The Heterogeneous Bank Lending Channel of Monetary Policy*

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Abstract

How does heterogeneity in banks' interest-rate risk exposure shape monetary policy transmission? We develop a quantitative macroeconomic model of heterogeneous banks to answer this question. We establish an irrelevance result: differences in interest-rate risk exposure between fixed- and variable-rate banking systems matter for transmission only when bank solvency concerns become relevant. Calibrating the model to the euro area, we show that idiosyncratic default risk pushes a substantial share of banks toward the solvency threshold, making heterogeneity quantitatively important. When policy rates rise, fixed-rate banks suffer net interest margin compression—funding costs increase while legacy loan income stays unchanged—eroding capital and triggering sharper deleveraging. The lending elasticity to monetary policy is one-third larger in fixed-rate economies. The effects extend to financial stability: tightening raises bank failure rates in fixed-rate systems while lowering them in variable-rate systems. The results lead to policy recommendations: that macroprudential and monetary policy should be coordinated and that monetary responses should be gradual.

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1. Introduction

This paper develops a quantitative model to analyze the role that heterogeneity in banks' interest-rate risk exposure plays in the transmission of monetary policy. It is widely accepted that monetary policy transmits to the real economy, in part, through the *bank lending channel* (Bernanke and Gertler, 1995). According to the bank lending channel, changes in central bank policies affect the economy by altering the banks' willingness or ability to provide credit.

While the bank lending channel is well understood, banks may respond differently to monetary policy depending on their interest-rate risk exposure.[1] For example, banks operating in specific geographic areas or specializing in specific industries predominantly offer fixed-rate loans, whereas others predominantly offer variable-rate loans. This heterogeneity raises important questions for central banking: when and by how much should we expect these differences to matter for aggregate outcomes? The answers bear directly on the design of both monetary and macroprudential policy.

The goal of our quantitative model is to provide a laboratory where we can ask these questions. Our framework compares two banking systems—one with fixed-rate loans and another with variable-rate loans—each containing a distribution of banks that differ in their leverage due to past idiosyncratic loan-default shocks and equity-financing frictions. Loans are long-term; whether loans are fixed- or variable-rate determines whether banks or their borrowers are exposed to interest-rate risk. In addition, banks face convex loan origination costs and loan demand curves that depend on the discounted value of loan repayments. Importantly, banks face regulatory capital requirements that can trigger bank failures.

We start by demonstrating an irrelevance result that serves as an organizing theoretical benchmark. A marginal loan creates surplus because it finances a positive-value project, but it also requires origination and funding resources. In a benchmark where bank solvency concerns are absent and banks and borrowers discount future repayments similarly, fixed-rate and variable-rate contracts do not change the joint discounted surplus of that loan; they only re-time how that surplus is split between bank and borrower. Monetary policy transmission is therefore identical in the two banking systems. Meaningful differences arise only when repayment timing changes bank valuation through the risk of bank failure.[2] This benchmark clarifies that heterogeneity in interest-rate risk exposure matters insofar as it affects the distribution of banks close to the solvency threshold imposed by regulatory capital requirements.

An implication of our irrelevance benchmark is that whether interest-rate risk exposure

[1]This distinction is recognized as early as in Samuelson (1945). Interestingly, Samuelson held the view that banks were advantageously exposed to interest-rate hikes because they reprise loans faster than deposits.

[2]This irrelevance resonates with the Modigliani-Miller Theorem, but narrowed down to the structuring of banks' loans while maintaining frictions in the external funding of banks and loans alike.

matters is ultimately a quantitative question: the answer depends on how likely banks are to approach the solvency threshold. Answering this question requires a model calibrated to a specific institutional context, with a realistic formulation of capital regulation and a good fit to both the cross-sectional distribution of bank leverage and the aggregate dynamic responses of credit to policy changes.

We calibrate our model to the euro area, a natural setting for our quantitative analysis. Interest-rate risk exposure heterogeneity is particularly pronounced in this region: banks in France, Germany, Belgium, and the Netherlands predominantly price loans at fixed rates, while those in Spain, Italy, Finland, and Portugal use variable rates. This institutional variation creates systematic differences in interest-rate risk exposures across countries within the monetary union. Moreover, due to market frictions, interest rate risk hedging remains modest and varies over time and across institutions, leaving most banks exposed to it.[3] A pressing question for the European Central Bank (ECB) is therefore whether this ex-ante heterogeneity translates into different cross-country monetary-policy responses—a concern explicitly raised by policymakers during the 2022–2023 tightening cycle (see, e.g., Lane, 2023). The calibration targets aggregate moments, while the model's untargeted fit to the left tail of the capital-ratio distribution provides the cross-sectional discipline needed to address this question.

We find that heterogeneity is quantitatively significant, but only because a substantial number of banks operate near the solvency threshold. In our model, this arises from two forces: convex loan-portfolio adjustment costs and idiosyncratic loan-default shocks that prevent banks from fully controlling their leverage. The mechanism operates through a feedback loop: when policy rates rise, fixed-rate banks experience net interest margin compression—funding costs increase while income from legacy loans remains unchanged—eroding equity and pushing highly leveraged banks closer to the solvency threshold. Variable-rate banks face the opposite dynamic, with rising legacy loan rates widening margins and rebuilding capital buffers. Because funding costs and new-loan rates are common across banks within each regime, what differs is how legacy portfolio profits affect proximity to the solvency threshold—and hence how banks discount future loan cash flows. Banks initially near the threshold respond sharply, contracting lending in fixed-rate economies and expanding it in variable-rate ones, driving a reallocation of credit across the capital distribution. This asymmetric pattern is consistent with the empirical evidence on interest-rate risk and monetary transmission documented by Gomez et al. (2021).[4]

[3]Empirical evidence indicates that larger euro area banks make greater use of derivatives to hedge interest rate risk than their U.S. counterparts (Hoffmann et al., 2018; Begenau et al., 2025b). However, the overall system's hedging remains modest: Hoffmann et al. (2018) and Guerrini and Rice (2025) document that European banks that actively engage in interest rate risk hedging typically offset only about 25% to 40% of on-balance-sheet exposures, leaving them exposed to interest rate risk.

[4]Complementary evidence by Ampudia and Van den Heuvel (2022) for the euro area shows that bank stock prices in fixed-rate countries respond more negatively to surprise increases in policy rates.

In aggregate, the elasticity of new lending to monetary policy is approximately one-third larger in fixed-rate systems. The divergence between fixed- and variable-rate banks extends to financial stability: rate hikes increase the probability of bank failures in fixed-rate economies but reduce it in variable-rate systems.

These findings carry implications for two dimensions of policy design: the coordination between monetary and macroprudential tools, and the pace of monetary tightening. First, we show that releasing capital requirements during a tightening cycle increases banks' distance away from the solvency threshold, reducing the gap in credit responses between fixed- and variable-rate economies and highlighting the need for coordination between the two instruments. Second, we provide a financial-stability rationale for gradualism in monetary policy. Comparing policy paths that deliver the same cumulative stance, we find that more gradual tightening substantially reduces failure rates in fixed-rate economies without materially increasing them in variable-rate systems. Gradualism avoids precisely the sharp equity losses that push fixed-rate banks toward the solvency threshold.

Beyond these insights, our framework combines several features essential for this analysis: long-term loan portfolios with vintage structure, idiosyncratic default risk generating ex-post leverage heterogeneity, convex origination costs that slow portfolio adjustment, and both liquidity and capital requirements. Despite this richness, we show how banks' decisions depend on only two state variables—leverage and the average interest rate on their loan portfolio—making our framework tractable and the comparison with data transparent. This parsimonious structure makes the model portable: it can be readily adapted to study other questions involving bank heterogeneity and regulation.

Related literature. A longstanding literature distinguishes the bank lending channel from other transmission channels of monetary policy that operate through effects on deposit rates or inflation (Bernanke and Gertler, 1995). In a static setting, Kashyap and Stein (1995) illustrates this distinction by noting that if bank loans can be funded with equity commanding a rate of return independent of monetary policy, loan rates are insulated from policy shocks affecting deposit rates. They emphasize that this irrelevance breaks down once banks face equity financing constraints—a manifestation of the Modigliani-Miller logic.

This observation implies that banks with heterogeneous leverage positions or interest-rate risk exposure, which shape their access to non-deposit financing, will respond heterogeneously to monetary policy. An extensive empirical literature corroborates this hypothesis. Early work by Kashyap and Stein (2000) established that the strength of the bank lending channel depends on bank characteristics. Subsequent research with improved identification has focused on two key dimensions. First, banks with low risk-bearing capacity—high leverage or low capital ratios—transmit policy rate changes more strongly than well-capitalized banks (Jiménez et al., 2012; Dell'Ariccia et al., 2017; Altavilla et al., 2020).[5] Second, banks with greater interest-rate risk exposure transmit policy changes more strongly—whether measured through the duration mismatch between assets and liabilities (Gomez et al., 2021) or through the share of fixed-rate loans in their portfolios (Altunok et al., 2023). Importantly, Gomez et al. (2021) show that this effect is amplified for more financially constrained banks, providing direct empirical evidence for the interaction between interest-rate risk exposure and risk-bearing capacity that is central to our model.

While this empirical literature identifies important differences in bank responses to monetary policy, structural models are essential for two complementary reasons. First, quantitative models are needed to understand aggregate responses: cross-sectional estimates explain differences across banks, but these heterogeneous effects do not translate directly to aggregate outcomes. Second, empirical estimates do not permit meaningful counterfactual analysis—for instance, quantifying how transmission would change if banks were homogeneous, or how the role of heterogeneity varies with regulatory stringency or the pace of policy. Our contribution is to present a framework capable of such analysis.

Our framework features long-term loans, interest-rate risk, and capital regulation, as in the dynamic banking model of Van den Heuvel (2007) and the more recent quantitative model of Elenev et al. (2021). Unlike in Kashyap and Stein (1995), banks in both Van den Heuvel (2007) and our model cannot issue equity freely. A central result in Van den Heuvel (2007) is that, when banks are forever unconstrained by capital regulation, current policy rates—not their leverage positions—are a sufficient statistic for the equilibrium response in the loan market. This result differs from Kashyap and Stein (1995), who show that the bank lending channel is muted when equity can be raised freely. In Van den Heuvel (2007), equity cannot be raised freely, but still responses are independent of equity levels absent regulation. We establish a related irrelevance result: when bank solvency concerns are absent and banks and borrowers discount future repayments equally, whether loans carry fixed or variable rates is also irrelevant for monetary policy transmission. Contract structure changes the timing of surplus allocation, not the quantity of lending. Our result thus clarifies that only the future path of interest-rate margins matters for the provision of loans, and not the path of earnings from past loans. These irrelevance results break down once solvency concerns become relevant or effective discount factors diverge, morphing into a quantitative question—and the interaction between leverage heterogeneity and loan-pricing heterogeneity is what our analysis explores.

While the structure and emphasis on the quantitative relevance of capital regulation are

[5] Other references include Kishan and Opiela (2000), Gambacorta and Mistrulli (2004), and Holton and Rodriguez d'Acri (2018). Beutler et al. (2020), in particular, controls for hedging positions.

shared with Elenev et al. (2021), our model emphasizes heterogeneity, both in terms of ex ante interest-risk exposure and ex-post leverage.[6] We articulate that credit reallocation within rate-fixation regimes is key to explaining differences between regimes.

Recent literature has developed quantitative banking models with heterogeneity to study monetary policy transmission, emphasizing different frictions. Some papers focus on the liability side: Leite (2025) study heterogeneity in deposit funding structures; Bianchi and Bigio (2022) investigate interbank market frictions and deposit withdrawals; Begenau et al. (2024) examine financial stability implications of uninsured deposit funding. Others emphasize capital and risk-taking: Coimbra and Rey (2023) analyzes how monetary policy affects risk-taking; Corbae and D'Erasmo (2021) studies regulation and bank risk-taking; Rios-Rull et al. (2023) examines capital requirements; Jamilov and Monacelli (2025) focuses on shocks to bank return dispersion[7]; Begenau et al. (2025a) study heterogeneity in unrecognized losses; Schneider (2025) studies interest-rate compression in the context of a zero-lower bound on deposits. We contribute by examining how heterogeneity in loan pricing—fixed versus variable rates—interacts with leverage heterogeneity to shape the bank lending channel.

Most closely aligned with our focus on interest-rate risk is Varraso (2025), who studies monetary transmission when intermediaries optimally choose interest-rate risk exposure by selecting assets of different maturities. Our framework abstracts from this margin of adjustment. Because the maturity structure is slow-moving, for our purposes, we treat risk exposure as institutionally predetermined and ask when these ex ante differences matter for transmission.

A related strand examines monetary transmission from the borrowers' side. For example, Berger et al. (2021) and Eichenbaum et al. (2022) emphasize the path-dependency of policy rates in shaping household consumption. Greenwald (2018) highlights the role of loan-to-value and payment-to-income constraints, while Beraja et al. (2018) focus on the importance of home equity values.[8] Guren et al. (2021) and Elenev and Liu (2025) examine how mortgage contract design—fixed versus adjustable rates—shapes macroeconomic volatility, household default risk, and housing demand. A natural implication of this literature is that households' interest-rate risk exposure amplifies consumption volatility and default risk. As a result, fixed-rate contracts can insulate households from interest-rate risk. However, aggregate risk does not vanish—it shifts to banks. Hence, relative to this literature, our paper provides the banking counterpart: we study how bank-side interest-rate risk exposure shapes monetary transmission.

[6] Despite featuring bank idiosyncratic defaults, there is a representative bank in Elenev et al. (2021). The non-financial sector is more realistic in that model, a feature that we sacrifice to allow an emphasis on bank heterogeneity.

[7] Bellifemine et al. (2022) extends this framework with nominal frictions.

[8] Kaplan et al. (2018), Auclert (2019), and Garriga and Hedlund (2020) examine monetary policy transmission in heterogeneous-agent economies. In the euro area, Corsetti et al. (2021) study cross-country heterogeneity in monetary transmission, while Calza et al. (2013) emphasize housing finance; more recently, Pica (2022) and Sciacovelli (2025) focus on adjustable-rate mortgages.

2. The model

We consider an infinite-horizon, discrete-time economy, where time is indexed by $t \in \{0, 1, 2, \ldots\}$ and there is a single good. The economy is populated by four types of agents: a representative household, a mass of entrepreneurs, a continuum of competitive banks, and a consolidated government.

The banking sector intermediates funds from households to entrepreneurs, who undertake risky long-term projects that require external finance. Entrepreneurs' entry decisions generate a microfounded, forward-looking demand for loans. The funding block is intentionally parsimonious: household asset demand is static, yet remains flexible enough to match the empirical response of deposit rates to monetary policy shocks. This structure keeps the focus on the bank lending channel.

Banks engage in maturity transformation by funding long-term loans with short-term retail deposits, wholesale debt, and equity accumulated through retained earnings. This activity exposes them to both credit risk and interest-rate risk.

Regulation determines when those exposures matter for lending. Capital requirements make net-worth losses relevant for credit supply by introducing the possibility of regulatory failure. Aggregate activity therefore depends on the interaction between banks' lending capacity and entrepreneurs' investment demand.

We compare two distinct institutional arrangements for loan contracts: one where the interest rate is fixed for the life of the loan, and another where the rate resets each period. We refer to these two setups as the *fixed-rate (FR) economy* and the *variable-rate (VR) economy*, respectively. This distinction allows us to isolate how the exposure to interest-rate risk affects the banking sector and, in turn, macroeconomic outcomes. The following subsections detail the objectives, constraints, and technology available to each agent.

2.1 Banks

The banking sector consists of a continuum of ex-ante identical, perfectly competitive banks, indexed by $j \in [0, 1]$. Banks operate under limited liability and are managed by risk-neutral bankers with a subjective discount factor $\beta \in (0, 1)$ who maximize the discounted value of dividends for their owners, the households.

Banks finance a portfolio of risky long-term loans and safe short-term assets using a combination of short-term insured deposits, wholesale debt, and equity accumulated through retained earnings. We present the bank's problem in five steps: assets, liabilities, constraints, entry and exit, and the recursive formulation.

Assets. Bank assets comprise risky long-term loans and safe short-term assets, which we refer to as reserves.[9] At the beginning of period t, bank j holds a portfolio of legacy loans, L_{jt}, originated in previous periods. It then chooses its origination of new loans, N_{jt}, and its holdings of central bank reserves, M_{jt}.

Reserves, M_{jt}, are a risk-free, one-period asset that pays a net interest rate r_t^M, which is the policy rate set by the monetary authority.

The loan portfolio consists of a continuum of long-term loans, each with a principal normalized to one. Following Leland and Toft (1996), each loan matures with an i.i.d. probability $\delta \in (0,1)$, implying an average loan maturity of $1/\delta$. The bank is exposed to idiosyncratic loan default risk: in each period, a fraction ω_{jt+1} of its loan portfolio defaults. ω_{jt+1} is drawn from a time-invariant distribution $F(\omega)$ with mean $\mathbb{E}[\omega] = p \in [0,1]$. Upon default, the bank recovers a fraction $1-\lambda$ of the principal, where $\lambda \in [0,1]$ represents the loss given default.

The law of motion for the bank's legacy loan portfolio is:

$$L_{jt+1} = (1-\omega_{jt+1})(1-\delta)(L_{jt} + N_{jt}). \tag{1}$$

This formulation implies that the portfolio at $t+1$ consists of the previous period's total loans, $L_{jt} + N_{jt}$, net of maturing and defaulted loans.

The origination of new loans incurs a cost $f(N_{jt}/L_{jt})L_{jt}$, where $f(\cdot)$ is an increasing and convex function.[10]

The contractual interest rate of a bank's loans depends on the institutional environment. The interest rate on new loans originated at time t is denoted r_t^N.[11] In the FR economy, the net interest rate r_t^N is fixed at origination and remains constant for the life of the loan. In the VR economy, what is fixed at origination is the spread s_t^N, which is added to the policy rate r_t^M set by the monetary authority, so that the rate is $r_t^N = r_t^M + s_t^N$. Hence, in this case, the contractual spread remains constant for the life of the loan, but the interest rate fluctuates over time with the policy rate.

For FR banks, the average interest rate on a bank's legacy loan portfolio, r_{jt}^L, evolves according to:

$$r_{jt}^L = \frac{r_{jt-1}^L L_{jt-1} + r_{t-1}^N N_{jt-1}}{L_{jt-1} + N_{jt-1}}. \tag{2}$$

For VR banks, the return is $r_{jt}^L = r_t^M + s_{jt}^L$, where the average contractual spread s_{jt}^L follows the

[9]These assets can be thought of as central bank reserves or as safe short-term government bonds.

[10]This convexity captures the increasing marginal difficulty of finding creditworthy borrowers or screening profitable investment opportunities as the bank expands its lending relative to its existing customer base.

[11]Note that, given our perfect-competition assumption, banks are price-takers in the loan market, making this rate the same for all banks in a given period and thus not indexed by j.

law of motion:

$$s_{jt}^{L} = \frac{s_{jt-1}^{L} L_{jt-1} + s_{t-1}^{N} N_{jt-1}}{L_{jt-1} + N_{jt-1}}. \tag{3}$$

Liabilities. The bank's assets are funded with a combination of wholesale debt B_{jt}, retail deposits D_{jt}, and equity E_{jt}. Wholesale debt is a one-period liability that pays a net interest rate r_t^B. Retail deposits are one-period liabilities paying r_t^D. They provide liquidity services to depositors (which implies that, in equilibrium, $r_t^D \leq r_t^B$).

We assume that retail deposits are fully insured by the government and that, while wholesale debt is not, its returns are also risk-free in equilibrium.[12]

Banks accumulate equity exclusively through retained earnings (i.e., we assume there is no external equity issuance). The law of motion for equity is:

$$E_{jt+1} = E_{jt} + (1-\tau)\Pi_{jt+1}, \tag{4}$$

where $\tau \in (0,1)$ is the corporate tax rate. Π_{jt+1} denotes pre-tax profits realized between period t and $t+1$:

$$\begin{aligned} \Pi_{jt+1} = (1-\omega_{jt+1})\left(r_{jt}^{L} L_{jt} + r_t^{N} N_{jt}\right) + r_t^{M} M_{jt} - r_t^{D} D_{jt} - r_t^{B} B_{jt} \\ - \lambda\omega_{jt+1}(L_{jt} + N_{jt}) - f\left(\frac{N_{jt}}{L_{jt}}\right) L_{jt} - \bar{\pi} E_{jt}. \end{aligned} \tag{5}$$

where the first line is the net interest income—the difference between the interest earned on assets and the interest paid on liabilities—and the second line includes realized credit losses, loan origination costs, and operational costs, which are a constant fraction $\bar{\pi} > 0$ of equity.

The balance sheet of the bank is:

$$L_{jt} + N_{jt} + M_{jt} = D_{jt} + B_{jt} + E_{jt}. \tag{6}$$

Constraints. The bank faces both regulatory and operational constraints on its balance sheet. First, liquidity regulation akin to the Basel III framework imposes a minimum reserve requirement proportional to the bank's short-term liabilities:

$$M_{jt} \geq \theta(D_{jt} + B_{jt}). \tag{7}$$

[12] To obtain this result, we need to assume that wholesale debt is either senior to deposits, or that it is collateralized with the bank's assets. This imposes some parametric restrictions on the relative size of each of these sources of funding and/or the recovery value of a bank's assets in case of default, such that wholesale debt returns are effectively risk-free (see Appendix A.1 for a derivation of those restrictions).

Second, a bank's ability to issue deposits is operationally constrained by the size of its legacy loan portfolio:

$$D_{jt} \leq \alpha L_{jt}, \tag{8}$$

with $\alpha \leq 1$. We interpret this restriction a reduced-form representation of the specific nature of relationship banking: deposits are often a by-product of lending relationships, as borrowers are required to open accounts or maintain balances as part of their loan covenants. Alternatively, this can be viewed as a reduced-form representation of the synergies between loan origination and deposit taking, such as the shared physical branch network required for both activities.

In equilibrium, both constraints bind with equality. The deposit constraint (8) binds because retail deposits are, by assumption, always strictly cheaper than wholesale debt ($r_t^D < r_t^B$). A profit-maximizing bank therefore exhausts the cheapest source of funding first. The liquidity requirement (7) binds because reserves yield less than loans and no more than any available liability. Consequently, banks hold only the minimum reserves required by regulation.

