net worth - a further parallel shift of the yield curve may have pushed a number of banks in our sample into negative economic net worth. Once that threshold is crossed uninsured depositors with sufficient knowledge of their bank's position have a strong incentive to withdraw. The apparent resilience observed during 2022–23 should therefore be interpreted as conditional on the magnitude of the rate shock that actually materialised, not as evidence that the system is immune to larger or more persistent increases in yields.

# 8 Conclusion

This paper uncovers the latent interest rate risks borne by euro-area banks during the unprecedented tightening cycle of 2022–2023. By moving beyond accounting measures and estimating each institution's economic net worth through mark-to-market valuation of loans and bond assets, we have shown that euro-area banks faced, on average, unrealised losses equivalent to nearly 30 per cent of pre-hike equity by September 2023. Crucially, almost half of these losses were offset by gains accruing from the deposit franchise and interest rate swap positions. Our theoretical framework, which links depositor incentives to banks' deposit rate setting, provided a lens through which to understand how banks with larger unrealised losses were able to leverage their deposit franchises by raising deposit rates more slowly in a high rate environment.

Empirically, we found significant heterogeneity across the euro area banking system in exposure to interest rate risk. Smaller, retail-oriented institutions with long-duration mortgage portfolios incurred the deepest mark-to-market losses, yet relied proportionally more on the deposit franchise and, to a lesser extent, on interest rate swaps to hedge their duration gaps. Regression analysis explored empirical findings in more depth, revealing that a ten-percentage-point increase in unrealised losses corresponded to roughly a ten-basis-point smaller rise in deposit rates, and that banks with a higher share of inert retail deposits faced less pressure to adjust deposit rates.

Our deposit run simulations in Section 5.3, which combine estimates of economic net worth with plausible withdrawal scenarios, further highlight the fragility that remains hidden beneath bank's seemingly robust reported accounting positions: even modest runs of uninsured deposits could have rendered a non-negligible fraction of institutions insolvent on a mark-to-market basis. Yet the absence of widespread runs during the 2022-2023 rate hike period reflects a delicate equilibrium sustained by relatively low asset durations (when compared to equivalent studies on U.S. banks), depositor inertia, and the partial hedges provided by both the deposit franchise and swaps.

From a policy perspective, our findings suggest supervisors and market participants should closely monitor economic net worth - including latent losses, interest rate swap positions and the evolving value of deposit franchises - when assessing bank resilience during rate hike episodes. Supervisors should be aware of the inherent risk of institutions relying on deposit stickiness as a hedge against long-duration assets. By extending the duration of assets, banks face larger unrealised losses dramatically increasing the probability of uninsured depositor runs should the bank fall into a position of negative economic net worth.

Finally, while our analysis benefits from unique granular data and reveals important new insights for euro area banks, it leaves open avenues for further inquiry. Future research might explore the dynamic interaction between macroprudential policy measures, such as liquidity buffers and banks' asset-liability management decisions. Also, further investigation is warranted into cross-country differences in depositor behaviour, and the implications of digitalisation and Central Bank Digital Currencies (CBDC) for the deposits market and the stability of the deposit franchise.