Third, capital regulation imposes a solvency threshold. After loan defaults are realized, a bank is resolved whenever its losses are such that its equity falls below a fraction $\gamma \in (0, 1)$ of its surviving loan portfolio. Unlike the two conditions above, this threshold does not constrain choices ex ante; rather, it affects them through the continuation value by making failure a possible outcome of today's lending decision. This failure risk is the central friction of the model. For sufficiently leveraged banks, an adverse default realization lowers the expected value of expanding the loan book by raising failure probability. Because the liquidity and deposit constraints bind in equilibrium, the bank's balance sheet is pinned down by loans and equity, so the problem reduces to the choice of new lending given current leverage.

Bank failure, entry, and exit. When a bank fails and is resolved by the regulator, its equity is wiped out, and the deposit insurance agency seizes its assets, liquidates a fraction of those assets, and sells the remainder to new entrants. The agency allocates its proceeds to the bank's liability holders, in order of seniority, and repays all retail depositors in full.

Additionally, banks face an independent exogenous exit shock with probability $\chi \in (0, 1)$ each period. Exiting banks repay liabilities and distribute remaining equity as dividends. To maintain a constant mass of banks, each exiting bank is replaced by a new entrant, which starts with an exogenous amount of equity $\bar{E}_t$ and a random amount of legacy loans that ensures that the leverage distribution of new banks is the same as that of surviving banks. These exit and entry dynamics ensure a stationary distribution of bank sizes. Loans in the legacy loan portfolio of exiting banks at $t+1$ that are not distributed among new banks are liquidated. Appendix A.7 derives derives the implied probability $\tilde{\chi}$ that a loan is liquidated because its financing bank exits.[13]

Recursive formulation. The state of an individual bank j at time t is summarized by its legacy loans L_{jt}, equity E_{jt}, and the average interest rate on its legacy portfolio r^L_{jt}, for FR banks, or the average spread s^L_{jt}, for VR banks. The bank's value function V_t satisfies:

$$V_t\left(L_{jt}, E_{jt}, x_{jt}\right) = \mathbf{1}_{\{E_{jt} \geq \gamma L_{jt}\}} \left[\max_{\{N_{jt}, M_{jt}, D_{jt}, B_{jt}\}} \beta \int_0^{\overline{\omega}_{jt+1}} \left[(1-\chi) V_{t+1}\left(L_{jt+1}, E_{jt+1}, x_{jt+1}\right) + \chi E_{jt+1} \right] \mathrm{d}F(\omega_{jt+1}) \right], \tag{9}$$

with $x_{jt} = r^L_{jt}$ for FR banks, $x_{jt} = s^L_{jt}$ for VR banks and $\overline{\omega}_{jt+1}$ denoting the maximum ω_{jt+1} for which the capital requirements can still be satisfied in $t+1$. The optimization problem of the bank is subject to the laws of motion for loans (1) and for average legacy rate (2) for FR banks, or the average legacy spread (3) for VR banks, the law of motion for equity (4), the balance-sheet constraint (6), the regulatory constraint (7), and retail deposit taking constraint (8). The indicator function captures the failure condition.

Because payoffs, costs, and regulatory constraints are all homogeneous of degree one in bank size, the problem can be normalized by equity. Let leverage be $l_{jt} \equiv L_{jt}/E_{jt}$, let the new-lending ratio be $n_{jt} \equiv N_{jt}/L_{jt}$, and let $x_{jt} \in \{r^L_{jt}, s^L_{jt}\}$ denote the legacy pricing state. The bank value can then be written as

$$V_t\big(L_{jt}, E_{jt}, x_{jt}\big) = v^B_t\big(l_{jt}, x_{jt}\big)\, E_{jt},$$

so optimal policy rules are size-independent. They depend only on leverage and the average legacy rate/spread, not on the bank's absolute size. The legacy pricing state x' then evolves according to (2) in the FR economy and (3) in the VR economy. Hence the individual bank problem has two state variables—leverage and the average legacy rate/spread—and one choice, the lending ratio. Appendix A.2 provides the formal derivation.

2.2 Entrepreneurs: Loan demand microfoundation

A mass of risk-neutral entrepreneurs, indexed by $i \in [0,1]$, has access to an investment technology requiring the upfront use of one unit of the final good. Entrepreneurs are endowed with no internal funds and must obtain a bank loan to finance their projects.

An active project yields A units of the final good per period. At the end of period t, the project

[13] We fix the amount of equity of entering banks $\bar{E}$ in the steady state to normalize the aggregate size of the banking sector. Given this parameter value, we can calculate the implied steady-state value of $\tilde{\chi}$. In response to shocks $\bar{E}_t$ adjusts such that the implied $\tilde{\chi}$ remains constant and equal to its steady state value.

terminates if: (i) it reaches successful completion, which occurs with probability δ, or (ii) it fails, which occurs with probability p. In addition to project-specific termination, the loan itself may be liquidated as a result of the exit of its financing bank, with exogenous probability $\tilde{\chi}$.[14] If the project is completed or the loan is liquidated, the principal is repaid in full to the bank. If the project fails, the bank recovers only $1-\lambda$ of the principal. For a loan originated at date t, the repayment stream in period $t+m$ is

$$\text{FR:} \quad q_{t,m}^{N,FR} = r_t^N,$$

$$\text{VR:} \quad q_{t,m}^{N,VR} = s_t^N + r_{t+m}^M,$$

for all $m \geq 0$. The distinction is therefore one of timing: FR loans keep payments flat over the life of the contract, whereas VR loans keep the spread fixed and let the policy-rate component reprice over time.

Entrepreneurs are long-lived agents who accumulate wealth by retaining earnings from their projects and investing at the rate r_t^E. In the baseline, we assume $r_t^E = 0$, but we revisit the possibility of a non-zero rate in Proposition 1 below. Earnings equal the yield minus interest payments, $A - q_{t,m}^N$, and they are subject to the corporate tax rate τ, so the law of motion for entrepreneur i's wealth is given by:

$$W_{it+1} = \left[1 + (1-\tau) r_t^E\right] W_{it} + (1-\tau)\left(A - q_{t,m}^N\right), \tag{10}$$

The entrepreneur accumulates wealth until the originating bank exits and liquidates the loan. Upon this event, the entrepreneur consumes accumulated wealth and leaves the economy.[15]

Initiating a project requires a utility cost of $a(N_t)$, where $a(\cdot)$ is an increasing function of N_t, the aggregate volume of new projects. This cost generates an upward-sloping supply curve for new projects, which captures aggregate decreasing returns to scale for the entrepreneurial sector. Free entry implies that, in equilibrium, the expected lifetime value of a new project at origination must exactly equal this startup cost. This zero-profit condition determines a uniform interest rate r_t^N (or spread s_t^N) for all new loans originated at time t.

It is convenient to write the entrepreneur's problem recursively. Let $V_{t,m}^E$ denote the date-t value of a project that remains active at horizon m. Conditional on reaching horizon m, the entrepreneur receives the operating payoff $A - q_{t,m}^N$ provided the project does not default, and

[14] We distinguish the bank's exogenous exit probability, χ, from the resulting loan liquidation probability, $\tilde{\chi}$. In particular, $\tilde{\chi}$ can be strictly smaller than the bank exit rate χ if, upon a bank's exit, only a fraction of its loan portfolio is liquidated while the remainder is transferred to newly entering banks.

[15] If the project terminates early because it matures or defaults, the entrepreneur does not exit immediately. Instead, the accumulated wealth continues to compound until the bank-level liquidation shock $\tilde{\chi}$ occurs.

continuation requires that the project neither defaults nor matures.

The Bellman equation is therefore

$$V^E_{t,m} = (1-p)\left[\Omega^E_{t,m}\left(A - q^N_{t,m}\right) + (1-\delta)V^E_{t,m+1}\right], \tag{11}$$

where $\Omega^E_{t,m}$ is the date-t value of one unit of pre-tax cash flow received at horizon m, taking into account that entrepreneurial earnings are retained and reinvested until the bank-level liquidation shock materializes:

$$\Omega^E_{t,m} \equiv (1-\tau)\sum_{k=m}^{\infty}\beta^{k+1}(1-\tilde{\chi})^k\tilde{\chi}\left(\prod_{q=m+1}^{k}\left[1+(1-\tau)r^E_{t+q}\right]\right) \tag{12}$$

Forward iteration of (11) yields the value of a newly originated project, $V^E_{t,0}$, as the discounted sum of future operating payoffs. This motivates the entrepreneur's effective discount factor:

$$\Lambda^E_{t,m} \equiv \Omega^E_{t,m}(1-p)^{m+1}(1-\delta)^m. \tag{13}$$

The term $(1-p)^{m+1}(1-\delta)^m$ is the probability that the project remains active long enough to deliver cash flow at horizon m. Thus, $\Lambda^E_{t,m}$ combines project survival with the entrepreneur's valuation of when that cash flow is eventually consumed.[16]

Equating the expected discounted value of these constant cash flows to the aggregate startup cost yields the free-entry condition $V^E_{t,0} = \sum_{m=0}^{\infty}\Lambda^E_{t,m}(A - q^N_{t,m}) = a(N_t)$. The implied aggregate demand for new loans is therefore:

$$N_t = a^{-1}\left(\sum_{m=0}^{\infty}\Lambda^E_{t,m}\left(A - q^N_{t,m}\right)\right). \tag{14}$$

2.3 Households: Supply of bank funds

Households have quasi-linear preferences over two consumption goods—one entering with curvature, the other linearly—and derive additional utility from holding a bundle of monetary assets. These assets are grouped into highly liquid assets, D^H_t, and less liquid bonds, A^H_t, so differences liquidity services generate an equilibrium spread between their returns. The liquid assets D^H_t consist of bank deposits D_{jt} and short-term government paper D^S_t, which pay the deposit rate r^D_t. The less liquid bonds A^H_t consist of bank wholesale debt, B^H_t, and central bank reserves, M^H_t, which pay the policy rate r^M_t. From the household's perspective, assets within

[16] Project survival and entrepreneur exit are independent. Project survival enters through $(1-p)^{m+1}(1-\delta)^m$, while the timing of consumption is captured by $\Omega^E_{t,m}$.

each tier are perfect substitutes. Appendix A.3 presents the full problem in detail.[17]

The core result is a canonical asset-demand system. In particular, the demands for highly liquid assets and bonds are:

$$D_t^H = h^D(r_t^D, r_t^M), \tag{15}$$

and

$$A_t^H = h^A(r_t^D, r_t^M), \tag{16}$$

where $h^D(\cdot)$ and $h^A(\cdot)$ are the respective demand functions. Perfect substitutability between wholesale debt and government bonds implies that only two rates enter this system. Because deposits provide greater liquidity services, in equilibrium $r_t^D \leq r_t^M$.

2.4 Consolidated government

The consolidated government includes a central bank and a fiscal authority. As is standard, the central bank supplies reserves to implement the policy rate r_t^M. The fiscal authority raises taxes from banks and households and manages the deposit insurance scheme. In addition, the government issues short-term bonds that, from the household's perspective, are perfect substitutes for deposits. Adjusting the supply of these bonds shifts the household demand system derived above, allowing the model to match the empirical response of the deposit rate r_t^D to monetary policy shocks. In the quantitative analysis, both the policy rate and the deposit rate paths adjust to match the data, with reserve and bond supplies adjusting in the background to implement them.

These operations are consolidated in the following government budget constraint:

$$T_t + \tau\Pi_t + M_t^S + D_t^S = \left(1 + r_{t-1}^M\right) M_{t-1}^S + \left(1 + r_{t-1}^D\right) D_{t-1}^S + \Theta_t, \tag{17}$$

where T_t denotes lump-sum taxes paid by households, Π_t aggregate profits from banks, M_t^S the supply of reserves, D_t^S the supply of short-term government bonds, and Θ_t the net operating deficit of the deposit insurance scheme.

[17]Appendix A.4 derives this representation from a richer institutional environment. In that environment, money market funds hold short-term government bonds and issue liquid shares, making those shares and bank deposits perfect substitutes within the liquid tier. A central bank facility allows banks to exchange government securities one-for-one for reserves, making those assets equivalent within the bond tier. The demand system in the main text is the reduced-form counterpart of that richer structure.

2.5 Equilibrium

Definition 1. *An equilibrium is a sequence of prices* $\{r_t^N, r_t^M, r_t^B, r_t^D\}_{t\geq 0}$ *(or* $\{s_t^N, r_t^M, r_t^B, r_t^D\}_{t\geq 0}$ *for the VR economy) and allocations such that:*

1. *Banks maximize the expected discounted value of dividends subject to regulatory and balance-sheet constraints, taking all prices as given.*

2. *Entrepreneurs enter until the free-entry condition is satisfied, determining aggregate loan demand.*

3. *Households maximize lifetime utility over consumption and asset holdings.*

4. *The government budget constraint holds.*

5. *Markets for new loans, deposits, wholesale debt, and reserves clear, i.e.,*

$$N_t = \int N_{jt}\,\mathrm{d}j, \quad D_t^H = D_t^S + \int D_{jt}\,\mathrm{d}j, \quad B_t^H = \int B_{jt}\,\mathrm{d}j, \quad M_t^H + \int M_{jt}\,\mathrm{d}j = M_t^S.$$

Appendix A.6 provides more details on all equilibrium objects and market-clearing conditions.

2.6 Discussion of modeling assumptions

The non-financial block is designed to isolate the bank-lending channel while preserving a coherent general-equilibrium environment. On the credit side, entrepreneurial entry generates a loan-demand schedule that is separate from household portfolio choice, in the spirit of the asset-demand systems used in empirical work (Koijen and Yogo, 2019; Diamond et al., 2024). This decoupling shuts down aggregate-demand feedbacks by construction, allowing us to focus on credit-supply transmission. At the same time, embedding household asset demand in general equilibrium disciplines the funding side and makes the implementation of monetary policy explicit.

The two sides of the non-financial block nonetheless differ in their intertemporal structure. Loan demand is forward-looking because entrepreneurial projects are long lived, so borrowing depends on the discounted value of future repayments. Two additional restrictions keep this block focused. First, default risk is exogenous and policy invariant, which shuts down credit-risk feedbacks from monetary policy. Second, interest-rate risk does not operate on the demand side through term-structure pricing (e.g., Piazzesi, 2005). These assumptions remove two transmission channels, but they do not eliminate financial amplification: bank equity still matters for loan pricing, so the model retains the bank-side mechanism emphasized by Brunnermeier and Sannikov (2014).

By contrast, household portfolio demand for deposits and bonds is static and depends only on current rates. This follows from quasi-linear preferences, a standard assumption in new-monetarist models (Lagos and Wright, 2005; Lagos et al., 2017), also adopted in dynamic banking models (Bianchi and Bigio, 2022). Because deposits and bonds provide different liquidity services, the resulting demand system features the cross-elasticities familiar from models with competing monetary assets (e.g., Drechsler et al., 2017; Di Tella and Kurlat, 2021).The household problem can be expressed as a two-tier asset-demand system: households choose between liquid assets earning r^D and less-liquid bonds earning $r^M > r^D$, with perfect substitutability within each tier.

A useful feature of the setup is that monetary policy shocks move two rates simultaneously. Empirically, pass-through from policy rates to deposit rates is nonlinear and time varying (Drechsler et al., 2017), which is difficult to reproduce in models without additional household-side state variables (e.g., Eichenbaum et al., 2025). Our setup sidesteps this difficulty by allowing contemporaneous government bond-supply shocks to move the deposit rate together with the policy rate, while the loan rate remains endogenous. This flexibility allows the model match the empirical path of funding costs without altering the core bank-lending mechanism and preserving endogenous loan pricing.

Having described the environment and its key simplifications, the next section presents a benchmark under which contract structure is irrelevant for monetary transmission, and then shows how that benchmark breaks down.

3. Benchmark irrelevance and the role of heterogeneity

This section establishes the conditions under which the distinction between FR and VR is irrelevant for monetary transmission and then shows when that irrelevance breaks down.

3.1 A benchmark irrelevance result

To isolate the benchmark in which contract structure is irrelevant for lending, consider an environment without idiosyncratic default risk, so the loan portfolio default rate is deterministic at $\omega_t = p$, and in which banks remain sufficiently well capitalized that the solvency threshold never affects continuation values. In that benchmark, FR and VR contracts differ only in the timing of repayments. Once insolvency risk is absent, that timing difference matters only if banks and entrepreneurs value repayments at different horizons differently. If their effective discount factors are proportional at origination, FR and VR contracts then generate the same discounted surplus for the lending relationship and therefore the same aggregate lending allocation. The following proposition formalizes this result.

Proposition 1 (Irrelevance of fixed- versus variable-rate lending)**.** *Consider an FR and VR economy starting from the same aggregate legacy loan portfolio* L_0 *and facing the same sequences of policy rates* $\{r_t^M\}_{t\geq 0}$ *and deposit rates* $\{r_t^D\}_{t\geq 0}$*. Assume loan portfolio default rates are deterministic,* $\omega_t = p$*, that banks remain sufficiently well capitalized along the compared paths that the solvency threshold never becomes relevant, and that, for each date* t*, there exists a scalar* $c_t > 0$ *such that*

$$\Lambda^E_{t,m} = c_t \Lambda^B_{t,m} \qquad \textit{for all } m \geq 0,$$

where $\Lambda^B_{t,m}$ *is the bank's effective discount factor for a cash flow received at horizon* m*. Then, the equilibrium path of aggregate new lending* $\{N_t\}_{t\geq 0}$ *is identical in the two economies.*

Moreover, the corresponding fixed loan rate r_t^N *in the FR economy and the spread* s_t^N *in the VR economy, are related as follows*

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda^E_{t,m} r^M_{t+m}}{\sum_{m=0}^{\infty} \Lambda^E_{t,m}} = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda^B_{t,m} r^M_{t+m}}{\sum_{m=0}^{\infty} \Lambda^B_{t,m}},$$

where the last term is the bank-weighted average of future policy rates under the bank's effective discount factors.

Proof. See Appendix A.8.

Proposition 1 states that FR and VR contracts differ only in the timing of the loan repayment streams, but quantities are the same. The proportionality condition ensures that banks and entrepreneurs agree on how to translate a VR contract into an equivalent FR contract. For a given VR spread s_t^N, the FR equivalent is the spread plus a weighted average of future policy rates, with the weights given by the agent's effective discount factors. If those discount factors are proportional, both sides attach the same relative weights to payments at different horizons and therefore compute the same fixed-rate equivalent. Equilibrium pricing can then fully offset the timing difference between FR and VR.

If discount factors are not proportional, that common mapping disappears. This also clarifies why the proposition separately requires banks to remain sufficiently well capitalized so that the solvency threshold never becomes relevant. Once insolvency risk becomes relevant, banks discount distant repayments more heavily because they may not survive long enough to collect them. Subsection 3.3 shows how this endogenous tilt in bank discounting is one channel through which the benchmark irrelevance result breaks down. Once the two sides no longer agree on the value of the repayment stream, there need not exist a pricing adjustment that leaves both loan supply and loan demand unchanged. Contract structure can then affect equilibrium lending.

Proportional effective discounting places restrictions on effective taxation, exit and liquidation risk, and reinvestment returns across the two sides of the credit relationship, detailed in Appendix A.8. While these conditions do not hold in the quantitative model, Section 5 shows that when idiosyncratic risk is muted enough to keep banks away from the solvency threshold, the remaining differences between FR and VR economies become quantitatively small.

3.2 Monetary policy transmission

To see how monetary policy operates in the benchmark, it is useful to combine the entrepreneur's loan-demand equation (14) with the corresponding benchmark supply condition

$$N_{j,t} = (f')^{-1}\left(\sum_{m=0}^{\infty} \Lambda^{B}_{t,m} q^{N}_{t,m} - \Gamma_t\right) L_{j,t},$$

where Γ_t collects the marginal costs, including funding, of originating one extra unit of loans. Because the coefficient on $L_{j,t}$ is common across banks, supply aggregates linearly. A monetary tightening raises banks' funding costs, summarized by a higher Γ_t. For any given loan repayment stream $q^{N}_{t,m}$, the term in parentheses falls, so banks are willing to supply fewer loans, and the supply schedule shifts inward. On the demand side, equation (14) is downward sloping in the repayment stream because higher promised repayments reduce the value of entry for entrepreneurs. Equilibrium therefore moves to a lower quantity of new loans and a higher loan rate in the FR economy, or, given the policy-rate path, a higher spread in the VR economy. This is the benchmark transmission mechanism.

3.3 Why heterogeneity matters

Once idiosyncratic risk is present and bank failure becomes possible, repayment timing matters for banks through two balance-sheet channels. First, there is a *discount-factor channel*: a bank closer to the solvency threshold is less likely to survive long enough to collect distant loan cash flows, so it values those payoffs less. Second, there is a *precautionary channel*: current lending raises future leverage and therefore future solvency risk, which adds an extra cost to expanding credit today. Interest-rate risk exposure is therefore consequential only when banks differ in their distance to the solvency threshold—the margin that the irrelevance benchmark shuts down.

In the full quantitative model, both channels are active. A convenient way to summarize their effect is through the bank-specific lending condition

$$N^{x}_{j,t} = L_{j,t}(f')^{-1}\left(\sum_{m=0}^{\infty} \tilde{\Lambda}^{B,x}_{j,t,m}\, q^{N}_{t,m} - \Xi^{x}_{j,t}\right), \qquad x \in \{FR, VR\}, \tag{18}$$

where $\tilde{\Lambda}^{B,x}_{j,t,m}$ are bank-specific effective discount factors, and $\Xi^{x}_{j,t}$ is a bank-specific marginal-cost term collecting the components of the cost of new lending that do not operate through the discounted repayment stream. Appendix A.9 derives the exact bank-specific supply condition.

Equation (18) makes both channels explicit. The discount-factor channel operates through $\tilde{\Lambda}^{B,x}_{j,t,m}$: a bank closer to the solvency threshold assigns lower weight to distant loan income, reducing the present value of the repayment stream. The precautionary channel operates through $\Xi^{x}_{j,t}$: expanding the loan book today raises future leverage and therefore the expected solvency cost of lending. Heterogeneity in these two objects is what breaks the aggregation logic behind Proposition 1.

These two channels represent the margins through which FR and VR lending can differ after a monetary policy shock. Following a monetary tightening, any effect of the shock on banks' net interest margins changes net worth and therefore banks' distance to the solvency threshold. Through the discount-factor channel, this changes the weight banks place on distant loan cash flows. Through the precautionary channel, it changes the marginal solvency cost of expanding credit today. The sign and quantitative importance of both forces, therefore, depend on how monetary policy affects net interest margins, and hence bank capitalization, under each contract structure. Because these mechanisms operate through banks' capitalization, their aggregate implications depend on how the shock reshapes the cross-sectional distribution of bank capitalization relative to the solvency threshold. Sections 5 and 6 quantify those effects and show when they amplify or dampen the benchmark transmission mechanism.