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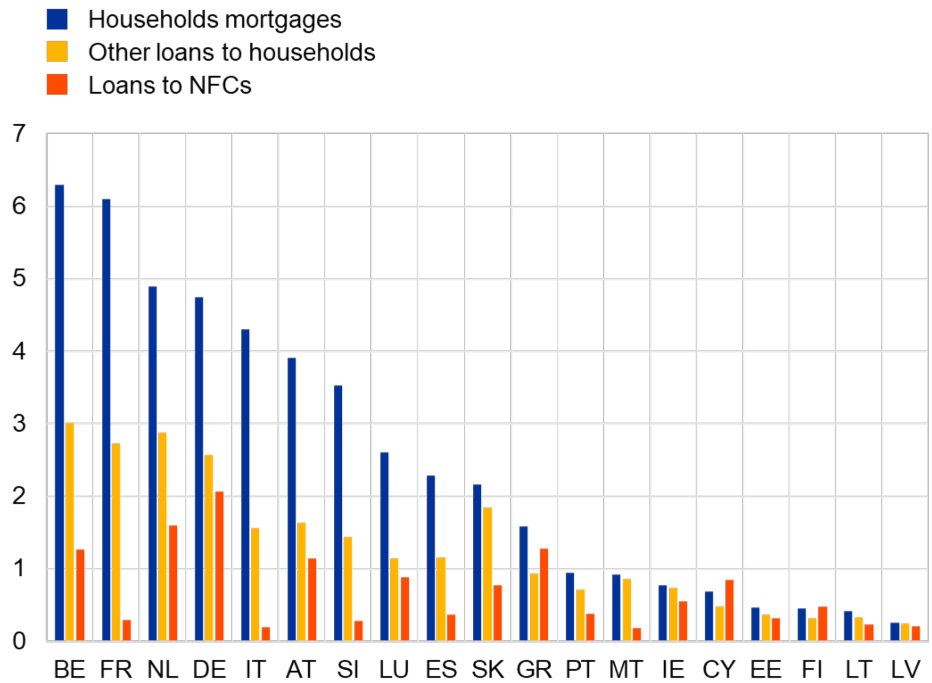
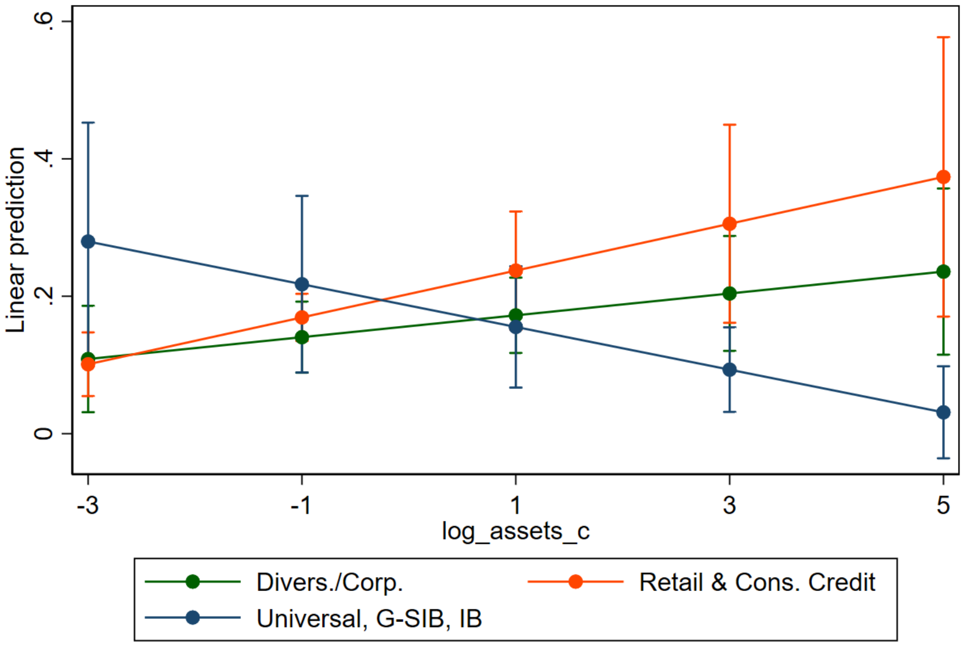
# Appendix