Because effective discount factors $\tilde{\Lambda}^{B,x}_{j,t,m}$ and marginal-cost terms $\Xi^{x}_{j,t}$ are bank-specific, aggregation fails: aggregate lending can no longer be summarized by average leverage alone. The full leverage distribution matters because banks nearest the solvency threshold respond the most and do so differently under FR and VR contracting.

4. Calibration and quantitative discipline

This section presents the solution method, parameterization, and quantitative fit of the model. Subsection 4.1 presents the functional forms and presents the parameterization and the identification logic behind the key moments. Subsection 4.2 validates the steady state against the cross-sectional object central to the mechanism—the left tail of the capital-ratio distribution—along with along with balance-sheet composition and the bank asset-size distribution. Subsection 4.3 then compares the model's dynamic responses to monetary tightening with their empirical counterparts.

4.1 Functional forms and identification of parameter values

We calibrate the model to the euro area economy at quarterly frequency. The calibration follows a two-step procedure. First, we set institutional and steady-state parameters from regulation and external evidence. Second, we choose the remaining parameters jointly to match the moments that discipline the mechanism: bank failure risk, voluntary capital buffers, average loan pricing, the lending response to monetary tightening, operating costs, and the cross-sectional size distribution. Table 1 summarizes the parameter values and targets.

The calibrated economy departs from the conditions required for irrelevance benchmark in Proposition 1 to hold. In particular, banks and borrowers discount the same loan cash flows at different rates, reflecting differences in survival risk, subjective time preference, and outside options.

Pre-set parameters. The first block of Table 1 corresponds to the pre-set parameters. We follow Mendicino et al. (2020) and set the annualized average loan default rate p to 2.65% and the annual loan loss given default λ to 0.3. The annual average loan maturity δ is set to 0.2, implying an expected loan duration of 5 years, consistent with the average maturity of syndicated loans in developed economies reported by Cortina et al. (2018). The corporate tax rate τ is set to 20%, matching the average effective tax rate for European banks.[18]

These parameters pin down the institutional environment and steady-state rate levels. On the regulatory side, the minimum capital requirement γ is set to 7%, equal to the Basel III CET1 minimum of 4.5% plus the capital conservation buffer of 2.5%. The deposit-to-loan ratio $\alpha = 0.97$ and the liquidity requirement $\theta = 11.8\%$ are set to match the observed deposit-loan mix and liquid-asset share in the consolidated balance sheet of euro area for the reference period 2013-2023.[19] Finally, the steady-state policy rate r^M and deposit rate r^D are set to 1% and 0.5%, respectively, roughly matching their euro area averages over a long time sample.[20]

Jointly calibrated parameters. The second block of Table 1 reports the parameters calibrated jointly to match a set of targeted moments. To model portfolio credit risk, we specify the cumulative distribution function (CDF) of loan default rates, ω_{jt+1}, using the Vasicek (2002)

[18]See the Damodaran database http://www.stern.nyu.edu/~adamodar/pc/datasets/taxrateEurope.xls

[19]Appendix B.1 reports the balance-sheet construction in detail.

[20]We use a longer window (2003–2023) for these two rates to avoid overweighting the zero-lower-bound period, when both rates showed limited variability; this is also the earliest start date for which the euro area average overnight rates paid by commercial banks on household and corporate deposits, sourced from the ECB's MFI Interest Rate (MIR) statistics, are publicly available. Over 2003–2023, the deposit facility rate (DFR) — the overnight rate paid by the ECB on commercial bank deposits, and the effective euro area policy rate since the Global Financial Crisis — averaged 0.92% (0.97% over 1999–2023), while the average overnight rate that commercial banks paid on their customers' deposits was 0.46%.

Table 1: Parameter values and calibration targets

Pre-set parameters

	Parameter	Value	Target/Source
p	Loan default rate, mean (%)	2.65	Mendicino et al. (2020)
λ	Loan loss-given-default	0.30	Mendicino et al. (2020)
δ	Loan maturity	0.20	Cortina et al. (2018)
τ	Corporate tax rate	0.20	Damodaran database.
γ	Min. capital requirement (%)	7.0	Basel III CET1 + Buffer requirement.
α	Deposits-to-legacy-loans ratio	0.97	Consolidated EA banks balance sheet.
θ	Liquidity requirement (%)	11.8	Reserves-to-total-debt ratio.
r^M	Steady-state policy rate (%)	1.0	EA deposit facility rate.
r^D	Steady-state deposit rate (%)	0.5	EA overnight deposit rate.

Jointly calibrated parameters

	Parameter	Value	Target	Data	Model
β	Subjective discount factor	0.933	Banks' return on equity (%)	6.41	6.4
ρ	Loan default correlation	0.51	Bank failure probability (%)	0.66	0.66
η	Loan origination cost	0.22	Voluntary capital buffer (%)	5.12	4.8
ζ_1	Ent. entry cost (level)	5.78	Average loan rate (%)	3.13	3.0
ζ_2	Ent. entry cost (power)	0.50	Response of new lending (%)	-0.38	-0.37
$\bar{\pi}$	Fixed operating cost	0.012	Non-interest expenses to assets (%)	0.29	0.22
χ	Bank's exit rate (pp)	2.00	Slope of log-log asset distribution	-1.56	-1.56

Note: Interest rates and probabilities are reported in annualized terms.

single risk-factor model:[21]

$$F_j(\omega) = \Phi\left(\frac{\sqrt{1-\rho}\,\Phi^{-1}(\omega) - \Phi^{-1}(p)}{\sqrt{\rho}}\right), \tag{19}$$

where $\Phi(\cdot)$ is the CDF of a standard normal, $\Phi^{-1}(\cdot)$ denotes its inverse, and $\rho \in [0,1]$ is the loan correlation parameter. This parameter governs the dispersion of bank portfolio default rates and, therefore, the bank failure rate. We choose it to match the average annualized failure probability of 0.66% for European banks reported by Mendicino et al. (2024).

[21] See Appendix A.10 for derivations. This distribution assumes that individual banks face limits to fully diversifying their loan portfolios and that loan defaults arise from common dependence on a single risk factor, as in the model underlying the internal ratings based (IRB) approach of Basel II. See Gordy (2003) and Repullo and Suarez (2004).

We assume that banks face a convex loan origination cost:

$$f(N_{jt}/L_{jt}) = \eta \left(\frac{N_{jt}}{L_{jt}} \right)^2, \tag{20}$$

with $\eta > 0$. The functional form for entrepreneurs' entry costs, which underlies the aggregate loan demand derived in Section 2.2, is:

$$a(N_t) = \zeta_1 N_t^{\zeta_2}, \tag{21}$$

where $\zeta_1 > 0$ governs the scale of loan demand and $\zeta_2 > 0$ controls its semi-elasticity to interest rates.

The parameters ζ_1, ζ_2, and η are calibrated to match three moments central to the transmission mechanism:[22] (i) the average loan rate of 3.13% for our reference period, sourced from the ECB's MFI Interest Rate (MIR) statistics; (ii) the peak response of log new lending to a 100 basis-point monetary policy shock, equal to −0.38 (computed using the local projection methodology detailed in subsection 4.3); and (iii) the average voluntary capital buffer of 5.12 percentage points, consistent with the mean CET1 buffer in 2021Q4 for banks supervised by the ECB.[23]

Finally, the discount factor β, the fixed operating cost parameter $\bar{\pi}$, and the exit rate χ are calibrated to three moments: the average ROE of European banks from Mendicino et al. (2024); the average non-interest-expense-to-asset ratio in the ECB's Consolidated Banking Data over 2013–2023; and the log-log tail coefficient of the bank asset-size distribution (Figure 2).[24] This last target allows the model to replicate the power-law distribution of bank sizes observed in the data, as discussed in Section 4.2.

Ex-ante heterogeneity: FR and VR economies. We compare two counterfactual economies: one in which all loans are fixed-rate and one in which all loans are variable-rate (FR and VR economies, respectively). Figure 1, which presents the share of VR loan contracts in each country, shows that this distinction maps naturally into the euro area. We define VR loans as contracts with a maturity over one year and whose interest rate resets within the next 12 months.[25] The cross-country dispersion is large and persistent: in Germany, France, Belgium, and the Netherlands, approximately 80% of outstanding loans are fixed-rate, whereas in Finland, Portugal, Spain,

[22]Though all the parameters in this group are jointly calibrated, some subgroups are more relevant for certain subsets of moments.

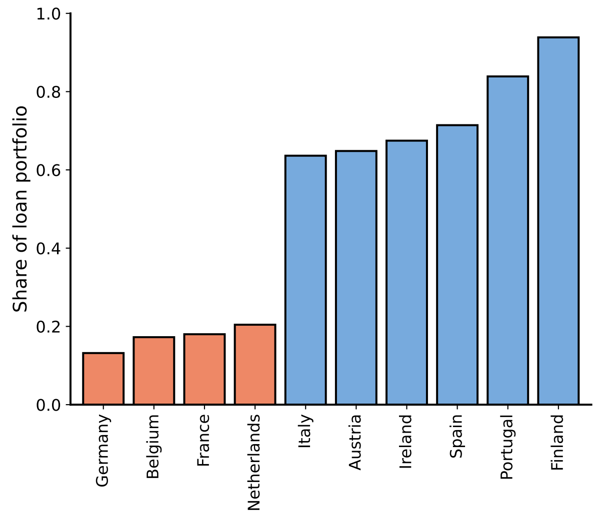
[23]We calibrate the model based on CET1 data for ECB-supervised banks, which provide the most accurate available estimates of capital buffers. Appendix B.2 compares alternative CET1 ratio and buffer estimates.

[24]Our approach of disciplining the model to fit cross-sectional characteristics of the bank size distribution aligns with that of recent studies (Corbae and D'Erasmo, 2021; Jamilov and Monacelli, 2025).

[25]The categorization in Figure 1 also aligns with results reported by Core et al. (2025) using granular data on non-financial corporate loans in the euro area.

Ireland, Italy, and Austria, more than 60% are variable-rate.[26] We use these two groups when comparing empirical and model responses to monetary shocks below.

Figure 1: Share of variable-rate loans.



Note: Average share of total outstanding loans issued at variable rates, 2013–2023. Includes loans to non-financial corporations and to households (mortgage, consumer, and other loans). Orange bars correspond to our fixed-rate country classification; blue bars correspond to variable-rate countries. *Source*: ECB MFI Statistics.

4.2 Cross-sectional validation

The cross-sectional moments serve a specific purpose in this paper. The mass of banks near the capital requirement is the main driver of amplification, so the quantitative exercise requires the model to reproduce the left tail of the capital-ratio distribution observed in the data. This distribution is therefore the key validation object. Balance-sheet composition disciplines net interest margins given the interest rate differentials in the model. The bank asset-size distribution, although irrelevant for policy functions—which are scale-invariant—pins down the exogenous exit rate that governs entry and exit dynamics.

Capital ratio distribution. Table 2 reports the distribution of capital ratios in the data and in the model's steady state.[27] The model reproduces the left tail of the distribution well. The capital ratio at the first percentile is 9.7% in the model and 9.4% in the data, both only modestly above

[26] Appendix B.3 provides additional evidence on this classification and shows that these patterns are stable across loan categories and alternative thresholds.

[27] Since the gradual implementation of Basel III beginning in 2013, capital ratios for euro area banks have trended upward over time. To adjust for this time trend, we demean capital ratios period by period and recenter the pooled distribution using the 2019 mean capital ratio. See Appendix B.2 for further details.

the regulatory minimum of 7%. More generally, the model places substantial mass close to the requirement: at the 40th percentile, the capital ratio is 12.7% in the model versus 13.5% in the data. This is the region of the distribution that matters for the mechanism, because banks near the solvency threshold are the ones whose lending choices are most sensitive to equity losses.

The model is less successful in the right tail. For banks in the upper half of the distribution, the average capital ratio is 13.1% in the model versus 18.7% in the full sample. We do not interpret the calibration as a claim to match the entire bank cross section perfectly. For our purposes, the fit to the left tail is the crucial one, because banks far from the regulatory threshold behave nearly homogeneously in the model. The fit improves when the comparison is restricted to large banks, for which the average capital ratio in the upper half of the distribution falls to 14.7% in the data. Part of the remaining gap likely reflects regulatory margins outside the model, notably the Minimum Requirement for Own Funds and Eligible Liabilities (MREL), which smaller banks often satisfy with extra CET1 capital rather than with bail-inable liabilities.[28]

Table 2: Capital-ratio distribution

	All Banks	Large Banks	Model
1st Percentile	9.36	9.68	9.71
5th Percentile	11.22	10.91	11.10
10th Percentile	11.68	11.28	11.66
20th Percentile	12.31	11.67	12.18
30th Percentile	13.03	12.00	12.46
40th Percentile	13.54	12.41	12.65
Avg. Top 50%	18.71	14.73	13.13

Note: Capital ratios are defined as CET1 capital divided by risk-weighted assets. The sample covers more than 60 euro area banks from 2013 to 2020. The "Large Banks" column refers to banks with assets exceeding €100 billion. *Sources*: S&P Global and ESRB supervisory data on European banks' capital requirements.

Bank balance sheet composition. We compare the consolidated balance sheet of monetary financial institutions (MFIs) in the euro area to its model counterpart.[29] Table 3 shows that the model's steady-state consolidated balance sheet closely matches the composition of assets and liabilities observed in the data. This matters because the mechanism operates through maturity transformation: banks fund a large stock of long-duration loans with deposits, wholesale debt,

[28]MREL requires banks to hold sufficient own funds and eligible liabilities to absorb losses and, if necessary, facilitate recapitalization in the event of failure.

[29]Appendix B.1 details the composition of MFIs and the time series used.

and a relatively small amount of equity and liquid assets. Asset-side ratios are directly targeted in the calibration, but on the liability side only deposits are targeted.[30]

Table 3: Consolidated bank balance sheet: Model vs. data (2013–2023)

Assets			**Liabilities**		
	Model	Data		Model	Data
Loans	89%	88%	Deposits	81%	78%
Short-term securities and reserves	11%	12%	Wholesale funding	9%	14%
			Equity capital	10%	8%

Note: The composition is expressed as percentages of total assets. Model counterparts correspond to the steady state. Data correspond to the consolidated balance sheet of euro area MFIs, excluding the Eurosystem, as reported by the European Central Bank. *Loans* include loans to the private sector, to the general government, and other risky assets. *Short-term securities and reserves* include short-term securities holdings, operations with national central banks (repos and securities lending), and other short-term external assets. *Deposits* include retail deposits of different maturities, external liabilities, and other liabilities. *Wholesale funding* corresponds to debt securities issued. *Equity capital* comprises capital and reserves. In the Model, loans include legacy and new loans. *Source*: European Central Bank, Statistical Data Warehouse (SDW).

Asset-size distribution. The model also reproduces the heavy right tail of the bank asset-size distribution observed in the data.[31] Figure 2 compares the right tails of the model and empirical asset distributions in log-log space. The model reproduces the power-law behavior observed in the data, which emerges endogenously from the combination of size-independent growth rates and stochastic exit, consistent with Gabaix (2009). This regularity is well documented empirically, both for U.S. banks (Janicki and Prescott, 2006) and across European banking systems (Bremus et al., 2018).

4.3 Time-series validation

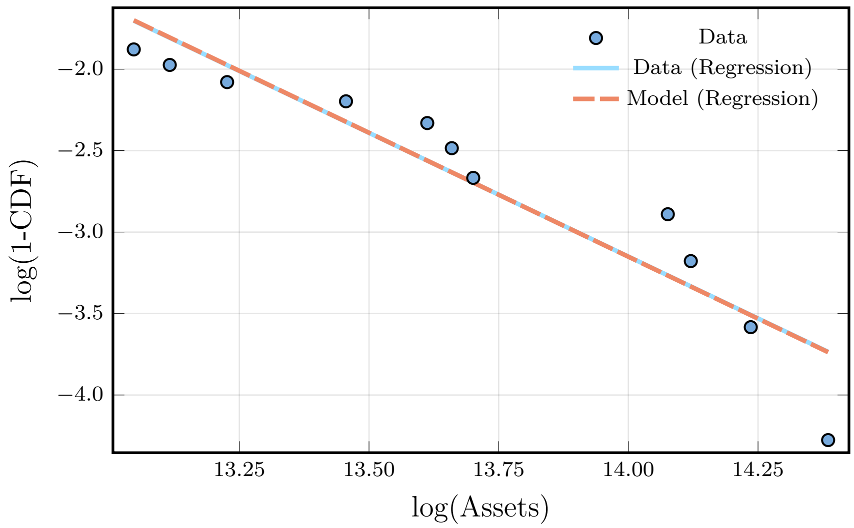
We examine whether the calibrated model reproduces the response patterns that motivate the paper. We estimate empirical impulse responses using local projections (Jordà, 2005; Jordà et al., 2015) on a balanced panel of the ten largest euro area countries, grouped into FR and VR systems using the classification above.[32] We then feed the model the empirical paths of the policy rate and the deposit rate following a 100 basis-point monetary tightening. Model transitional

[30] In the consolidated data, the aggregate measure of *equity capital* is broad and includes multiple forms of bank capital. As a result, it does not correspond to the regulatory capital measure used in the calibration, namely CET1 capital expressed as a percentage of risk-weighted assets.

[31] We characterize the distribution of bank assets using an unbalanced bank-level panel from S&P Global, a proprietary source. This quarterly dataset covers more than 70 euro area banks from 2013 to 2020 and includes information on CET1 capital levels, risk-weighted assets, and total assets. See Appendix B.2 for details.

[32] Appendix B.4 reports the local projection estimation details, Appendix B.5 shows robustness to using all twenty euro area countries

Figure 2: Bank asset size distribution: Tail behavior.



Note: Blue dots represent different observations in the right tail of the empirical asset distribution in 2019Q4. *Data (Regression)*: We fit a power-law distribution of the form $f(x) = \bar{A}x^{-(\psi+1)}$, where ψ captures the tail behavior and equals the slope of a log-log regression of the complementary empirical cumulative distribution function on asset size. The light blue line shows the fitted relationship. *Model (Regression)*: The dashed red line is the model counterpart, based on the steady-state distribution. We scale the model asset size to make the plotted slopes easier to compare.

dynamics are computed following an unanticipated (MIT) shock, using an algorithm similar to Boppart et al. (2018).[33]

The rate paths are exogenous inputs to the quantitative experiment. This allows us to focus on whether, given a common tightening in policy and funding costs, the model reproduces the relative responses of lending-side variables across FR and VR systems.

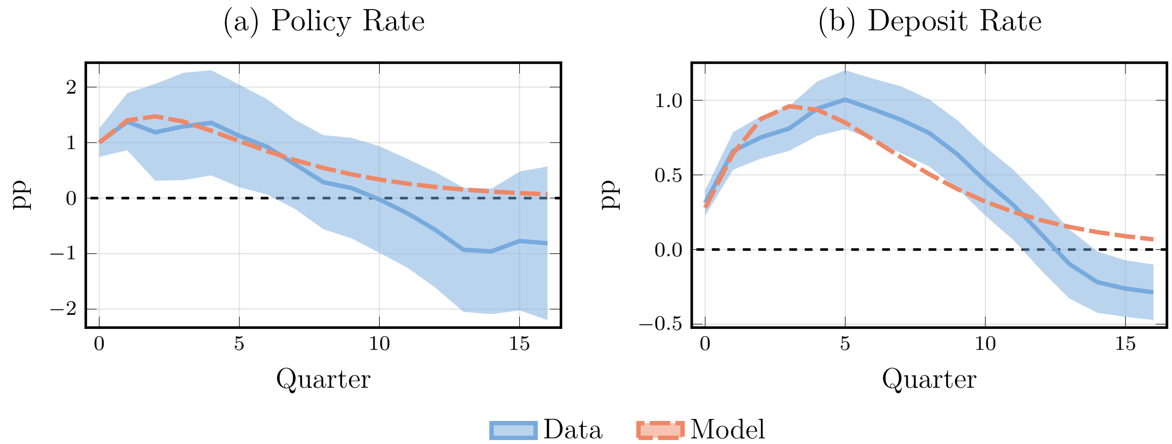
Exogenous rate paths. Figure 3 reports the policy-rate and deposit-rate paths used in the experiment. We approximate these paths using AR(2) processes for r^M and r^D so that the quantitative exercise isolates the bank-lending channel rather than the pass-through from monetary policy to deposit rates.[34] Given those inputs, loan prices and quantities are determined endogenously in equilibrium.

Untargeted impulse responses. Figure 4 shows the dynamic responses of the key objects of interest: loan rates, net interest margins on legacy loans, and legacy loan volumes. Although the calibration uses the average response of new lending as a target, it does not target the regime-specific responses of these variables. The left panels correspond to VR countries, while

[33] This is equivalent to solving a model with aggregate risk using a first-order perturbation method. Appendix C describes the solution algorithm.

[34] See Section 6 below for details.