**Figure 16: Weighted average remaining fixation duration at country level (years)**



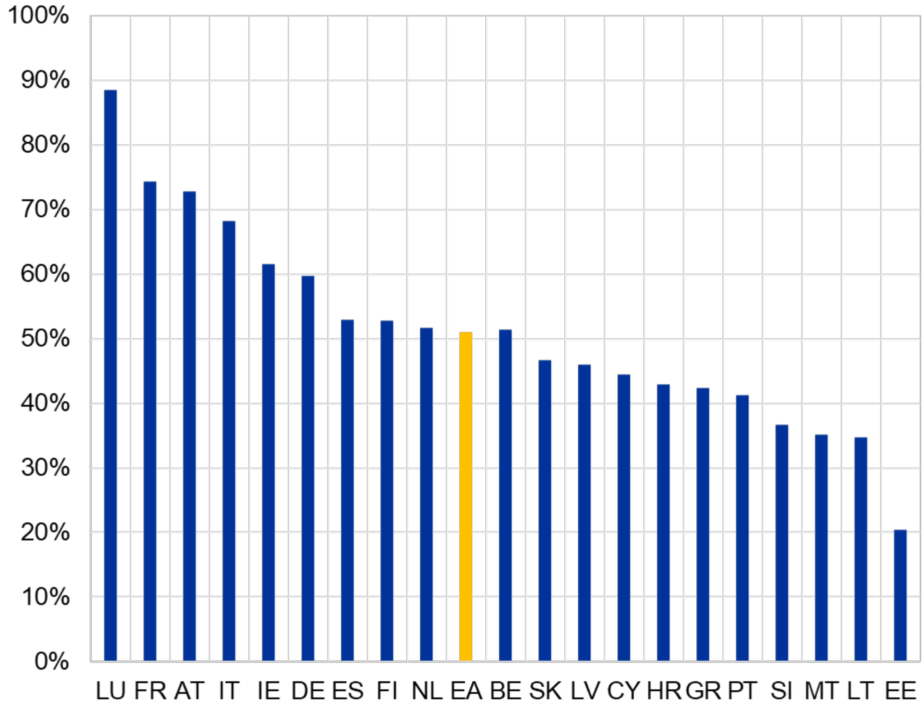

*Notes:* Remaining fixation duration for NFCs is taken directy from AnaCredit. For household loans we use IMIR data, supplemented with ESRB data on fixation duration at issuance. For each bank, we have new lending stocks and their interest rate fixation duration from the year 2000, which we use to estimate the average remaining fixation duration in 2023. *Source:* ECB Individual Interest Rate Statistics (IMIR), ESRB March 2023 Mortgage Questionnaire, AnaCredit.

**Figure 17: Regression interaction term: Bank size and business model**




*Notes:* The figure shows the predicted outcome of the interaction term (bank size and business model) in regression specification (7) of in Table 5. The log of total assets is centered in the regression and figure.
*Source:* Authors calculations.

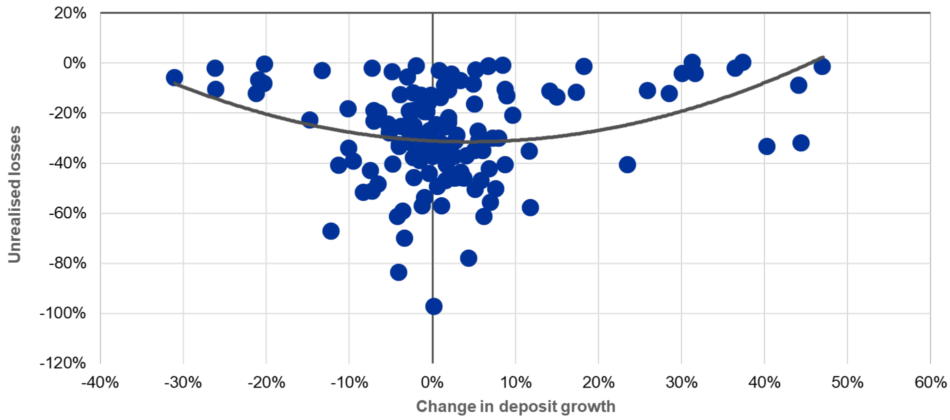
**Figure 18: Average share of uninsured deposits in domestic banks across the euro area**




*Notes:* The figure shows the average share of uninsured deposits on the liabilities of domestic banks.

*Source:* European Banking Authority (EBA).

**Figure 19: Bank-level change in deposit volumes between 2022Q3-2023Q3 and unrealised losses**




*Notes:* The figure plots the relationship between the bank-level change in total deposit volumes occurred between Q3 2022 and Q3 2023 for our sample of banks, and unrealised losses as a share of pre-rate hike equity. *Source:* Various, as described in the text, and own calculations.

## Table 7: Parameter assumptions for Section 4 simulations

| Parameter | Parameter Name | Value / Assumption Sources & Notes |
|---|---|---|
| $r_{alt}$ | Outside option / Alt. return | 0.0293 (2.93%) — Peak weekly avg. yield on German 10-year gov. bonds during 2023. |
| $\gamma$ | Deposit stickiness | Non-monetary utility/switching costs for depositors. Varies to show effect. |
| $\sigma_{NW}$ | Depositor uncertainty | Std. dev. of depositors' estimate of % change in economic net worth ($\Delta$ENW), relative to initial equity. Not applicable to insured depositors. |
| $\lambda$ | Fractional deposit loss in default | Loss incurred by uninsured depositors if the bank fails (set to 10%). Not applicable to insured depositors. |
| $r_{dep}^{max}$ | Max. deposit rate bank can offer | Calculated based on profitability constraints (declines linearly as economic net worth depletes). Shared curve across figures. |

| Parameter | Fig. 1 (Insured) | Fig. 2 (Unin., Var. $\sigma_{NW}$) | Fig. 3a (Unin., $\sigma_{NW}$=40%) | Fig. 3b (Unin., $\sigma_{NW}$=0%) |
|---|---|---|---|---|
| $r_{alt}$ | 2.93% | 2.93% | 2.93% | 2.93% |
| $\gamma$ | 0%, 1%, 3% | 3% | 0%, 2%, 10% | 0%, 2%, 10% |
| $\sigma_{NW}$ | N/A | 0%, 20% | 40% | 0% |
| $\lambda$ | N/A | 10% | 10% | 10% |
| $r_{dep}^{max}$ | Shared Curve | | | |

**General assumptions for $r_{dep}^{max}$ calculation (applicable to all figures):**
Pre-rate-hike equity: €5 billion. Deposits: €7 billion.
**Inputs specifically for $r_{dep}^{max}$ calculation:** Profit calculation: Decreases linearly from €2.8 million to €0 as depletion in economic net worth ($\Delta$ENW) goes from 0% to -150%, yielding $r_{dep}^{max}$ = 5% when $\Delta$ENW = 0%.