Figure 3: Exogenous rate paths after a monetary shock



Note: Solid blue lines show the empirical impulse responses to a monetary policy shock; dashed red lines show the exogenous paths fed into the model. Light blue bands indicate 95% confidence intervals. Panels (a) and (b) report the responses of the policy rate and the deposit rate, respectively. See Appendix B.4 for details.

the right panels correspond to FR countries. The model matches three central patterns. First, pass-through to new loan rates is stronger in VR economies than in FR ones (Panels a and b). Second, the NIM on legacy loans rises in VR economies but falls in FR economies (Panels c and d). Third, legacy loan volumes decline more, and more persistently, in FR economies (Panels e and f).[35]

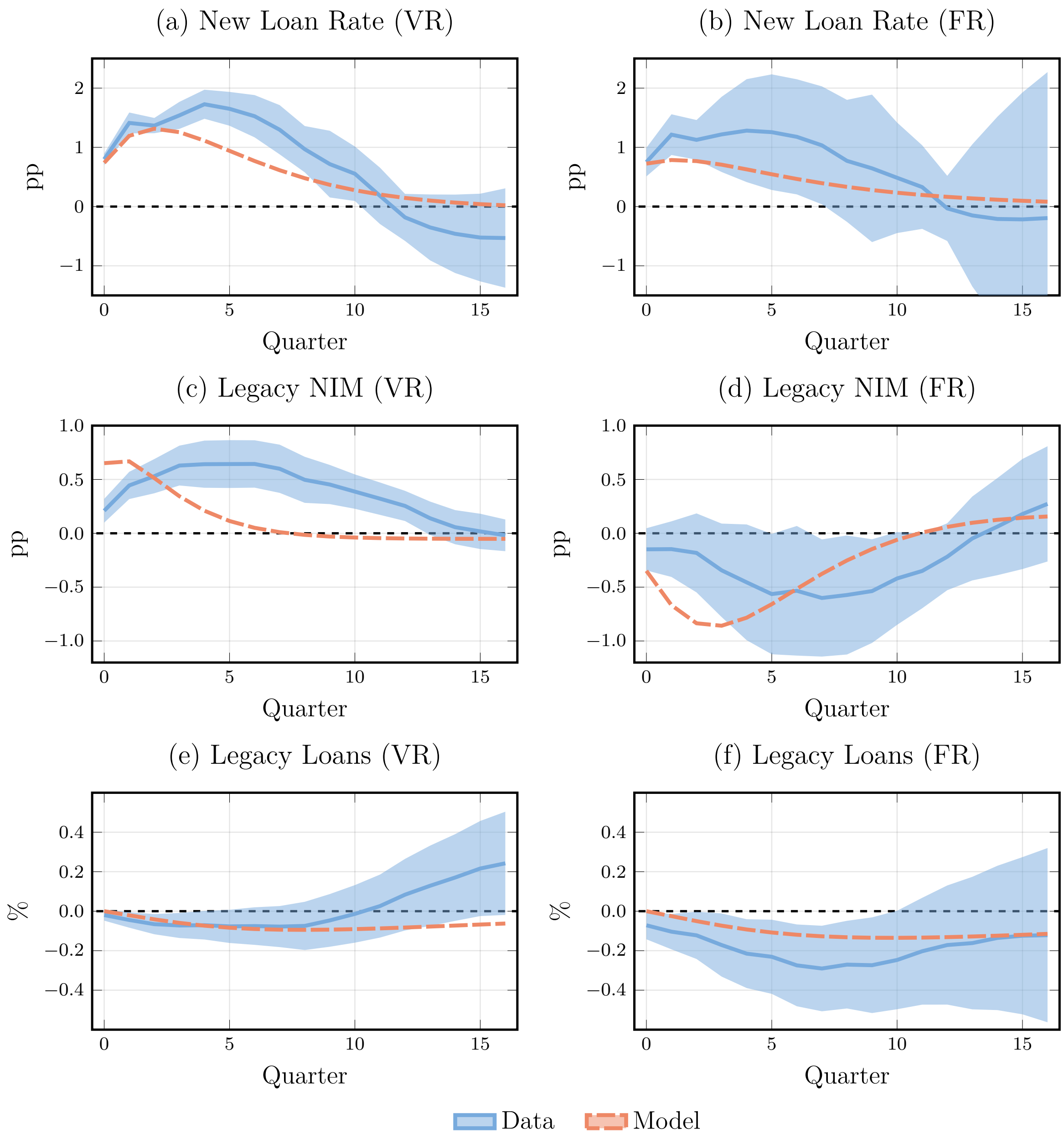
The model simultaneously captures several demanding qualitative and quantitative features of the data. While it understates the persistence of the NIM response, it successfully reproduces the signs, relative magnitudes, and regime ranking of the main lending-side variables. Furthermore, it captures a seeming paradox: new loan rates rise by more in VR economies, yet credit contracts by less than in FR economies. The fact that these patterns arise as untargeted predictions, disciplined only by aggregate moments and the cross-sectional distribution of capital ratios, lends credibility to the model's core mechanism. We explore this mechanism in turn.

5. Quantitative results

We now compare the transmission of interest-rate shocks to bank lending in FR vs. VR economies. Under the same path of funding costs, lending declines by substantially more in the FR economy because legacy NIM dynamics move the distribution of bank capital in opposite directions across regimes. We first present aggregate impulse responses and then test the role of heterogeneity

[35] In the data, the NIM for legacy loans is defined as the difference between the average interest rate on the stock of legacy loans and the average deposit rate.

Figure 4: Untargeted impulse responses



Note: Solid blue lines show the empirical impulse responses to a monetary policy shock; dashed red lines show the model counterparts. Light blue bands indicate 95% confidence intervals. Panels (a) and (b) report the response of the interest rate on new loans; panels (c) and (d) report the response of the legacy NIM; panels (e) and (f) report the response of legacy loans. Left panels correspond to VR countries; right panels correspond to FR countries. See Appendix B.4 for details.

by compressing idiosyncratic risk until the benchmark conditions of Proposition 1 are nearly restored. We next examine bank-level responses to show that banks closest to the regulatory threshold drive the aggregate divergence. Finally, we assess when borrower-side credit-risk feedbacks can overturn the baseline ranking.

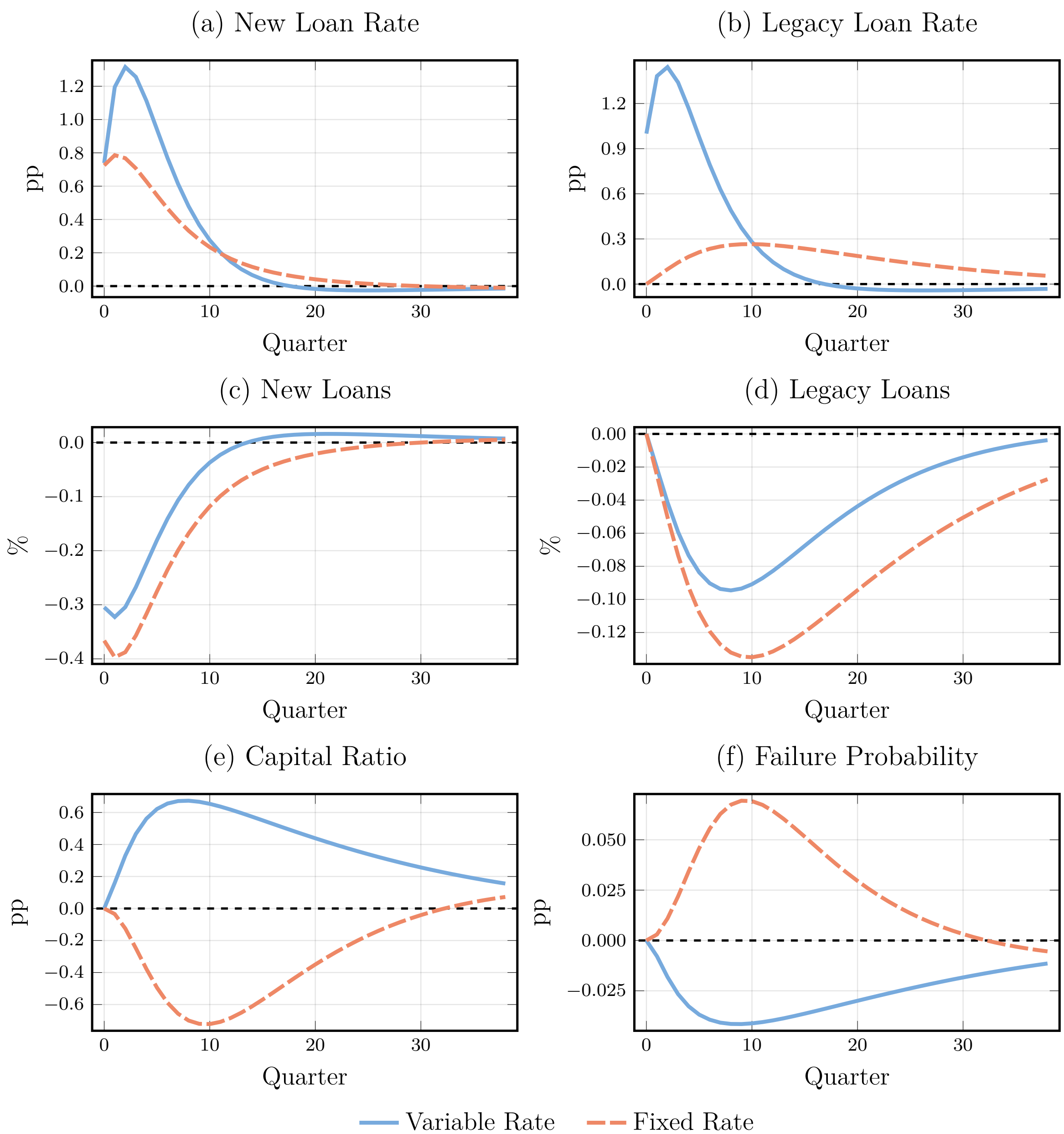
Aggregate responses. Figure 5 presents the aggregate responses to the one-percentage-point monetary tightening. By design, both economies face the identical path of funding costs: wholesale rates rise one-for-one with the policy rate, while deposit rates pass through more slowly, as shown in Figure 3. The difference across regimes originates in the divergence in net interest margins (NIM) documented in Figure 4. In the VR economy, legacy loan rates reprice with the policy rate, so the legacy NIM expands as asset returns outpace the slower pass-through of deposit rates. In the FR economy, legacy loan rates are fixed, so the legacy NIM compresses as funding costs rise against unchanged contractual rates (Panels a and b).

If the conditions of Proposition 1 held, these diverging NIM paths would be irrelevant for aggregate credit supply. They would merely represent different intertemporal transfers of surplus between banks and borrowers, all perfectly offset by equilibrium pricing of new loans. However, idiosyncratic default risk generates dispersion in bank capital positions, so the cross-sectional distribution of bank capital matters. In both the data and the model's steady state, a nontrivial mass of banks operates close to the solvency threshold, as already seen in Table 2. For these banks, legacy NIM dynamics translate into equity changes that shift their distance to that threshold.

When the monetary shock hits, legacy NIM dynamics shift the distribution of bank capital in opposite directions. In the VR economy, NIM expansion rebuilds equity and capital ratios, pulling banks away from the threshold (Panels e and f). In the FR economy, NIM compression erodes equity and capital ratios , pushing banks closer to the solvency threshold. This activates the two heterogeneity channels from Section 3: higher insolvency risk lowers the value banks assign to distant repayments, and the precautionary cost of new lending rises. As a result, the decrease in bank lending is amplified in the FR economy. By contrast, in the VR economy, NIM expansion builds equity, pulling banks away from the threshold and dampening the precautionary contraction. Consequently, aggregate lending declines by about one-third more in the FR economy, even though the interest rate on new loans initially rises by less there than in the VR economy (Panels c and d).

If this logic is correct, the divergence between the FR and VR aggregate lending responses should disappear if banks are kept sufficiently far from the solvency threshold, shutting down the two heterogeneity channels regardless of the behavior of the legacy NIM. This motivates our next exercise.

Figure 5: Aggregate impulse response functions



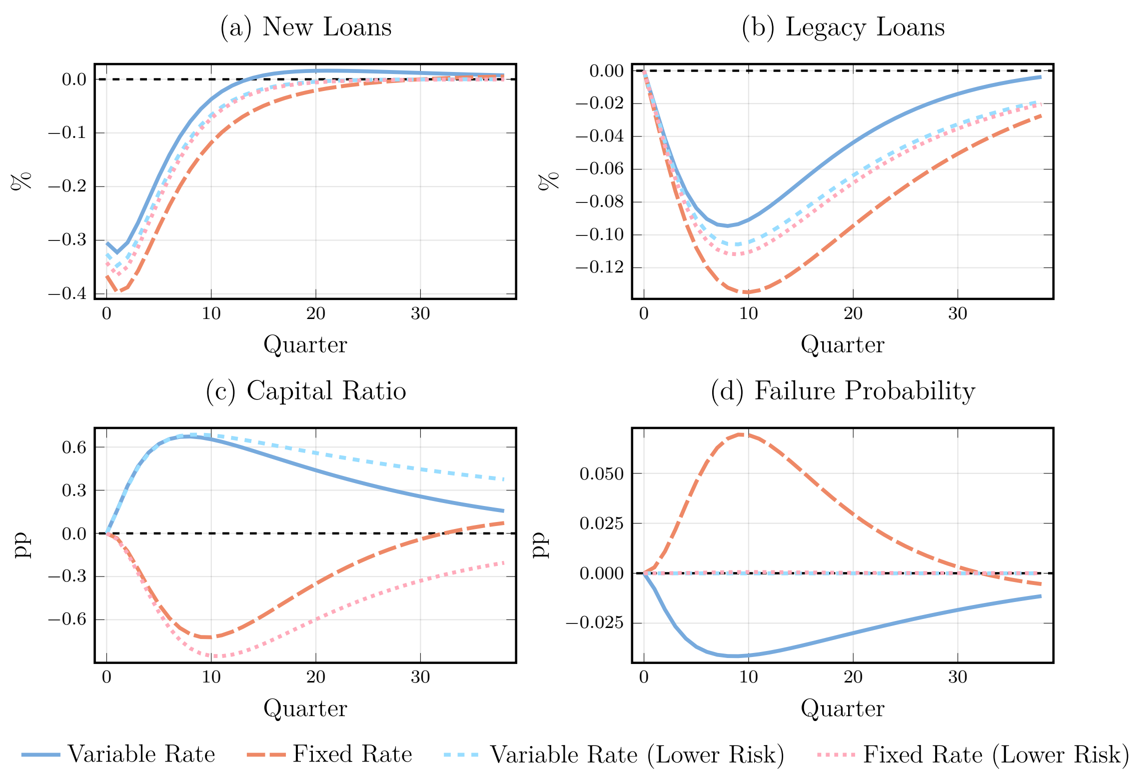
Note: Impulse responses to a 1 percentage point increase in the policy rate. Solid blue lines correspond to the variable-rate (VR) economy; dashed red lines correspond to the fixed-rate (FR) economy.

Restoring the benchmark. We test this implication by lowering the default-correlation parameter from $\rho = 0.51$ in the baseline to $\rho = 0.1$, thereby reducing idiosyncratic loan-default risk. This counterfactual does not impose the conditions of Proposition 1 exactly—banks and entrepreneurs still discount future repayments differently—but it keeps banks away from the regulatory threshold and makes insolvency risk negligible, thereby nearly restoring the benchmark condition that the threshold never becomes relevant.

Once insolvency risk is negligible, FR/VR differences essentially disappear (se. dotted lines in Figure 6). Lending responses become almost identical across regimes (Panels a and b), and failure probabilities are essentially zero throughout (Panel d). If contract structure alone were the quantitatively dominant force, large FR/VR differences would survive: legacy repricing patterns and equity dynamics still differ across regimes, yet lending responses converge.

Low idiosyncratic risk compresses the dispersion in bank leverage, so neither heterogeneity channel operates materially. In the FR economy, legacy NIM compression no longer pushes a meaningful mass of banks toward the constraint. In the VR economy, legacy NIM expansion provides meaningful relief because solvency pressure is already negligible. This shows that endogenous bank fragility is the quantitatively dominant departure from Proposition 1, while the importance of the residual wedge between bank and borrower discount factors is quantitatively minor.

Figure 6: Impulse response functions — Lower idiosyncratic risk



Note: The impulse responses denoted “Variable Rate” and “Fixed Rate” correspond to the baseline calibration. “Variable Rate (Lower Risk)” and “Fixed Rate (Lower Risk)” correspond to alternative parameterizations with $\rho = 0.1$ (versus $\rho = 0.51$ in the baseline), implying substantially lower idiosyncratic risk.

Cross-sectional responses. Which banks drive the aggregate differences? Figure 7 plots impulse responses for banks at selected percentiles of the steady-state capital-ratio distribution, with lighter shades corresponding to more highly leveraged institutions. Within a regime, all banks face the same funding conditions and the same loan demand curve. Cross-sectional dispersion therefore cannot come from different prices, so the new-loan rate moves identically across banks. Cross-sectional dispersion in lending therefore cannot come from different prices. It arises because the same NIM dynamics have different consequences for banks at different leverage levels: the mapping from legacy profits to solvency risk depends on each bank's distance to the regulatory threshold.

The two heterogeneity channels from Section 3—the discount-factor channel and the precautionary channel—are both visible in the cross-section. Legacy NIM dynamics across economies, and capital ratios across the distribution of banks, determine how strongly they operate after the shock.

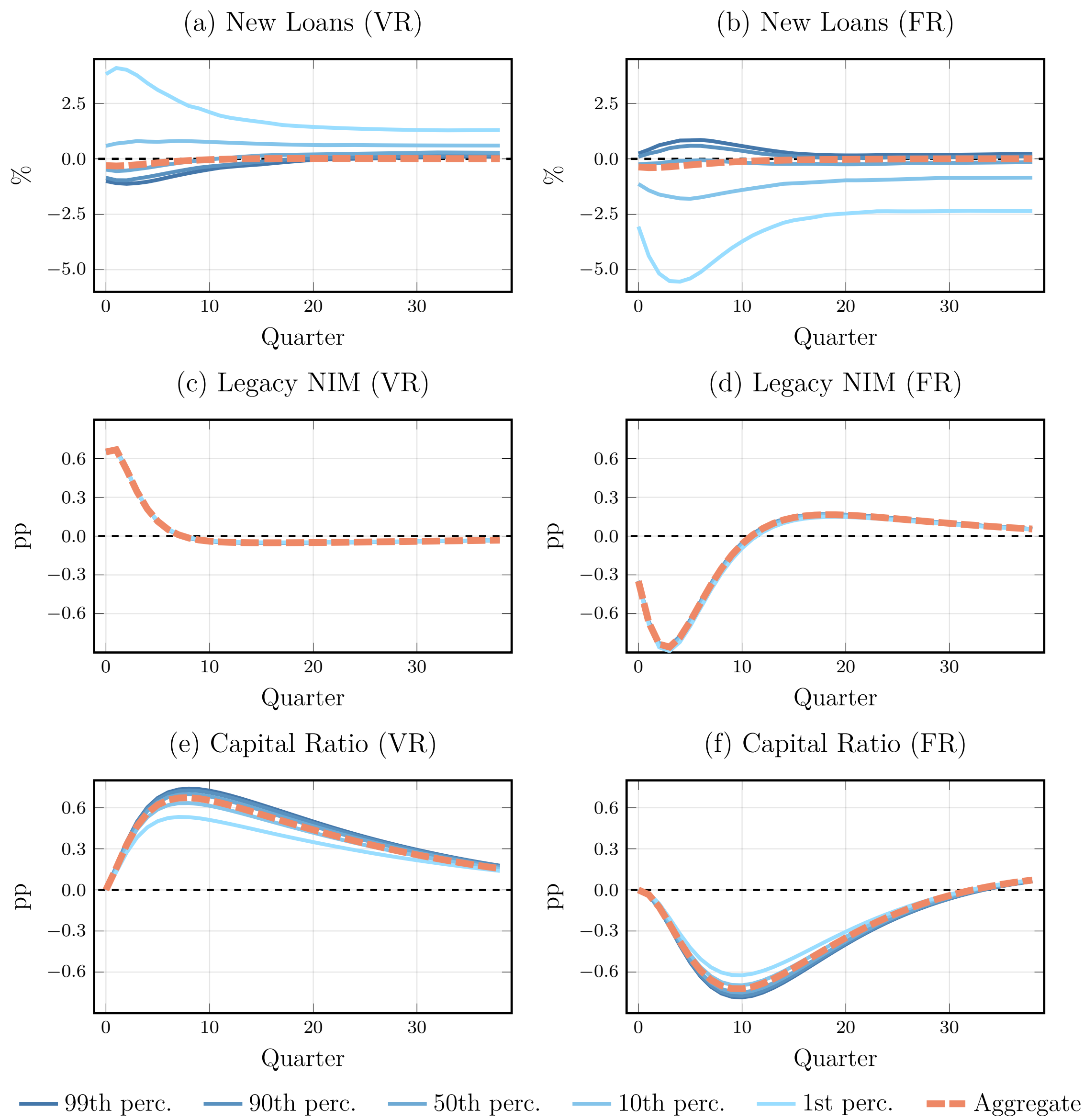
In FR economies, legacy NIM compression activates both channels for low-capital banks. Equity losses push those banks closer to the regulatory threshold, lowering the value of distant repayments and increasing the solvency cost of expanding credit. These banks therefore contract lending the most. Banks far from the threshold are much less affected, so they absorb part of the slack despite the aggregate contraction.

In VR economies, the same two channels operate in the opposite direction. Because legacy NIM expands, banks near the threshold rebuild capital buffers, assign greater value to future repayments, and face a smaller solvency cost of lending. Those banks contract much less, so their share of aggregate lending rises. The most leveraged banks in the figure—those at the 1st and 10th percentiles of the steady-state capital-ratio distribution—even expand their lending, because the legacy NIM expansion relaxes solvency pressure. Banks far from the threshold are already well capitalized, so neither channel shifts much for them, and their response is comparatively muted. The aggregate VR response is still a contraction, but a smaller one.

Figure 7 thus shows that the aggregate FR/VR gap is a reallocation outcome: common rate paths generate different aggregates because they shift the strength of the two channels differently across the capital-ratio distribution. This is why new-loan rates can rise by more in VR economies while aggregate lending falls by less.

Robustness to credit-risk endogeneity. As noted in our discussion of the literature, a rich body of work examines how interest-rate risk exposure affects loan demand by heterogeneous borrowers. This paper focuses on the counterpart: heterogeneous banks. To isolate the bank capital channel, we assume that the loan demand schedule is independent of legacy portfolio dynamics. However, when banks do not bear interest-rate risk, borrowers must. In VR economies,

Figure 7: Individual impulse response functions



Note: Dashed red lines show the aggregate impulse response for each variable, separately for fixed-rate (FR) and variable-rate (VR) banking systems. Solid blue lines show the impulse responses of banks at the 1st, 10th, 50th, 90th, and 99th percentiles of the capital-ratio distribution. The lightest shade corresponds to the 1st percentile (banks closest to the regulatory threshold in the steady state); darker shades correspond to higher percentiles.

borrowers face variable-rate loans, and higher interest rates raise their debt-servicing burdens—potentially increasing default probabilities. This feedback could reverse the greater sensitivity we find in FR economies.

We study the robustness of our results by extending the baseline exercise to allow default probabilities to respond endogenously to interest rates in the VR economy. Specifically, we let the probability of default p_t vary with the new loan rate according to:

$$p_t - p = \beta_p (r_t^N - r^N),$$

where β_p governs the sensitivity of credit risk to the path of rates on new loans. We keep the default probability in the FR economy fixed, as legacy loans are not exposed to interest-rate risk. Everything else remains the same, including the corresponding steady states from which we perturb the economy.

Figure 8 presents results for three values of the exposure: $\beta_p \in \{0.01, 0.03, 0.05\}$. We motivate these exposure rates based on available empirical evidence for the euro area, thinking of $\beta_p = 0.01$ as the most reasonable number.[36] An important observation is that the sensitivity of loan demand to changes in p, is very small. Instead, what drives the equilibrium response is how defaults widen the distribution of bank capital ratios. The key finding is that, for $\beta_p = 0.01$, FR economies continue to exhibit larger lending contractions than VR economies. For $\beta_p = 0.03$, the credit-risk feedback equalizes the lending response across regimes, whereas for $\beta_p = 0.05$, the results reverse.

This exercise suggests that our finding of a weaker bank lending channel in VR economies holds for small shocks but may reverse for larger ones. Indeed, while the lower sensitivity in VR economies is a feature of the empirical IRFs in Figure 4, those local projections are derived from many small policy shocks, for which it is plausible that default rates remain roughly constant and are predominantly driven by idiosyncratic factors. The results show that if interest-rate increases are sufficiently large, nonlinear effects can lead VR economies to experience greater contractions.

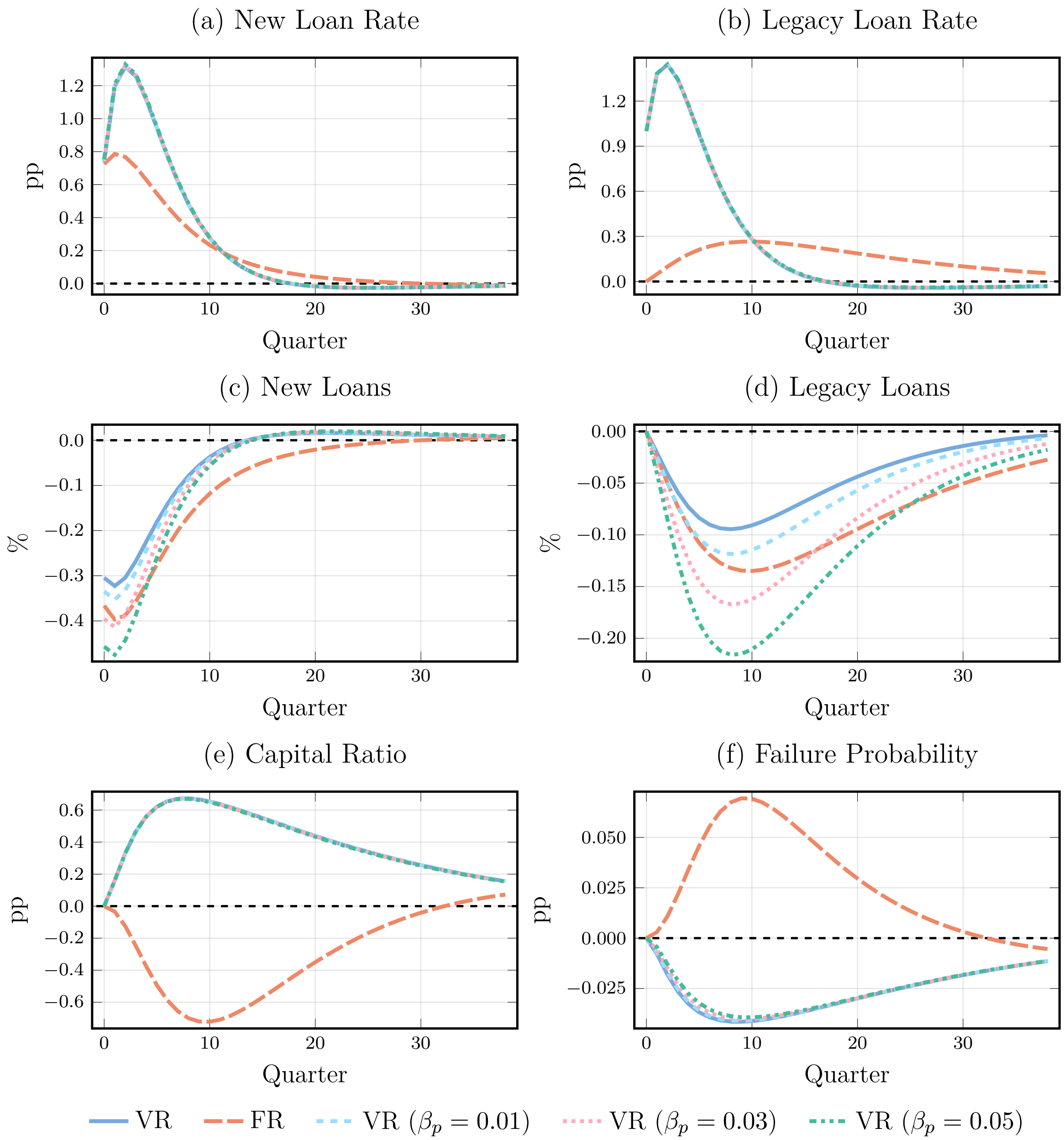
We emphasize that this exercise is intentionally reduced-form: we do not model borrowers' strategic default, endogenous screening by banks (which could dampen the effect on credit risk), or aggregate-demand feedback effects (which could amplify them).[37] A richer model would be

[36] Although limited, this evidence suggests that the effect of interest-rate changes on borrower defaults is generally small, highly non-linear, and path-dependent: On the household side, Bandoni et al. (2025) study variable-rate securitized mortgages in Spain, Italy, Portugal, and Ireland over 2014–2019 and find that, for lending rate increases below 70 basis points, the response of the one-year-ahead probability of default is between 0 and 8 basis points -—implying an elasticity of at most 0.1. On corporate loans, Core et al. (2025)'s findings suggest that loan renegotiation and firms' pricing behavior further dampen the transmission to variable-rate borrowers.

[37] Moreover, we apply the same default-probability rule to both new and legacy loans, though in practice legacy

needed to fully assess such non-linearities; we keep this exercise purposely simple to preserve focus on the core mechanism.

Figure 8: Aggregate impulse response functions: Credit-risk endogeneity



Note: Impulse responses to a 1 percentage point increase in the policy rate. Solid blue lines correspond to the variable-rate (VR) economy; dashed red lines correspond to the fixed-rate (FR) economy.

borrowers facing higher variable rates are more likely to default than new borrowers underwritten at current rates.

Taking stock. The heterogeneous bank lending channel in this model operates through a feedback loop: legacy portfolio dynamics affect the distribution of bank capital, which shapes how banks discount future loan cash flows. Funding costs and new-loan rates are common across banks within each regime; what differs is how legacy portfolio profits impact proximity to capital constraints. The core mechanism operates through reallocation of lending: In FR economies, NIM compression erodes equity, pushing constrained banks to curtail lending and amplifying the aggregate contraction. In VR economies, NIM expansion rebuilds equity, encouraging constrained banks to expand and dampening the aggregate contraction.

These findings align closely with recent cross-sectional evidence in Gomez et al. (2021), who study how banks' interest-rate risk exposures shape the transmission of monetary policy. They document that banks with larger interest-rate risk exposure experience NIM compression when rates rise, and that this compression reduces lending through its effect on bank equity. Crucially, the lending response is amplified for banks with lower capital ratios. Each of these patterns maps directly onto our model: NIM compression on legacy portfolios drives capital erosion (Figures 4 and 5), the effect operates only when the solvency threshold becomes relevant (Proposition 1), and low-capital banks are the key margin of transmission (Figure 7). The greater sensitivity of highly levered banks is also consistent with the broader literature on bank capital and lending (Jiménez et al., 2012; Dell'Ariccia et al., 2017; Altavilla et al., 2020).[38] Market-valuation evidence also corroborates the same mechanism: for the euro area, Ampudia and Van den Heuvel (2022) show that surprise policy-rate increases are associated with more negative bank stock price responses in fixed-rate countries, consistent with the asymmetric equity dynamics our model predict across the two regimes.

The same forces that amplify lending contractions in FR systems also raise failure risk there. The policy exercises in the next section therefore work by shifting the distribution of distance to the solvency threshold and, with it, the strength of the two heterogeneity channels.

6. Implications: monetary policy and financial stability

So far, we set aside an important issue: financial stability. Figure 5, Panel (f), shows that bank failure probabilities rise in FR economies but fall in VR economies—opposite responses to a common shock. This result is unsurprising given our analysis: the NIM on legacy loans drives profits, and hence equity, in opposite directions across regimes. While the direction of these

[38]The divergence across regimes is consistent with Hoffmann et al. (2018), who show that cross-sectional variation in European banks' interest-rate risk exposures is driven primarily by asset-side differences in loan-pricing conventions, and that net worth rises with interest rates for banks in VR-dominated economies. Altunok et al. (2023) find a similar pattern for U.S. banks: those with higher shares of adjustable-rate mortgages benefit from rate hikes through higher interest income, stronger stock-price reactions, and credit expansion.

effects follows naturally from profit accumulation, the findings have important implications for the design and coordination of monetary and macroprudential policies. We explore two dimensions.

Countercyclical capital regulation. A prominent macroprudential tool is the countercyclical capital buffer (CCyB). The CCyB requires banks to build additional capital during credit expansions. The objective is to build resilience during booms and support credit supply during downturns, thereby dampening excessive volatility in credit cycles that may threaten financial stability. Because monetary policy affects credit, a natural question is how these policies interact under the FR or VR regime.

We model the CCyB release as a reduction in the capital requirement γ_t, which then reverts according to $\gamma_t - \gamma = \rho_{\text{ccyb}}(\gamma_{t-1} - \gamma)$ with $\rho_{\text{ccyb}} = 0.95$. This reaction implies that the capital requirement slowly reverts to its steady-state value. Figure 9 displays the impulse response functions following a monetary policy tightening in the baseline scenarios and when the CCyB is released by 1 percentage point in both economies—the VR counterparts in blue (with the dashed series corresponding to the CCyB) and the FR counterparts in red (with the dotted series corresponding to the CCyB).

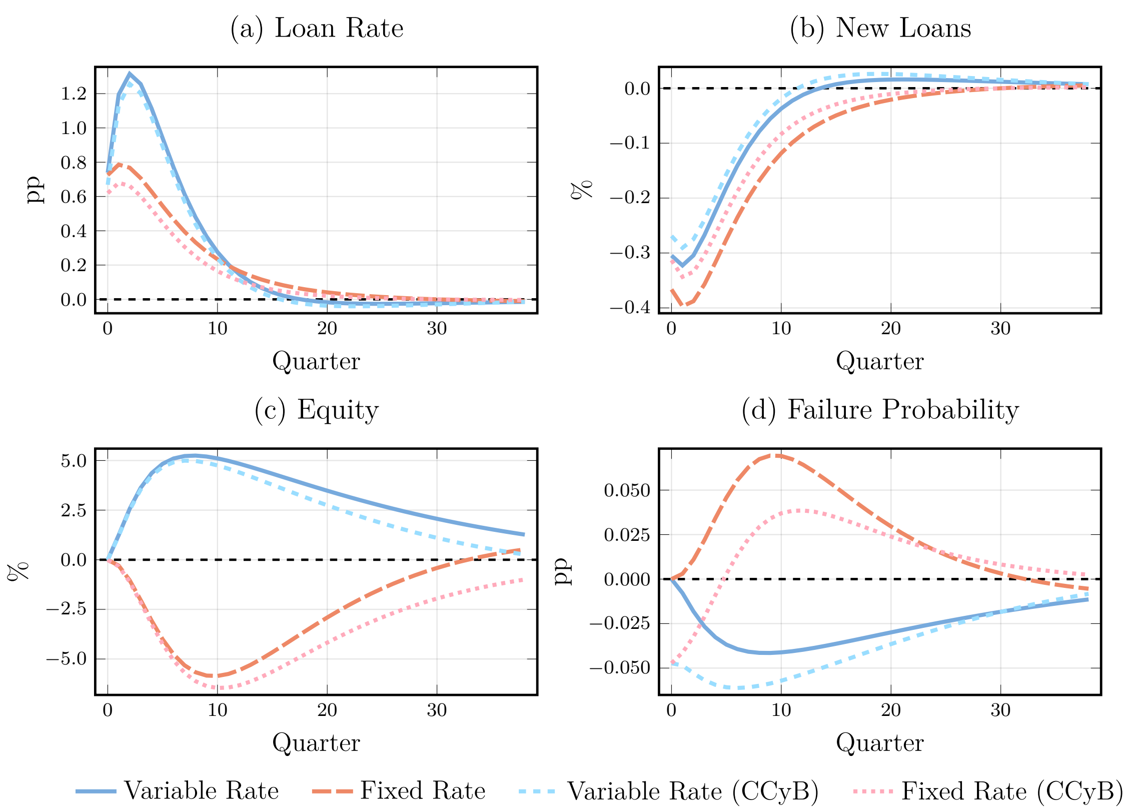
The main finding is that a temporary relaxation of capital requirements dampens the differential effects of monetary policy across banking systems. A release in the capital requirement increases each bank's distance to the regulatory threshold for all banks, but this has an asymmetric effect across regimes. Because equity dynamics move in opposite directions in FR and VR economies (Panel c), the banks most exposed to failure risk differ across systems: FR banks lose equity and drift toward the threshold, while VR banks gain equity and move away from it. By shifting the threshold itself, the CCyB release relieves levered banks in the FR regime, narrowing the gap in credit responses across the two systems (Panel b). This is consistent with Proposition 1: the farther banks are from the solvency threshold, the less consequential is ex-ante heterogeneity in interest-rate risk exposure.

The immediate effect of the release is a reduction in failure probability on impact in both banking systems, as banks enjoy greater capital headroom (Panel d). However, in the FR economy, the failure probability subsequently builds up: the persistent compression of net interest margins continues to erode equity even as the capital requirement gradually reverts to its steady-state level, eventually pushing some banks back toward the solvency threshold.[39]

This interaction is especially relevant for monetary unions, where a single policy rate coexists

[39]The converse also holds, though we do not display it here: if macroprudential policy tightens during a monetary contraction, the divergence in credit responses across banking systems is amplified. Tighter requirements push more banks toward the solvency threshold precisely when interest-rate risk exposure is generating the largest differences in equity dynamics, magnifying the gap that Proposition 1 identifies.

Figure 9: Impulse response functions — Interest rate increase + CCyB release



Note: The impulse responses denoted "Variable Rate" and "Fixed Rate" correspond to the baseline calibration. "Variable Rate (CCyB)" and "Fixed Rate (CCyB)" correspond to alternative scenarios in which γ_t is reduced by 1 percentage point at the time of the policy rate increase and then gradually reverts to its steady-state value.

with heterogeneous national banking structures. In such settings, macroprudential decisions at the national level can either offset or reinforce the regional asymmetries induced by uniform monetary policy.

Financial stability origins of monetary policy gradualism. The CCyB analysis shows that adequately timing a capital-buffer release can narrow the divergence between banking systems. A related question is whether the *path* of monetary policy itself can achieve a similar effect. We next compare policy rate paths that deliver the same cumulative stance—measured by the area under the policy rate impulse response—but differ in their speed of implementation. The motivation for holding the cumulative stance fixed is that, in the standard three-equation New Keynesian model, two such paths have equivalent effects on aggregate demand.[40] The

[40] To see this, note that the three-equation New Keynesian model features an IS curve of the form $x_t = \mathbb{E}_t(x_{t+1}) - \varsigma(i_t - \mathbb{E}_t(\pi_{t+1}) - r_t^n)$, where x_t is the output gap, i_t is the nominal interest rate, π_t is the inflation rate, r_t^n is the natural rate of interest, and $\varsigma > 0$ is the intertemporal elasticity of substitution. Variables are expressed as log-linear deviations from the steady state. Iterating forward and defining the ex-ante real rate gap as $\hat{r}_t \equiv i_t - \mathbb{E}_t(\pi_{t+1}) - r_t^n$,

exercise thus isolates the trade-offs that emerge through the bank lending channel: paths that are equivalent from an aggregate demand perspective can have markedly different financial stability implications.

To formalize the comparison, we consider variations of the AR(2) process used in the baseline calibration:

$$\hat{r}_t^M = \phi_1 \hat{r}_{t-1}^M + \phi_2 \hat{r}_{t-2}^M + \sigma \varepsilon_t,$$

where σ is the shock size and ε_t is an i.i.d. innovation. This process can be decoupled as two first-order processes:

$$\hat{r}_t^M = \mu_1 \hat{r}_{t-1}^M + z_t, \quad z_t = \mu_2 z_{t-1} + \sigma \varepsilon_t,$$

where μ_1 and μ_2 are the roots of the characteristic polynomial $x^2 - \phi_1 x - \phi_2 = 0$.

In our perfect-foresight environment, the area under the policy rate path equals

$$\sum_{t=0}^{\infty} \hat{r}_t^M = \frac{\sigma}{(1-\mu_1)(1-\mu_2)}.$$

Fixing μ_1 at its baseline value, we generate more gradual policy paths with the same cumulative stance by increasing μ_2 while reducing σ proportionally, so that the area under the IRF remains unchanged.

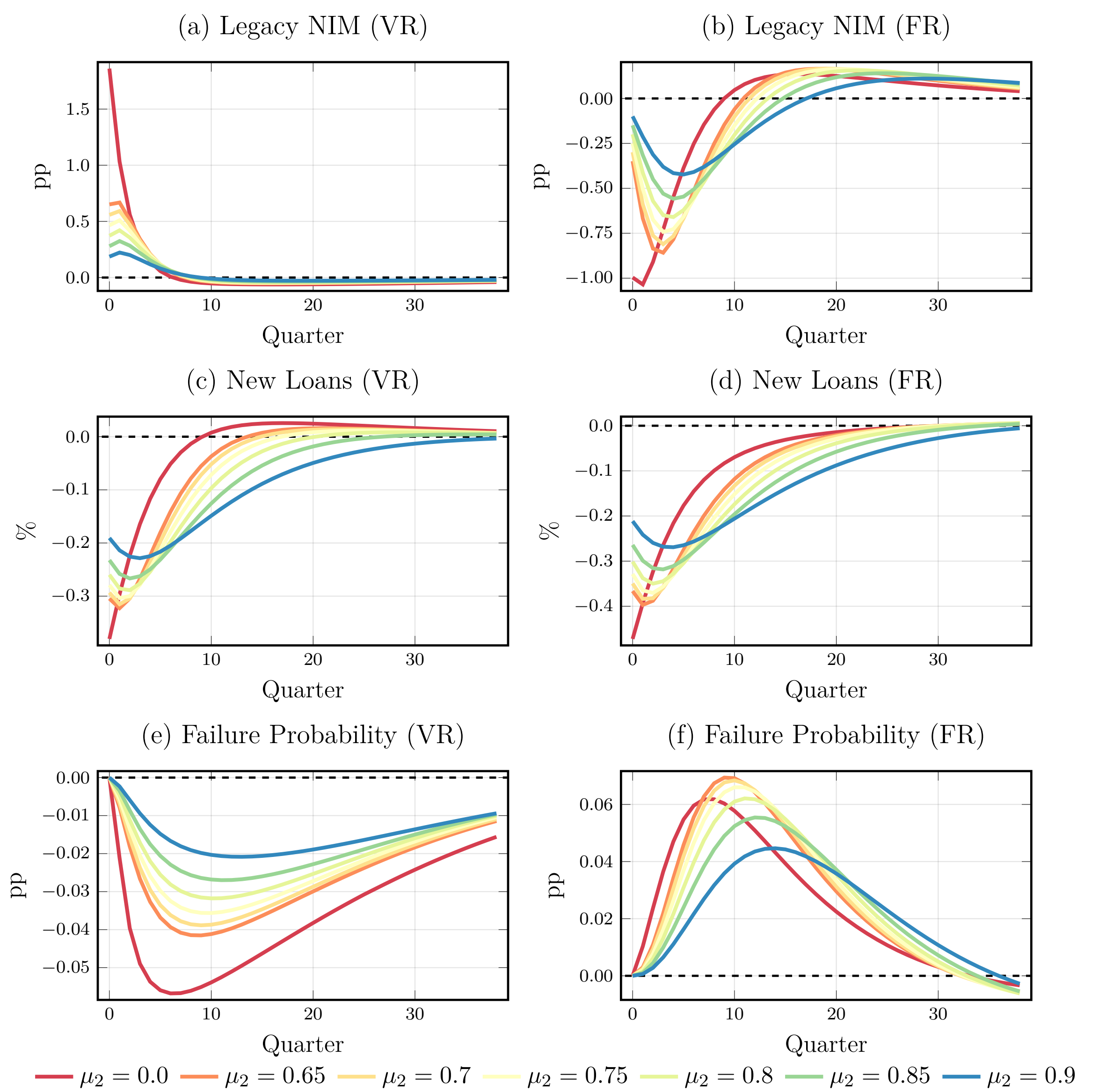
By the nature of the exercise, a more gradual policy path has direct effects on loan origination through entrepreneurs' pricing of new loans. The more subtle feature is a second-round effect via bank capital accumulation.

To build intuition, consider first what would happen if the pass-through from policy rates to loan rates were constant—that is, absent any feedback from bank equity. In the FR economy, a more gradual rate path mechanically produces a smaller impact response of loan rates followed by a more persistent one; since the area under the path is the same, new loan origination falls by less on impact but remains depressed for longer. In the VR economy, entrepreneurs are forward-looking with respect to the variable rates they will pay, but because they discount future payments, the present value of a back-loaded rate path is lower than that of a front-loaded one with the same cumulative area. New loans, therefore, also fall by less on impact under a more gradual path, even holding bank equity fixed.

Of course, the pass-through to loan rates is not constant—it depends on bank capital, which evolves differently across the two regimes. In the FR economy, a more gradual rate path reduces the initial compression of the net interest margin (Panel b). This comes at the cost of a more prolonged period of depressed profitability, but the overall effect is to soften the decline in both

we obtain $x_t = -\varsigma \mathbb{E}_t \sum_{m=0}^{\infty} \hat{r}_{t+m}$. Two policy paths yielding the same cumulative real rate gap—i.e., $\mathbb{E}_t \sum_{m=0}^{\infty} \hat{r}_{1,t+m} = \mathbb{E}_t \sum_{m=0}^{\infty} \hat{r}_{2,t+m}$—produce the same output gap. The exercise makes sense here without considering the effect on inflation.

Figure 10: Effects of gradualism



Note: Panels a and b show the response of the legacy NIM; panels c and d show the response of new loans; panels e and (f) show failure probabilities. Left panels correspond to VR economies; right panels correspond to FR economies. Colors from red to blue correspond to increasing degrees of gradualism, captured by $\mu_2 \in \{0.0, 0.65, 0.7, 0.75, 0.85, 0.9\}$. Red corresponds to an AR(1) process ($\mu_2 = 0$); blue corresponds to the most gradual AR(2) process.

equity and new loans (Panel d). Gradualism gives banks more time to reduce leverage by allowing legacy loans to mature before the full force of the rate increase arrives. The payoff is visible in failure probabilities: more gradual paths substantially reduce peak failure rates (Panel f).