**Table 8: Contributions to changes in economic and accounting net worth by Size, Business Model, and Fixation Duration**

| | Bank Size | | | Business Model | | | Fixation Duration | | |
|---|---|---|---|---|---|---|---|---|---|
| | Small | Medium | Large | Div. | Retail | Univ. | <2 yrs | 2–5 yrs | 5+ yrs |
| **Deposit Franchise** | 9.0% | 10.1% | 8.1% | 8.1% | 10.0% | 7.4% | 8.6% | 10.4% | 7.3% |
| | [6.8%] | [4.3%] | [7.1%] | [6.2%] | [6.4%] | [4.8%] | [6.0%] | [5.8%] | [6.8%] |
| **IRS Derivatives** | 1.5% | 10.7% | 8.2% | 8.1% | 7.0% | 1.8% | 0.8% | 7.9% | 10.8% |
| | [4.3%] | [19.9%] | [20.7%] | [17.3%] | [17.5%] | [13.9%] | [8.2%] | [15.9%] | [23.3%] |
| **Bonds (AC)** | -12.0% | -9.5% | -12.0% | -9.9% | -12.3% | -9.2% | -12.5% | -12.2% | -8.1% |
| | [11.6%] | [8.3%] | [15.7%] | [9.7%] | [14.0%] | [8.5%] | [15.3%] | [11.6%] | [9.2%] |
| **Bonds (FV)** | -6.9% | -7.9% | -6.9% | -5.7% | -7.1% | -12.1% | -6.0% | -8.6% | -6.1% |
| | [5.8%] | [6.7%] | [8.4%] | [5.2%] | [6.6%] | [10.9%] | [4.9%] | [7.2%] | [8.1%] |
| **NFC Loans** | -1.1% | -3.2% | -1.9% | -3.1% | -1.7% | -1.1% | -1.9% | -2.8% | -0.9% |
| | [1.7%] | [4.2%] | [2.9%] | [3.7%] | [3.1%] | [1.1%] | [2.9%] | [3.8%] | [1.6%] |
| **HH Loans** | -16.4% | -13.3% | -14.6% | -11.6% | -17.2% | -11.8% | -2.8% | -17.1% | -22.8% |
| | [15.4%] | [13.1%] | [19.4%] | [11.6%] | [18.8%] | [9.5%] | [6.2%] | [13.1%] | [20.7%] |
| **Change in Econ. NW** | -25.9% | -13.2% | -19.1% | -14.0% | -21.3% | -25.0% | -13.7% | -22.5% | -19.8% |
| | [18.1%] | [18.8%] | [22.1%] | [16.9%] | [22.0%] | [17.2%] | [18.1%] | [18.1%] | [24.7%] |
| **Change in Acct. NW** | 3.6% | 12.9% | 9.4% | 10.6% | 9.9% | -3.0% | 3.4% | 9.6% | 12.0% |
| | [8.1%] | [20.7%] | [27.0%] | [19.2%] | [21.1%] | [16.2%] | [11.2%] | [18.3%] | [28.6%] |

*Notes:* Each cell displays the mean (top) and standard deviation [in brackets] of the row item expressed as a share of pre-rate hike equity, for each respective bank cohort.

**Table 9: Variance Inflation Factors (VIF) for Independent Variables**

| Variable | Spec 1/2 | Spec 3 |
|---|---|---|
| Unrealised loss / equity | 1.23 | 1.47 |
| Household overnight dep / total dep | 1.12 | 1.46 |
| HHI | 1.86 | — |
| IRS change / equity | 1.13 | 1.26 |
| Uninsured dep / total dep | 1.71 | — |
| NPL ratio | 1.22 | 1.58 |
| Liquid assets / total assets | 1.08 | 1.23 |
| log(assets) | 1.43 | 1.55 |
| Bus. model | 1.24 | 1.35 |
| Fixation length | 1.27 | 1.98 |

*Note*: Variance inflation factors (VIFs) above about 5 (some use 10) signal potential multicollinearity concerns; here all VIFs are well below that threshold.

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