In the VR economy, the dynamics are reversed. A more gradual rate path reduces the initial boost to the net interest margin (Panel a), dampening the equity gains that, under the baseline shock, temporarily encourage lending. Without that equity-driven overshooting, new loans decline more persistently (Panel c). Failure probabilities also move in the opposite direction from the FR case: the baseline decline in failure rates is progressively muted as the policy path becomes more gradual, leaving failure probabilities at a higher level than under a sharp tightening.

Taking stock. Both exercises share a common logic rooted in Proposition 1: policy choices that keep banks further from the solvency threshold reduce the relevance of heterogeneous interest-rate risk exposure. However, the specific implications for policy design are distinct.

The CCyB exercise reveals a tension in the conventional timing of macroprudential and monetary policy. In standard practice, both instruments often move in the same direction: capital buffers are tightened during credit expansions, when policy rates also tend to rise. Indeed, Hempell et al. (2024) document that euro area macroprudential authorities routinely take the monetary policy stance into account when calibrating buffer requirements, and that in the early stages of a contractionary phase—with inflation above target and monetary policy tightening—the prevailing guidance is to continue raising buffers. However, buffer releases are envisaged only later, once the interest-rate tightening begins to impact bank returns. Our analysis suggests that this sequencing can be counterproductive from a financial stability perspective, particularly in FR economies where rate increases erode bank equity. Rather than waiting for risks to materialize before releasing buffers, a preemptive release at the onset of monetary policy tightening would push banks away from the solvency threshold precisely when interest-rate risk exposure generates the largest divergence across regimes. Of course, the optimal coordination depends on the nature of the underlying shock and the relative weight placed on price stability versus financial stability, not only on the timing. The broader message is that buffer decisions should account for the banking system's interest-rate risk profile and the prevailing monetary policy stance, rather than relying on backward-looking indicators such as the credit-to-GDP gap prescribed as, for exampley, in the Basel III CCyB framework.

The gradualism exercise offers a distinct and perhaps counterintuitive prescription. A conventional view holds that central banks should raise rates aggressively to demonstrate resolve and anchor inflation expectations. Our results identify a countervailing force: for a given cumulative policy stance, more gradual rate paths substantially reduce bank failure rates in FR economies without materially increasing them in VR systems. The mechanism is that gradualism allows banks to deleverage organically—by letting legacy loans mature—before the full force of higher rates compresses their margins. This is not an argument against tightening, but rather for spreading it over time. Crucially, such a strategy requires credibility: markets must believe that smaller initial moves will be followed by persistent, sustained increases. Without that credibility, a gradual path may fail to deliver the intended cumulative stance.

Both sets of results likely understate the true importance of better policy timing and coordination because our model abstracts from endogenous deposit outflows.[41]

7. Conclusion

This paper achieves three objectives. First, it delivers a heterogeneous-bank model to analyze how the bank lending channel transmits differently in fixed- versus variable-rate banking systems. The model is particularly transparent. It provides a benchmark irrelevance result that demonstrates that differences in the transmission arise only when interest-rate shocks affect the distribution of banks near the solvency threshold asymmetrically across regimes. Second, because these differences depend on quantitative aspects, we calibrate the model to the euro area and show that it can capture the greater sensitivity to monetary policy of fixed-rate systems observed in data. Third, it provides experiments that showcase how whether a system operates under fixed or variable rates has implications for countercyclical financial regulation and for the gradualism of monetary policy.

Several simplifications suggest directions for extensions to the model that are particularly relevant for analyzing large shocks. First, our framework treats the choice between fixed- and variable-rate lending as institutionally predetermined, abstracting from banks' endogenous portfolio decisions. This is a good approximation for settings where policy shocks are small, but may not be adequate as economies experience transitions after a crisis or to different regulatory regimes. Incorporating contracting decisions and interest-rate risk hedging would be natural extensions. Second, we treat the response of credit risk from the borrower's side as exogenous. This is because our econometric analysis picks responses after typical monetary policy shocks, which are small in settings where default rates are low to begin with. However, for large shocks, credit risk responses will likely be sensitive to the borrower's own interest-rate risk exposure. Finally, the funding side is particularly simple. Extending the analysis to incorporate nominal rigidities and aggregate demand effects would allow for an analysis of monetary policy that does not treat the bank lending channel in isolation. The model is portable enough to admit those extensions with ease.

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Appendices

A. Model derivations

A.1 Conditions for risk-free wholesale debt

The balance sheet of the bank, after substituting for the binding constraints (8) and (7), reads:

$$L_{jt} + N_{jt} + \theta\alpha L_{jt} = \alpha L_{jt} + (1-\theta)B_{jt} + E_{jt}.$$

Solving for B_t:

$$B_{jt} = \frac{1}{1-\theta}\left([1+\alpha(\theta-1)]L_{jt} + N_{jt} - E_{jt}\right).$$

Consider the worst possible realization for the iid shock ($\omega_{jt+1} = 1$). If wholesale debt is collateralized, debt holders recover at most $(1+r_t^M)M_{jt} + (1-\lambda)(L_{jt}+N_{jt})$. Thus, for debt to be risk free, we need:

$$(1+r_t^B)B_{jt} \leq (1+r_t^M)M_{jt} + (1-\lambda)(L_{jt}+N_{jt}).$$

Using B_{jt} and the equilibrium condition $r_t^B = r_t^M$, this can be rewritten as:

$$(1+r_t^B)\left([1+\alpha(\theta-1)]l_{jt} + n_{jt} - 1\right) \leq (1+r_t^M)\theta\alpha l_{jt} + (1-\lambda)(l_{jt}+n_{jt}),$$

where each balance-sheet item has been expressed in ratios to equity. We numerically confirm this condition to be satisfied across the state space for our calibration.

A.2 Simplification of the bank's problem

We now show how the problem can be significantly reduced by collapsing it to a dynamic problem with two state variables and one control variable. We start by summarizing the problem of a bank presented in Section 2.1. The problem of a bank is

$$
\begin{aligned}
V_t^B(L_{jt},E_{jt},x_{jt}^L) = \mathbf{1}_{\{E_{jt}\geq\gamma L_{jt}\}}\Bigg[\max_{\{N_{jt},M_{jt},D_{jt},B_{jt}\}}\beta\int_0^{\overline{\omega}_{jt+1}}&\Big[(1-\chi)V_{t+1}^B(L_{jt+1},E_{jt+1},x_{jt+1}^L)\\
&+\ \chi E_{jt+1}\Big]\,\mathrm{d}F(\omega_{jt+1})\Bigg]\\
\text{s.t.}\quad B_{jt} &= L_{jt}+N_{jt}+M_{jt}-D_{jt}-E_{jt}, &&\text{(Balance sheet identity)}\\
D_{jt} &\leq \alpha L_{jt}, &&\text{(Deposits constraint)}\\
L_{jt+1} &= \left(1-\omega_{jt+1}\right)(1-\delta)\left(L_{jt}+N_{jt}\right), &&\text{(Loan LOM)}\\
E_{jt+1} &= E_{jt}+(1-\tau)\Pi_{jt+1}, &&\text{(Equity LOM)}\\
M_{jt} &\geq \theta(D_{jt}+B_{jt}), &&\text{(Reserve requirement)}
\end{aligned}
$$

with profits Π_{jt+1} defined as

$$
\begin{aligned}
\Pi_{jt+1} = (1-\omega_{jt+1})\left(r_{jt}^L L_{jt}+r_t^N N_{jt}\right)+r_t^M M_{jt}-r_t^D D_{jt}-r_t^B B_{jt}\\
-\lambda\omega_{jt+1}(L_{jt}+N_{jt})-f\left(\frac{N_{jt}}{L_{jt}}\right)L_{jt}-\bar{\pi}E_{jt}.
\end{aligned}
$$

The state variable x_{jt}^L corresponds to either the loan rate spread on legacy loans s_{jt}^L or the average loan rate on legacy loans r_{jt}^L depending on whether we are in a variable-rate or fixed-rate economy. We have that

$$
r_{jt}^L = \frac{r_{jt-1}^L L_{jt-1}+r_{t-1}^N N_{jt-1}}{L_{jt-1}+N_{jt-1}},
$$

for fixed-rate banks, and

$$
s_{jt}^L = \frac{s_{jt-1}^L L_{jt-1}+s_{t-1}^N N_{jt-1}}{L_{jt-1}+N_{jt-1}}
$$

for variable-rate banks with $r_{jt}^L = r_t^M + s_{jt}^L$.

The problem above implies a solvency threshold $\overline{\omega}_{jt+1}$. If the realization of ω lies above the threshold, a bank fails endogenously

$$
\overline{\omega}_{jt+1} = \frac{E_{jt}+(1-\tau)\left[r_{jt}^L L_{jt}+r_t^N N_{jt}+r_t^M M_{jt}-r_t^D D_{jt}-r_t^B B_{jt}-f\left(\frac{N_{jt}}{L_{jt}}\right)L_{jt}-\bar{\pi}E_{jt}\right]-\gamma(1-\delta)(L_{jt}+N_{jt})}{(1-\tau)(r_{jt}^L L_{jt}+r_t^N N_{jt})+\left[(1-\tau)\lambda-\gamma(1-\delta)\right](L_{jt}+N_{jt})}
$$

Reduction in State Variables. Let lower case variables denote ratios of stocks/flows to equity, e.g., $y_{jt} = \frac{Y_{jt}}{E_{jt}}$. The problem of a bank can be written as

$$
\begin{aligned}
v_t^B(l_{jt}, x_{jt}^L) &= \mathbf{1}_{\{1 \geq \gamma l_{jt}\}} \left[\max_{\{n_{jt}\}} \quad \beta \int_0^{\overline{\omega}_{jt+1}} g_{jt+1} \left[(1-\chi) v_{t+1}^B (l_{jt+1}, x_{jt+1}^L) + \chi \right] \mathrm{d}F(\omega_{jt+1}) \right], \\
\text{s.t.} \quad b_{jt} &= l_{jt} + n_{jt} + m_{jt} - d_{jt} - 1, && \text{(Balance sheet identity)} \\
d_{jt} &= \alpha l_{jt}, && \text{(Deposits constraint)} \\
l_{jt+1} &= (1-\omega_{jt+1}) \frac{(1-\delta)(l_{jt}+n_{jt})}{g_{jt+1}}, && \text{(Loans LOM)} \\
g_{jt+1} &= 1 + (1-\tau)\pi_{jt+1}, && \text{(Equity growth LOM)} \\
m_{jt} &= \theta(d_{jt} + b_{jt}), && \text{(Binding liq. requirement)}
\end{aligned}
$$

with

$$
\pi_{jt+1} = (1-\omega_{t+1})(r_{jt}^L l_{jt} + r_t^N n_{jt}) + r_t^M m_{jt} - r_t^B b_{jt} - r_t^D d_{jt} - \lambda \omega_{jt+1}(l_{jt}+n_{jt}) - f\left(\frac{n_{jt}}{l_{jt}}\right) l_{jt} - \overline{\pi},
$$

$$
\overline{\omega}_{jt+1} = \frac{1 + (1-\tau)\left[r_{jt}^L l_{jt} + r_t^N n_{jt} + r_t^M m_{jt} - r_t^D d_{jt} - r_t^B b_{jt} - f\left(\frac{n_{jt}}{l_{jt}}\right) l_{jt} - \bar{\pi} \right] - \gamma(1-\delta)(l_{jt}+n_{jt})}{(1-\tau)(r_{jt}^L l_{jt} + r_t^N n_{jt}) + \left[(1-\tau)\lambda - \gamma(1-\delta) \right](l_{jt}+n_{jt})}.
$$

A bank's decisions, therefore, only depends on its leverage l_t and on the average loan rate spread on legacy loans s_{jt}^L for variable-rate banks and the average loan rate on legacy loans r_t^L for fixed-rate banks, respectively.

After substituting the binding constraints and the fact that $r_t^B = r_t^M$ for all t, the problem can be rewritten as

$$
\begin{aligned}
v_t^B(l_{jt}, x_{jt}^L) &= \mathbf{1}_{\{1 \geq \gamma l_{jt}\}} \left[\max_{\{n_{jt}\}} \quad \beta \int_0^{\overline{\omega}_{jt+1}} g_{jt+1} \left[(1-\chi) v_{t+1}^B (l_{jt+1}, x_{jt+1}^L) + \chi \right] \mathrm{d}F(\omega_{jt+1}) \right], \\
\text{s.t.} \quad l_{jt+1} &= (1-\omega_{jt+1}) \frac{(1-\delta)(l_{jt}+n_{jt})}{g_{jt+1}}, && \text{(Loans LOM)} \\
g_{jt+1} &= 1 + (1-\tau)\pi_{jt+1}, && \text{(Equity growth LOM)}
\end{aligned}
$$

with

$$\pi_{jt+1} = (1-\omega_{jt+1})(r^L_{jt} l_{jt} + r^N_t n_{jt}) + r^B_t - \left[r^B_t(1-\alpha) + r^D_t \alpha\right] l_{jt} - r^B_t n_{jt} - \lambda\omega_{jt+1}(l_{jt}+n_{jt}) - f\left(\frac{n_{jt}}{l_{jt}}\right) l_{jt} - \overline{\pi},$$

$$\overline{\omega}_{jt+1} = \frac{1 + (1-\tau)\left[r^L_{jt} l_{jt} + r^N_t n_{jt} + r^B_t - \left[r^B_t(1-\alpha) + r^D_t\alpha\right] l_{jt} - r^B_t n_{jt} - f\left(\frac{n_{jt}}{l_{jt}}\right) l_{jt} - \bar{\pi}\right] - \gamma(1-\delta)(l_{jt}+n_{jt})}{(1-\tau)(r^L_{jt} l_{jt} + r^N_t n_{jt}) + \left[(1-\tau)\lambda - \gamma(1-\delta)\right](l_{jt}+n_{jt})}.$$

A.3 A microfundation for aggregate deposits demand

This section provides a microfoundation for the deposit supply function used in the main text. We develop a household problem that generates demand functions for deposits and less liquid assets, which can then be aggregated to obtain the supply of deposits to banks. This microfoundation is critical to allow us to treat r^M_t and r^D_t as exogenous paths with perfectly-elastic supply schedules.

The household problem. Consider a representative household that derives utility from two consumption goods, C_t and C^H_t, and from holding a bundle of assets. The household solves the following recursive problem:

$$V^H_t(A^H_{t-1}, D^H_{t-1}) = C^H_t + U\left(C_t + \ell(A^H_{t-1}, D^H_{t-1})\right) + \beta V^H_{t+1}(A^H_t, D^H_t),$$

subject to the budget constraint:

$$C_t + C^H_t + \underbrace{B^H_t + M^H_t}_{=A^H_t} + D^H_t + \Xi_t = (1+r^B_{t-1})B^H_{t-1} + (1+r^M_{t-1})M^H_{t-1} + (1+r^D_{t-1})D^H_{t-1} + \Pi^E_t - T_t.$$

The household's balance sheet is presented in table A.1

Table A.1: Household Balance Sheet

Assets	**Liabilities**
Highly liquid assets: D^H (deposits + ST gov't bonds)	—
Bonds: $A^H = B^H + M^H$ (wholesale debt + reserves)	

The function $\ell(m,d)$ captures the liquidity services provided by the household's portfolio of assets. We assume a Cobb-Douglas aggregator:

$$\ell(A,D) = \kappa \frac{\left(A^{\nu} D^{1-\nu}\right)^{1-\vartheta}}{1-\vartheta},$$

with $\nu \in (0,1)$ and $\kappa, \vartheta > 0$. The parameter ν governs the relative importance of bonds versus deposits in providing liquidity services.

Solution. To solve the problem, we substitute the budget constraint into the objective function:

$$\begin{aligned} V_t^H(A_{t-1}^H, D_{t-1}^H) = U\left(C_t + \ell(A_{t-1}^H, D_{t-1}^H)\right) - \left(C_t + A_t^H + D_t^H\right) \\ + (1+r_{t-1}^M)A_{t-1}^H + (1+r_{t-1}^D)D_{t-1}^H + \beta V_{t+1}^H(A_t^H, D_t^H). \end{aligned}$$

We conjecture that $V_t^H(A_{t-1}^H, D_{t-1}^H)$ is linear in its arguments. Under this conjecture, we derive the first-order conditions. The first-order condition with respect to C_t yields:

$$U'\left(C_t + \ell(A_{t-1}^H, D_{t-1}^H)\right) = 1. \tag{A.1}$$

The first-order condition with respect to A_t^H is:

$$-1 + \beta V_{A,t+1}^H(A_t^H, D_t^H) = 0, \tag{A.2}$$

where $V_{A,t+1}^H(A,D) \equiv \frac{\partial V_{t+1}^H}{\partial A}$. Using the envelope theorem and the fact that, in equilibrium, $r_t^M = r_t^B$ for all t:

$$V_{A,t+1}^H(A_t^H, D_t^H) = (1+r_t^M) + U'\left(C_{t+1} + \ell(A_t^H, D_t^H)\right) \cdot \ell_A(A_t^H, D_t^H).$$

Substituting (A.1) evaluated at $t+1$, we have $U\left(C_{t+1} + \ell(A_t^H, D_t^H)\right) = 1$. Thus:

$$\beta\left[(1+r_t^M) + \ell_A(A_t^H, D_t^H)\right] = 1.$$

Rearranging and using (A.1):

$$\ell_A(A_t^H, D_t^H) = \frac{1}{\beta} - (1+r_t^M) := s_t^M, \tag{A.3}$$

where s_t^M denotes the spread between the household's rate of time preference and the return on bonds.

Proceeding analogously for deposits, we obtain:

$$\ell_D(A_t^H, D_t^H) = \frac{1}{\beta} - (1 + r_t^D) := s_t^D, \tag{A.4}$$

where s_t^D denotes the corresponding spread for deposits.

Given the functional forms in (A.1), we compute the partial derivatives:

$$\ell_A(A_t^H, D_t^H) = \frac{\nu\kappa\left[\left(A_t^H\right)^\nu \left(D_t^H\right)^{1-\nu}\right]^{1-\vartheta}}{A_t^H}, \text{ and} \tag{A.5}$$

$$\ell_D(A_t^H, D_t^H) = \frac{(1-\nu)\kappa\left[\left(A_t^H\right)^\nu \left(D_t^H\right)^{1-\nu}\right]^{1-\vartheta}}{D_t^H}. \tag{A.6}$$

Dividing (A.5) by (A.6) and using the first-order conditions (A.3) and (A.4):

$$\frac{\nu}{1-\nu}\frac{D_t^H}{A_t^H} = \frac{s_t^M}{s_t^D}. \tag{A.7}$$

This expression determines the optimal ratio of deposits to bonds as a function of the spreads.

Optimal quantities. To solve for the individual quantities, substitute the portfolio ratio back into the first-order conditions. From (A.3):

$$\frac{\nu\kappa\left[\left(A_t^H\right)^\nu \left(D_t^H\right)^{1-\nu}\right]^{1-\vartheta}}{A_t^H} = s_t^M,$$

which can be rewritten as:

$$\nu\kappa\left[\left(A_t^H\right)^\nu \left(D_t^H\right)^{1-\nu}\right]^{1-\vartheta} = s_t^M A_t^H.$$

From (A.7), we have:

$$D_t^H = \frac{(1-\nu)s_t^M}{\nu s_t^D} A_t^H.$$

Substituting into (A.8), we obtain the demand for bonds:

$$A_t^H = \left(\frac{\nu\kappa\left[\frac{(1-\nu)s_t^M}{\nu s_t^D}\right]^{(1-\nu)(1-\vartheta)}}{s_t^M}\right)^{\frac{1}{\vartheta}}. \tag{A.8}$$

Similarly, the demand for deposits satisfies:

$$D_t^H = \left(\frac{(1-\nu)\kappa \left[\frac{\nu s_t^D}{(1-\nu) s_t^M} \right]^{\nu(1-\vartheta)}}{s_t^D} \right)^{\frac{1}{\vartheta}}. \tag{A.9}$$

Market clearing. On the supply side, banks demand reserves according to the liquidity requirement:

$$M_t = \theta(D_t + B_t),$$

where D_t denotes the deposits supplied by banks and B_t denotes wholesale debt.

Market clearing in the deposit market requires:

$$D_t^H = D_t + D_t^S \tag{A.10}$$

where D_t^H denotes household demand for deposits and D_t^S the supply of deposits.

Market clearing in the reserve market requires:

$$M_t^S = M_t^H + \int M_{jt} dj, \tag{A.11}$$

where M_t^S denotes the reserve supply by the central bank, M_t^H is household demand for bonds, and $\int M_{jt} dj$ is bank demand for reserves.

The key feature is that the government has two instruments, short-term bonds and reserves $\{D_t^S, M_t^S\}$, to target two rates: r_t^M and r_t^D. De facto, this makes the banks' deposit supply schedule perfectly elastic: any increase in their desired demand for deposits is offset by the central bank's position.

A.4 Microfoundation for the asset structure

This Appendix introduces explicit government bond markets and money market funds (MMFs) to provide clearer microfoundations for the asset structure. We suppress the time subindex in this subsection.

The key modifications are:

1. **Two types of government bonds:**

    - Long-term bonds B^g: held by households (B^{hg}) and banks (B^{bg}), earning r^M.
    - Short-term bonds S^g: held by MMFs, earning r^D.

2. **Money Market Funds (MMFs):** Pass-through entities that hold S^g and issue liquid shares D^S to households.

3. **Central bank facility:** Banks can exchange long-term government bonds B^{bg} one-for-one for reserves M at the central bank.

Banks. Banks obtain reserves by exchanging long-term government bonds at the central bank:

$$M = B^{bg}. \tag{A.12}$$

Both M and B^{bg} earn the policy rate r^M. This arbitrage condition ensures that banks are indifferent between holding reserves directly or holding government bonds that can be converted to reserves.[42]

Households. Households allocate wealth across two categories of assets: (i) Highly liquid assets (earning r^D, providing liquidity services):

$$D^H = D + D^S, \tag{A.13}$$

where D are bank deposits and D^S are MMF shares; (ii) bonds (earning $r^M = r^B$) :

$$A^H = B^H + B^{hg}, \tag{A.14}$$

where B^H is bank wholesale debt and B^{hg} are long-term government bonds. Table A.2 displays the balance sheet.

The household problem yields static demand functions:

$$D^H = h^D(r^D, r^M), \tag{A.15}$$

$$A^H = h^A(r^D, r^M). \tag{A.16}$$

In equilibrium, $r^D \le r^M$ because highly liquid assets provide greater liquidity services.

Money Market Funds. MMFs are pass-through entities that provide households with liquid claims backed by short-term government securities. The MMF structure provides a realistic interpretation of how households access liquid government-backed assets without directly holding government securities.

[42]All constraints (deposit, liquidity, capital) and laws of motion remain identical to the baseline setup.

Table A.2: Household Balance Sheet

Assets	**Liabilities**
Highly liquid assets: D^H	—
Bank deposits: D	
MMF shares: D^S	
Illiquid bonds: A^H	
Bank wholesale debt: B^H	
Gov't bonds: B^{hg}	

Table A.3: Money Market Fund Balance Sheet

Assets	**Liabilities**
Short-term gov't bonds: S^g	MMF shares: D^S

MMFs hold short-term government bonds S^g earning r^D. They issue shares D^S to households, also earning r^D. MMFs earn zero profits. Their balance sheet is displayed in Table A.3 and the market clearing condition is $S^g = D^S$

Government. The Government budget constraint is

$$T_t + \tau \Pi_t + B_t^g + S_t^g = (1 + r_{t-1}^M) B_{t-1}^g + (1 + r_{t-1}^D) S_{t-1}^g + \Theta_t. \tag{A.17}$$

The Government's balance sheet can be found in Table A.4.

A.5 Market clearing condition for bond markets

Long-term bonds:

$$B^g = B^{hg} + B^{bg}, \tag{A.18}$$

where B^{hg} is held by households and B^{bg} is held by banks. These, in turn, are exchanged for reserves at the central bank.

Short-term bonds:

$$S^g = D^S, \tag{A.19}$$

Table A.4: Consolidated Government Balance Sheet

Assets	**Liabilities**
Gov't bonds (repo): B^{bg}	Reserves: M
Tax revenue: T	Long-term bonds: $B^g - B^{bg}$
Corporate taxes: $\tau\Pi$	Short-term bonds: S^g
	Deposit insurance: Θ

held entirely by MMFs.

A.6 Derivation of Resource Constraint

Let $y_t(l,x)$ denote the policy for variable y_t of a bank with leverage l and average loan rate/spread x on legacy loans and let $H_t(l,x,e)$ denote the joint distribution of leverage, the loan rate/spread on legacy loans and equity.[43] Furthermore, let $\bar{v}_{t+1}(l,x,\omega)$ denote the recovery value (per unity of equity) of a bank failing after a bad realization of ω at $t+1$. The recovery value can be written as:

$$\begin{aligned}
\bar{v}_{t+1}(l,x,\omega) = {} & (1-\omega)\left[(1+r_t^L(x))l + (1+r_t^N)n_t(l,x)\right] + \omega(1-\lambda)(l+n_t(l,x)) \\
& + (1+r_t^M)m_t(l,x) - f\left(\frac{n_t(l,x)}{l}\right)l - \overline{\pi} \\
= {} & 1 + \pi_{t+1}(l,x,\omega) + (1+r_t^D)d_t(l,x) + (1+r_t^B)b_t(l,x) \\
= {} & g_{t+1}(l,x,\omega) + \tau\pi_{t+1}(l,x,\omega) + (1+r_t^D)d_t(l,x) + (1+r_t^B)b_t(l,x)
\end{aligned}$$

where

$$\begin{aligned}
\pi_{t+1}(l,x,\omega) = {} & (1-\omega)(r_t^L(x)l + r_t^N n_t(l,x)) + r_t^M m_t(l,x) \\
& - r_t^D d_t(l,x) - r_t^B b_t(l,x) - \lambda\omega(l+n_t(l,x)) - f\left(\frac{n_t(l,x)}{l}\right)l - \overline{\pi}, \\
g_{t+1}(l,x,\omega) = {} & 1 + (1-\tau)\pi_{t+1}(l,x,\omega)
\end{aligned}$$

are profits and the gross equity growth rate, respectively.

We start the derivation by combining the household budget constraint and the consolidated

[43] For simplicity, we omit the subscript j in the derivations in this section.

Table A.5: Consolidated Government Balance Sheet

Assets	**Liabilities**
Tax revenue: T	Reserves: M^S
Corporate taxes: $\tau\Pi$	Short-term bonds: D^S
	Deposit insurance: Θ

government budget constraint (the government balance sheet is displayed in Table A.5):

$$C_t + C_t^H + B_t + M_t^H + D_t^H + \Xi_t = (1 + r_{t-1}^B)B_{t-1} + (1 + r_{t-1}^M)M_{t-1}^H + (1 + r_{t-1}^D)D_{t-1}^H + \Pi_t^E - T_t, \tag{HHs BC}$$

$$T_t + \tau\Pi_t + M_t^S + D_t^S = \left(1 + r_{t-1}^M\right) M_{t-1}^S + \left(1 + r_{t-1}^D\right) D_{t-1}^S + \Theta_t, \tag{Gov BC}$$

where

$$\Theta_t = \int\int_{\bar{\omega}}^1 \Big[\left(1 + r_{t-1}^D\right) d_{t-1}(l,x) + \left(1 + r_{t-1}^B\right) b_{t-1}(l,x) - \bar{v}_t(l,x,\omega)\Big] e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e), \tag{DIS \& bank resolution}$$

$$\Xi_t = \bar{\mathscr{F}}_{t-1}\bar{E}_t - \chi\int\int_0^{\bar{\omega}} g_t(l,x,\omega)\,e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e), \tag{Net equity injections}$$

$$\Pi_t^E = (1-p)\left((A - \bar{r}_{t-1}^{L*})L_{t-1} + (A - r_{t-1}^N)N_{t-1}\right), \tag{Entrepreneurs' profits}$$

$$Y_t = (1-p)A(L_{t-1} + N_{t-1}). \tag{Aggregate output}$$

The expression for the mass of failing banks $\bar{\mathscr{F}}_{t-1}$ is derived in Appendix A.11.

Combining the aggregate balance sheet across all banks $L_t + N_t + M_t = D_t + B_t + E_t$, the government budget constraint, and the household budget constraint yields:

$$C_t + C_t^H + L_t + N_t = \left(1 + r_{t-1}^B\right) B_{t-1} + \left(1 + r_{t-1}^D\right) D_{t-1} - \left(1 + r_{t-1}^M\right) M_{t-1} + \Pi_t^E + E_t - \Xi_t + \tau\Pi_t - \Theta_t.$$

Using the expression of the recovery value $\bar{v}_t(l,x,\omega)$, the costs from deposit insurance and bank resolution Θ_t can be rewritten to separate resource cost from revenues from the sale of bank assets:

$$\begin{aligned}\Theta_t &= \int\int_{\bar{\omega}}^{1} \left[\left(1+r_{t-1}^D\right) d_{t-1}(l,x) + \left(1+r_{t-1}^B\right) b_{t-1}(l,x) - \bar{v}_t(l,x,\omega)\right] e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e) \\ &= \int\int_{\bar{\omega}}^{1} \left[\left(1+r_{t-1}^D\right) d_{t-1}(l,x) + \left(1+r_{t-1}^B\right) b_{t-1}(l,x) - \bar{v}_t(l,x,\omega)\right] e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e) \\ &= \int\int_{\bar{\omega}}^{1} \left[-g_t(l,x,\omega) - \tau\pi_t(l,x,\omega)\right] e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e)\end{aligned}$$

where $\bar{V}_t = \int\int_{\bar{\omega}}^{1} \bar{v}_t(l,x,\omega)e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e)$.

Combining bank profit taxes with the deposit insurance and bank resolution costs yields:

$$\begin{aligned}\tau\Pi_t - \Theta_t &= \tau\int\int_{0}^{\bar{\omega}} \pi_t(l,x,\omega)e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e) \\ &\quad + \int\int_{\bar{\omega}}^{1} \left[g_t(l,x,\omega) + \tau\pi_t(l,x,\omega)\right] e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e) \\ &= \tau\int\int_{0}^{1} \pi_t(l,x,\omega)e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e) \\ &\quad + \int\int_{\bar{\omega}}^{1} g_t(l,x,\omega)e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e).\end{aligned}$$

Combining net equity injections with the equity law of motion yields:

$$\begin{aligned}E_t - \Xi_t &= (1-\chi)\int\int_{0}^{\bar{\omega}} g_t(l,x,\omega)edF(\omega)dH_t(l,x,e) + \bar{\mathscr{F}}_{t-1}\bar{E}_t \\ &\quad - \left(\bar{\mathscr{F}}_{t-1}\bar{E}_t - \chi\int\int_{0}^{\bar{\omega}} g_t(l,x,\omega)e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e)\right) \\ &= \int\int_{0}^{\bar{\omega}} g_t(l,x,\omega)e\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e).\end{aligned}$$

Combining the last two expressions yields:

$$\begin{aligned} E_t - \Xi_t + \tau \Pi_t - \Theta_t &= \int \int_0^{\bar{\omega}} g_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) \\ &\quad + \tau \int \int_0^1 \pi_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) \\ &\quad + \int \int_{\bar{\omega}}^1 g_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) \\ &= \int \int_0^1 g_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) \\ &\quad + \tau \int \int_0^1 \pi_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,e) \\ &= E_{t-1} + \int \int_0^1 \pi_t(l,\bar{r},\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,\bar{r},e). \end{aligned}$$

The double integral over profits in the last expression can be rewritten as follows

$$\begin{aligned} \int \int_0^1 \pi_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) &= (1-p)(\bar{r}^{L*}_{t-1} L_{t-1} + r^N_{t-1} N_{t-1}) + r^M_{t-1} M_{t-1} \\ &\quad - r^D_{t-1} D_{t-1} - r^B_{t-1} B_{t-1} \\ &\quad - \lambda p (L_{t-1} + N_{t-1}) \\ &\quad - \int \int_0^1 f\left(\frac{n_{t-1}(l,x)}{l}\right) l e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) \\ &\quad - \bar{\pi} E_{t-1}, \end{aligned}$$

where the aggregate rate on legacy loans $\bar{r}^{L*}_{t-1}$ is such that

$$\bar{r}^{L*}_{t-1} L_{t-1} = \int r^L_{t-1}(x) \, l \, e \, \mathrm{d}H_{t-1}(l,x,e).$$

Replacing the double integral over profits in the previous expression yields:

$$E_t - \Xi_t + \tau \Pi_t - \Theta_t = E_{t-1} + (1-p)(\bar{r}^{L*}_{t-1} L_{t-1} + r^N_{t-1} N_{t-1}) + r^M_{t-1} M_{t-1} - r^D_{t-1} D_{t-1} - r^B_{t-1} B_{t-1} - RC_t,$$

where $RC_t = \lambda p (L_{t-1} + N_{t-1}) + \int \int_0^1 f\left(\frac{n_{t-1}(l,x)}{l}\right) l e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e) + \bar{\pi} E_{t-1}$ is the sum of all resource costs in the model.

Substituting this expression into the budget constraint yields

$$C_t + C^H_t + L_t + N_t = E_{t-1} + D_{t-1} + B_{t-1} - M_{t-1} + \Pi^E_t + (1-p)(\bar{r}^{L*}_{t-1} L_{t-1} + r^N_{t-1} N_{t-1}) - RC_t.$$

Using the definitions of output and entrepreneur profits, and the balance sheet constraint, we can further simplify the expression

$$C_t + C_t^H + L_t + N_t = L_{t-1} + N_{t-1} + Y_t - RC_t,$$

or

$$Y_t = C_t + C_t^H + \Delta(L_t + N_t) + RC_t.$$

Thus, output is used for consumption, investment in entrepreneurs' projects, or resource cost.

Note that we can express the investments in entrepreneurs' projects as

$$\begin{aligned}
\Delta(L_t + N_t) &= L_t + N_t - (L_{t-1} + N_{t-1}) \\
&= (1-p)(1-\tilde{\chi})(1-\delta)(L_{t-1} + N_{t-1}) + N_t - (L_{t-1} + N_{t-1}) \\
&= N_t - (1-(1-p)(1-\tilde{\chi})(1-\delta))(L_{t-1} + N_{t-1}),
\end{aligned}$$

meaning that it's the amount of new loans made by banks minus the projects that ended regularly, due to project failures, or due to bank exits.

A.7 Derivation of Loan Liquidation Probability

As in Appendix A.6, let $y_t(l,x)$ denote the policy for variable y_t of a bank with leverage l and average loan rate/spread x on legacy loans and let $H_t(l,x,e)$ denote the joint distribution of leverage, the loan rate/spread on legacy loans and equity.

The aggregate loan portfolio of exiting banks (including both endogenous failures and exogenous exits) L_{t+1}^{exit} is given by

$$L_{t+1}^{exit} = \int\int_0^1 \left(\chi \mathbf{1}_{\{\omega \leq \bar{\omega}\}} + \mathbf{1}_{\{\omega > \bar{\omega}\}}\right)(1-\omega)(1-\delta)(l + n_t(l,x))e\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e).$$

As described in Section 2.1, entering banks draw leverage from the distribution of surviving banks and enter with equity $\bar{E}_{t+1}$. Using the average leverage of surviving banks l_{t+1}^s

$$l_{t+1}^s = \frac{\int\int_0^{\bar{\omega}}(1-\omega)(1-\delta)\frac{l+n_t(l,x)}{g_{t+1}(l,x)}(\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,e)}{\int F(\bar{\omega})\mathrm{d}H_{t-1}(l,x,e)}$$

and the mass of banks exiting or failing banks $\bar{\mathscr{F}}_t$ derived in Appendix A.11, we can write the aggregate loan portfolio of entering banks L_{t+1}^{entry} as

$$L_{t+1}^{entry} = \bar{\mathscr{F}}_t l_{t+1}^s \bar{E}_{t+1}$$

The aggregate law of motion of loans is then given by

$$
\begin{aligned}
L_{t+1} &= (1-p)(1-\delta)(L_t + N_t) - (L_{t+1}^{exit} - L_{t+1}^{entry}) \\
&= (1-\tilde{\chi})(1-p)(1-\delta)(L_t + N_t),
\end{aligned}
$$

where we implicitly defined the loan liquidation probability as

$$
\tilde{\chi} = \frac{L_{t+1}^{exit} - L_{t+1}^{entry}}{(1-p)(1-\delta)(L_t + N_t)}.
$$

A.8 Proof of Proposition 1

We prove Proposition 1 in the analytical benchmark described in the main text. Throughout this subsection we assume: (i) deterministic portfolio defaults, $\omega_{jt} = p$ for all banks and dates; (ii) banks remain sufficiently well capitalized along the paths being compared that the insolvency threshold never affects continuation values; (iii) there is therefore no endogenous bank failure in either economy along those paths; and (iv) the FR and VR economies face the same exogenous sequences $\{r_t^M, r_t^D\}_{t\geq 0}$.

Bank problem in the benchmark. Consider first an FR bank. Its objective is

$$
\max_{\{N_{j,t}, M_{j,t}, D_{j,t}, B_{j,t}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^{t+1}(1-\chi)^t \chi E_{j,t+1},
$$

subject to

$$
\begin{aligned}
L_{j,t+1} &= (1-p)(1-\delta)(L_{j,t} + N_{j,t}), \\
E_{j,t+1} &= E_{j,t} + (1-\tau)\Pi_{j,t+1}, \\
r_{j,t+1}^L &= \frac{r_{j,t}^L L_{j,t} + r_t^N N_{j,t}}{L_{j,t} + N_{j,t}}, \\
\Pi_{j,t+1} &= (1-p)\left(r_{j,t}^L L_{j,t} + r_t^N N_{j,t}\right) + r_t^M M_{j,t} - r_t^D D_{j,t} - r_t^B B_{j,t} \\
&\quad - \lambda p (L_{j,t} + N_{j,t}) - f\left(\frac{N_{j,t}}{L_{j,t}}\right) L_{j,t} - \bar{\pi} E_{j,t}, \\
L_{j,t} + N_{j,t} + M_{j,t} &= D_{j,t} + B_{j,t} + E_{j,t}, \\
D_{j,t} \leq \alpha L_{j,t}, &\qquad M_{j,t} \geq \theta(D_{j,t} + B_{j,t}).
\end{aligned}
$$

In any equilibrium with $r_t^D < r_t^B$ and $r_t^B \geq r_t^M$, the deposit and liquidity constraints bind. Substituting them out leaves new lending $N_{j,t}$ as the only choice variable. Define $\varrho \equiv (1-p)(1-\delta)$ and the total interest income on legacy loans as $I_{j,t} \equiv r^L_{j,t} L_{j,t}$. Then the laws of motion for loans and legacy interest income are

$$L_{j,t+k} = \varrho^k L_{j,t} + \sum_{m=0}^{k-1} \varrho^{k-m} N_{j,t+m},$$

$$I_{j,t+k} = \varrho^k I_{j,t} + \sum_{m=0}^{k-1} \varrho^{k-m} r^N_{t+m} N_{j,t+m}.$$

Compact equity recursion and bank valuation kernel. After substituting the binding constraints, and the equilibrium condition $r^M_t = r^B_t$ for all t, bank profits can be written compactly as

$$\Pi_{j,t+1} = (1-p) I_{j,t} + \Phi_t L_{j,t} + \Psi_t N_{j,t} - f\left(\frac{N_{j,t}}{L_{j,t}}\right) L_{j,t} + (r^M_t - \bar{\pi}) E_{j,t},$$

where

$$\Phi_t \equiv \alpha(r^B_t - r^D_t) - \lambda p - r^M_t,$$

$$\Psi_t \equiv (1-p) r^N_t - \lambda p - r^M_t.$$

Hence equity evolves according to

$$E_{j,t+1} = \Upsilon^B_t E_{j,t} + (1-\tau)\left[(1-p) I_{j,t} + \Phi_t L_{j,t} + \Psi_t N_{j,t} - f\left(\frac{N_{j,t}}{L_{j,t}}\right) L_{j,t}\right],$$

with

$$\Upsilon^B_t \equiv 1 + (1-\tau)(r^M_t - \bar{\pi}).$$

Forward iteration yields

$$E_{j,t+k+1} = \left(\prod_{m=0}^{k} \Upsilon^B_{t+m}\right) E_{j,t} + (1-\tau) \sum_{m=0}^{k} \left(\prod_{q=m+1}^{k} \Upsilon^B_{t+q}\right) \left[(1-p) I_{j,t+m} + \Phi_{t+m} L_{j,t+m} + \Psi_{t+m} N_{j,t+m} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right) L_{j,t+m}\right],$$

where the empty product equals one.

Bank supply in the FR economy. Differentiating the objective with respect to $N_{j,t}$ yields the following first-order condition:

$$0 = \Omega^B_{t,0}\left[\Psi_t - f'\left(\frac{N_{j,t}}{L_{j,t}}\right)\right] + \sum_{m=1}^{\infty}\Omega^B_{t,m}\varrho^m\left[(1-p)r^N_t + \Phi_{t+m} + f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right],$$

where

$$\Omega^B_{t,m} \equiv (1-\tau)\sum_{k=m}^{\infty}\beta^{k+1}(1-\chi)^k\chi\left(\prod_{q=m+1}^{k}\Upsilon^B_{t+q}\right)$$

is the bank's raw valuation kernel for one unit of pre-tax profit at horizon m. Dividing by $\Omega^B_{t,0}$ and using $\Psi_t = (1-p)r^N_t - \lambda p - r^M_t$ gives

$$N^{FR}_{j,t} = (f')^{-1}\left(\sum_{m=0}^{\infty}\Lambda^B_{t,m}r^N_t - \Gamma_{j,t}\right)L_{j,t}, \tag{A.20}$$

where

$$\Gamma_{j,t} \equiv \lambda p + r^M_t - \sum_{m=1}^{\infty}\frac{\Lambda^B_{t,m}}{1-p}\left[\Phi_{t+m} + f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right]$$

and

$$\Lambda^B_{t,m} \equiv \frac{\Omega^B_{t,m}}{\Omega^B_{t,0}}(1-p)^{m+1}(1-\delta)^m.$$

Bank supply in the VR economy. For a VR bank, the same derivation applies with horizon-m loan cash flow $s^N_t + r^M_{t+m}$, where the VR first-order condition becomes

$$N^{VR}_{j,t} = L_{j,t}(f')^{-1}\left(\sum_{m=0}^{\infty}\Lambda^B_{t,m}(s^N_t + r^M_{t+m}) - \Gamma_{j,t}\right). \tag{A.21}$$

Supply-side pricing relation. Because $(f')^{-1}$ is strictly increasing, the FR and VR supply schedules coincide whenever

$$r^N_t = s^N_t + \frac{\sum_{m=0}^{\infty}\Lambda^B_{t,m}r^M_{t+m}}{\sum_{m=0}^{\infty}\Lambda^B_{t,m}}. \tag{A.22}$$

This is the bank-side pricing relation: the fixed rate must equal the variable spread plus the bank-weighted average of future policy rates.

Entrepreneur-side pricing relation. The entrepreneur's raw valuation kernel is

$$\Omega^E_{t,m} = (1-\tau)\sum_{k=m}^{\infty}\beta^{k+1}(1-\tilde{\chi})^k\tilde{\chi}\left(\prod_{q=m+1}^{k}\Upsilon^E_{t+q}\right), \qquad \Upsilon^E_t \equiv 1+(1-\tau)r^E_t, \tag{A.23}$$

and the corresponding effective discount factors are

$$\Lambda^E_{t,m} = \Omega^E_{t,m}(1-p)^{m+1}(1-\delta)^m.$$

Equating the free-entry conditions for the FR and VR economies implies

$$r^N_t = s^N_t + \frac{\sum_{m=0}^{\infty}\Lambda^E_{t,m}r^M_{t+m}}{\sum_{m=0}^{\infty}\Lambda^E_{t,m}}. \tag{A.24}$$

Primitive sufficient conditions for aligned effective discount factors. For (A.22) and (A.24) to describe the same pricing relation for every horizon, it is sufficient that the entrepreneur and bank effective discount factors be proportional:

$$\frac{\Lambda^E_{t,m}}{\Lambda^E_{t,0}} = \frac{\Lambda^B_{t,m}}{\Lambda^B_{t,0}} \qquad \text{for all } m \geq 0. \tag{A.25}$$

A primitive sufficient set of restrictions is: symmetric taxation, $\chi = \tilde{\chi}$, and $\Upsilon^E_t = \Upsilon^B_t$ for all t. Under those restrictions, the summands in $\Omega^E_{t,m}$ and $\Omega^B_{t,m}$ coincide term by term, so $\Omega^E_{t,m} = \Omega^B_{t,m}$ for all t and m. Since the same project-survival term $(1-p)^{m+1}(1-\delta)^m$ multiplies both kernels, the two effective discount-factor sequences are proportional. Under $r^B_t = r^M_t$, this primitive restriction implies

$$r^E_t = r^M_t - \bar{\pi}.$$

Under condition (A.25), the supply-side and entrepreneur-side pricing relations coincide. A fixed rate r^N_t and a variable-rate spread s^N_t satisfying that common relation therefore leave banks and entrepreneurs assigning the same discounted value to the FR and VR repayment streams. Since the bank supply coefficient multiplying $L_{j,t}$ is common across banks in this benchmark, bank supply aggregates linearly. Starting from the same aggregate legacy loan portfolio, the same aggregate supply schedule and the same aggregate loan-demand schedule imply the same equilibrium sequence $\{N_t\}_{t\geq 0}$ in the FR and VR economies.

□

A.9 Bank loan supply with idiosyncratic risk

When portfolio default risk is idiosyncratic, current lending affects bank value not only through future cash flows, but also through the future insolvency thresholds that determine survival. This is the source of the additional precautionary motive emphasized in the main text.

Let $\phi_{j,t+i} = 1 - F(\bar{\omega}_{j,t+i})$ denote the probability that bank j fails in period $t+i$, and define the cumulative survival probability

$$S_{j,t,k} \equiv \prod_{i=1}^{k} (1 - \phi_{j,t+i}).$$

For any horizon $k \geq 0$, let $\tilde{\mathbb{E}}_{j,t,k}[\cdot]$ denote expectations conditional on the event that the bank survives through period $t+k+1$, that is, conditional on $\{\omega_{j,t+i} \leq \bar{\omega}_{j,t+i}\}_{i=1}^{k+1}$. Using this notation, the bank's value can be written as

$$V_{j,t} = \sum_{k=0}^{\infty} \beta^{k+1} (1-\chi)^k \chi \, S_{j,t,k+1} \, \tilde{\mathbb{E}}_{j,t,k}\left[E_{j,t+k+1}\right].$$

Differentiating the value function. Taking the first-order condition with respect to $N_{j,t}$ requires differentiating both conditional cash flows and the survival sets themselves. Applying Leibniz's rule yields

$$0 = \tilde{\mathbb{E}}_{j,t,0}\left[\frac{\partial \Pi_{j,t+1}}{\partial N_{j,t}}\right] + \sum_{m=1}^{\infty} \frac{\tilde{\Omega}^{B,x}_{j,t,m}}{\tilde{\Omega}^{B,x}_{j,t,0}} \tilde{\mathbb{E}}_{j,t,m}\left[\frac{\partial \Pi_{j,t+m+1}}{\partial N_{j,t}}\right] - \mathscr{R}^{x}_{j,t},$$

where $\mathscr{R}^{x}_{j,t}$ collects the boundary terms generated by the dependence of future insolvency thresholds on current lending. The object

$$\tilde{\Omega}^{B,x}_{j,t,m} \equiv (1-\tau) \sum_{k=m}^{\infty} \beta^{k+1} (1-\chi)^k \chi \, S_{j,t,k+1} \left(\prod_{q=m+1}^{k} \Upsilon^{B,x}_{j,t+q} \right)$$

is the bank-specific valuation kernel for one unit of pre-tax profit at horizon m, where $\Upsilon^{B,x}_{j,t+q}$ denotes the gross continuation-value effect of retaining one additional unit of equity from $t+q-1$ to $t+q$ along surviving paths in regime $x \in \{FR, VR\}$.

Marginal profit terms. Let $q^{N,x}_{t,m}$ denote the contractual payment on a loan originated at date t and received at horizon m, with

$$q^{N,FR}_{t,m} = r^{N}_{t}, \qquad q^{N,VR}_{t,m} = s^{N}_{t} + r^{M}_{t+m}.$$

The contemporaneous derivative of profits is

$$\tilde{\mathbb{E}}_{j,t,0}\left[\frac{\partial \Pi_{j,t+1}}{\partial N_{j,t}}\right] = (1-\tilde{\omega}^{x}_{j,t+1})q^{N,x}_{t,0} - \lambda\tilde{\omega}^{x}_{j,t+1} - \mu_t - f'\left(\frac{N_{j,t}}{L_{j,t}}\right),$$

where $\tilde{\omega}^{x}_{j,t+1} \equiv \tilde{\mathbb{E}}_{j,t,0}[\omega_{j,t+1}]$ is the conditional mean default rate and

$$\mu_t \equiv \frac{r^B_t - \theta r^M_t}{1-\theta}$$

is the marginal funding cost of one additional unit of lending once the reserve requirement is taken into account.

For $m \geq 1$, define the conditional expected repayment path of a marginal loan as

$$\tilde{\varrho}^{x}_{j,t,m} \equiv \tilde{\mathbb{E}}_{j,t,m}\left[(1-\omega_{j,t+m+1})\prod_{i=1}^{m}\left[(1-\omega_{j,t+i})(1-\delta)\right]\right].$$

Let

$$\Phi_{t+m}(\omega) \equiv \alpha(r^B_{t+m} - r^D_{t+m}) - \lambda\omega - \mu_{t+m},$$
$$\Xi\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right) \equiv f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right).$$

Then the expected derivative of profits at horizon m can be written as

$$\tilde{\mathbb{E}}_{j,t,m}\left[\frac{\partial \Pi_{j,t+m+1}}{\partial N_{j,t}}\right] = \tilde{\varrho}^{x}_{j,t,m}q^{N,x}_{t,m} + \tilde{\mathbb{E}}_{j,t,m}\left[\left(\prod_{i=1}^{m}\left[(1-\omega_{j,t+i})(1-\delta)\right]\right)\left(\Phi_{t+m}(\omega_{j,t+m+1}) + \Xi\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right)\right].$$

Generalized supply equation. Substituting these terms into the first-order condition and isolating the pricing sequence yields the bank-specific lending condition reported in the main text:

$$N^{x}_{j,t} = L_{j,t}(f')^{-1}\left(\sum_{m=0}^{\infty}\tilde{\Lambda}^{B,x}_{j,t,m}q^{N,x}_{t,m} - \tilde{\Gamma}^{x}_{j,t}\right), \qquad x \in \{FR, VR\},$$

where

$$\tilde{\Lambda}^{B,x}_{j,t,0} \equiv 1 - \tilde{\omega}^{x}_{j,t+1},$$
$$\tilde{\Lambda}^{B,x}_{j,t,m} \equiv \frac{\tilde{\Omega}^{B,x}_{j,t,m}}{\tilde{\Omega}^{B,x}_{j,t,0}}\tilde{\varrho}^{x}_{j,t,m}, \qquad m \geq 1, \tag{A.26}$$

and

$$\tilde{\Gamma}^x_{j,t} \equiv \lambda \tilde{\omega}^x_{j,t+1} + \mu_t + \mathscr{R}^x_{j,t} - \sum_{m=1}^{\infty} \frac{\tilde{\Omega}^{B,x}_{j,t,m}}{\tilde{\Omega}^{B,x}_{j,t,0}} \tilde{\mathbb{E}}_{j,t,m} \left[\left(\prod_{i=1}^{m} \left[(1-\omega_{j,t+i})(1-\delta) \right] \right) \left(\Phi_{t+m}(\omega_{j,t+m+1}) + \Xi \left(\frac{N_{j,t+m}}{L_{j,t+m}} \right) \right) \right]. \tag{A.27}$$

The decomposition highlights the two channels emphasized in Section 2. First, the effective weights $\tilde{\Lambda}^{B,x}_{j,t,m}$ are bank-specific because they inherit the full path of survival probabilities. Second, the term $\mathscr{R}^x_{j,t}$ introduces a precautionary wedge: by changing future insolvency thresholds, lending today affects the probability of reaching future states in which returns on both legacy and new loans are collected. Since both objects vary with leverage and with the loan-pricing regime, the supply schedule no longer aggregates to a representative-bank relation.

A.10 Portfolio credit risk

It is assumed that individual banks face limits in fully diversifying their loan portfolio and that loan defaults in the portfolio of bank j are correlated according to the *single risk factor* model of Vasicek (2002), in which the default of loan i from bank j is driven by the realization of a latent random variable:

$$\xi_{ijt+1} = -\Phi^{-1}(p) + \sqrt{\rho} z_{jt+1} + \sqrt{1-\rho}\varepsilon_{it+1}, \tag{A.28}$$

where $\Phi(\cdot)$ denotes the cdf of a standard normal random variable and $\Phi^{-1}(\cdot)$ its inverse, z_{jt+1} is a bank-idiosyncratic risk factor that affects all projects in bank's j portfolio, ε_{it+1} is a project-idiosyncratic risk factor that only affects the loan i, and $\rho \in [0,1]$ determines the extent of correlation in loan failures. It is assumed that z_{jt+1} and ε_{it+1} are standard normal random variables, independently distributed from each other, as well as across time, banks, and loans.

The loan i fails when $\xi_{ijt+1} < 0$. The deterministic term $-\Phi^{-1}(p)$ in (A.28) ensures that the unconditional probability of failure of project i satisfies:

$$\Pr(\xi_{ijt+1} < 0) = \Pr\left[\sqrt{\rho} z_{jt+1} + \sqrt{1-\rho}\varepsilon_{it+1} < \Phi^{-1}(p)\right] = \Phi\left[\Phi^{-1}(p)\right] = p.$$

Notice that for $\rho = 0$ the bank-idiosyncratic risk factor does not play any role and loan failures are statistically independent, while for $\rho = 1$ the entrepreneur-idiosyncratic risk factor does not play any role and loan failures are perfectly correlated within each bank. By the law of large numbers, the failure rate ω_{jt+1} (the fraction of loans within a bank's portfolio that fail) for a given realization of the bank-idiosyncratic risk factor z_{jt+1} coincides with the probability of failure of a (representative) project i conditional on z_{jt+1}; that is,

$$\begin{aligned}\omega_{jt+1} = \xi(z_{jt+1}) &= \Pr\left(-\Phi^{-1}(p) + \sqrt{\rho} z_{jt+1} + \sqrt{1-\rho}\varepsilon_{it+1} < 0 | z_{jt+1}\right) \\ &= \Phi\left(\frac{\Phi^{-1}(p) - \sqrt{\rho} z_{jt+1}}{\sqrt{1-\rho}}\right).\end{aligned}$$

From here it follows that the CDF of the loans' failure rate is

$$\begin{aligned}F(\omega_{jt+1}) = \Pr\left[\xi(z_{jt+1}) \leq \omega_{jt+1}\right] &= \Pr\left[z_{jt+1} \geq \xi^{-1}(\omega_{jt+1})\right] \\ &= \Phi\left(\frac{\sqrt{1-\rho}\Phi^{-1}(\omega_{jt+1}) - \Phi^{-1}(p)}{\sqrt{\rho}}\right).\end{aligned}$$

A.11 Law of motion of a bank's equity

Banks can either fail endogenously ($\omega > \bar{\omega}$), or exit exogenously ($\iota = 1$) with probability χ. Since the realization of ω and ι are independent, there are four possible cases, which we handle as follows:

$$\begin{aligned}
\omega > \bar{\omega} \text{ and } \iota = 1 \quad &\rightarrow \text{Exogenous Exit (Bank resolution mechanism)}, \\
\omega \leq \bar{\omega} \text{ and } \iota = 1 \quad &\rightarrow \text{Exogenous Exit (Regular)}, \\
\omega > \bar{\omega} \text{ and } \iota = 0 \quad &\rightarrow \text{Endogenous Failure}, \\
\omega \leq \bar{\omega} \text{ and } \iota = 0 \quad &\rightarrow \text{Continues Operating}.
\end{aligned}$$

A bank's equity at $t+1$ is a function of states $(l_{jt}, x^L_{jt}, e_{jt})$ at time t and shocks (ω, ι) at $t+1$.[44] We can write the law of motion of equity as

$$\begin{aligned}e_{jt+1}(l_{jt}, x^L_{jt}, e_{jt}, \omega, \iota) = &\mathbf{1}_{\{\omega \leq \bar{\omega}, \iota = 0\}} g_{t+1}(l_{jt}, x^L_{jt}, \omega) e_{jt} \\ &+ \mathbf{1}_{\{\omega > \bar{\omega}, \iota = 0\}} \bar{E}_{t+1} \\ &+ \mathbf{1}_{\{\omega \leq \bar{\omega}, \iota = 1\}} \bar{E}_{t+1} \\ &+ \mathbf{1}_{\{\omega > \bar{\omega}, \iota = 1\}} \bar{E}_{t+1} \,.\end{aligned}$$

Due to the independence of ω and ι, we can rewrite this as

$$\begin{aligned}e_{jt+1}(l_{jt}, x^L_{jt}, e_t, \omega, \iota) = &\mathbf{1}_{\{\omega \leq \bar{\omega}\}} \mathbf{1}_{\{\iota = 0\}} g_{t+1}(l_{jt}, x^L_{jt}, \omega) e_{jt} \\ &+ \left[\mathbf{1}_{\{\omega > \bar{\omega}\}} \mathbf{1}_{\{\iota = 0\}} + \mathbf{1}_{\{\omega \leq \bar{\omega}\}} \mathbf{1}_{\{\iota = 1\}} + \mathbf{1}_{\{\omega > \bar{\omega}\}} \mathbf{1}_{\{\iota = 1\}}\right] \bar{E}_{t+1} \,,\end{aligned}$$

[44] Since the mass of banks is constant, we are treating newly entering banks after endogenous failures and exogenous exits as direct successors of the failing bank.

where

$$g_{t+1}(l_{jt}, x^L_{jt}, \omega) = 1 + (1-\tau)\pi_{jt+1}(l_{jt}, x^L_{jt}, \omega),$$

denotes the gross equity growth rate in the case a bank operates successfully ($\omega \leq \bar{\omega}$).

Integrating over the Bernoulli distribution for ι yields

$$\begin{aligned}\int_0^1 e_{jt+1}(l_{jt}, x^L_{jt}, e_t, \omega, \iota) dX(\iota) = (1-\chi)\mathbf{1}_{\{\omega\leq\bar{\omega}\}} g_{t+1}(l_{jt}, x^L_{jt}, \omega) e_{jt} \\ + \left[\mathbf{1}_{\{\omega>\bar{\omega}\}} + \chi \mathbf{1}_{\{\omega\leq\bar{\omega}\}}\right] \bar{E}_{t+1}\,.\end{aligned}$$

Integrating over ω yields

$$\begin{aligned}\int_0^1\int_0^1 e_{jt+1}(l_{jt}, x^L_{jt}, e_{jt}, \omega, \iota) dX(\iota) dF(\omega) &= (1-\chi)\int_0^{\bar{\omega}} g_{t+1}(l_{jt}, x^L_{jt}, \omega) e_{jt} dF(\omega) \\ &\quad + \left(1 - F(\bar{\omega}) + \chi F(\bar{\omega})\right) \bar{E}_{t+1} \\ &= (1-\chi)\bar{g}_{t+1}(l_{jt}, x^L_{jt}) e_{jt} + \left[1 - (1-\chi)F(\bar{\omega})\right] \bar{E}_{t+1},\end{aligned}$$

where $\bar{g}_{t+1}(l_{jt}, x^L_{jt}) = \int_0^{\bar{\omega}} g_{t+1}(l_{jt}, x^L_{jt}, \omega) dF(\omega)$. Note that $\bar{\omega}$ itself is a function of leverage l_t and the average loan rate/spread x^L_{jt}, which for notational simplicity we have omitted.

Then, integrating over the joint distribution of leverage, the average loan rate/spread, and equity $H_t(l_{jt}, x^L_{jt}, e_{jt})$ yields

$$E_{t+1} = (1-\chi)G_t E_t + \bar{\mathscr{F}}_t \bar{E}_{t+1},$$

where the aggregate gross equity growth rate G_t and the mass of banks exiting or failing $\bar{\mathscr{F}}_t$ are given by

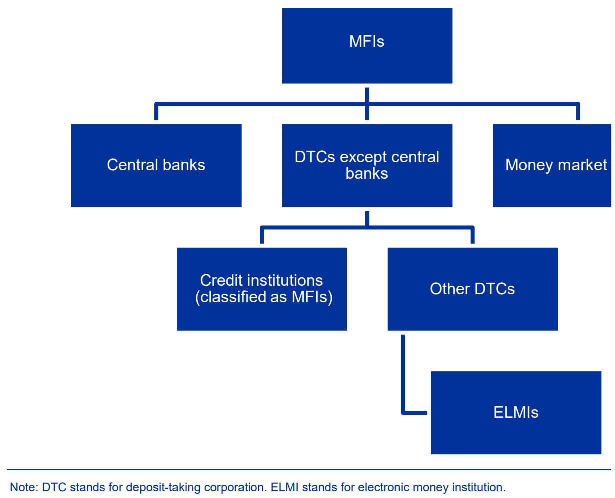
$$\begin{aligned}G_t &= \frac{1}{E_t}\int \bar{g}_{t+1}(l_{jt}, x^L_{jt}) e_{jt} dH_t(l_{jt}, x^L_{jt}, e_{jt}), \text{ and} \\ \bar{\mathscr{F}}_t &= \int \left[1 - (1-\chi)F(\bar{\omega})\right] dH_t(l_{jt}, x^L_{jt}, e_{jt})\,.\end{aligned}$$

B. Empirical Appendix

B.1 Euro Area MFIs Balance Sheet

This section summarizes the salient features of the aggregated balance sheet of monetary financial institutions (MFIs) operating in the euro area, excluding the Eurosystem.[45] These MFIs include deposit-taking institutions (banks), and money market funds (MMFs).

Figure B.1: Components of the MFIs sector



The main source is the Statistical Data Warehouse (SDW) of the ECB. We use monthly or quarterly data, subject to availability, and transform the series to quarterly frequency. The period of analysis is 2013.Q1 to 2023.Q4.[46] Our sample begins in 2013 to ensure comparability across the publicly available ECB datasets and with our proprietary bank-level data from S&P Global, whose coverage also starts in 2013. Datasets:

- Consolidated balance sheet of the MFIs (excluding the Eurosystem).

  https://data.ecb.europa.eu/publications/money-credit-and-banking/3031821

- MFI holdings of securities breakdown by maturity and types: Debt securities, equity, and non-MMF investment fund shares.

[45]The Eurosystem includes the European Central Bank (ECB) and the national central banks of the countries of the euro area.

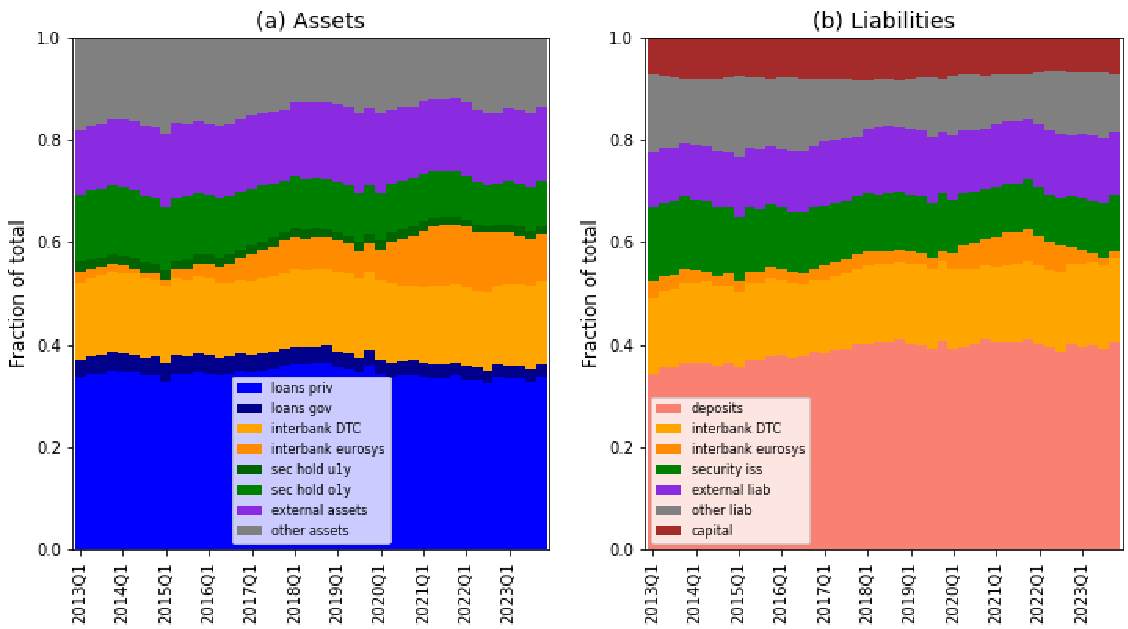
[46]We cannot distinguish MMF from the deposit-taking institutions for the entire time series, but this does not distort the data much as the size of MMFs is very small compared to deposit-taking institutions. In 2024Q2, for instance, MMF aggregate size was 1.8 tn euros, less than 5% the size of deposit-taking institutions, which amounts to 38 tn.

https://data.ecb.europa.eu/publications/money-credit-and-banking/3031889

- Sectoral breakdown of MFI loans vis-à-vis the private sector.

  https://data.ecb.europa.eu/publications/money-credit-and-banking/3031822

Figure B.2: MFIs consolidated balance sheet in the euro area, 2013-2023



Source: ECB SDW. Aggregated Balance Sheet of Euro Area Monetary Financial Institutions (MFIs) excluding the Eurosystem. MFIs are comprised of deposit-taking corporations, money market funds, and central banks.

An inspection of the asset side of Monetary and Financial Institutions (MFIs) in the euro area, in Figure B.2, shows that their asset composition has been remarkably stable. On average, the lending portfolio to households, firms, and the government accounts for 62% of assets. Interbank loans—which include repurchase agreements (repos), securities lending, and similar operations with other MFIs and national central banks—account for about 15% of assets. Security holdings, both short and long-term, account for the remaining 23%.[47] On the liabilities side, most liabilities (60%) are deposits and interbank deposits (17%). The remaining liabilities are securities (16 %) and capital (7%).[48] See the breakdown below in the Table B.1.

[47]We assign external assets and other assets proportionally to the loans and short-term security holdings categories. External assets are holdings of cash in currencies other than the euro, holdings of securities issued by non-residents of the euro area, and loans to non-residents of the euro area (including banks). For statistical purposes, these items

Table B.1: MFIs balance sheet composition (2013–2023)

Assets		**Liabilities**	
Loans	0.62	Deposits	0.63
Interbank loans	0.15	Interbank deposits	0.15
Short-term security holdings	0.12	Security issuance	0.14
Long-term security holdings	0.11	Capital	0.08

Source: ECB Statistical Data Warehouse. Aggregated Balance Sheet of Euro Area MFIs, excluding the Eurosystem. Time series averages across periods. Loans: include loans to the private sector, loans to government, a fraction (85%) of external assets (i.e. operations with non-euro area residents) and other assets. Interbank loans: includes interbank loans with other DTCs. Short-term security holdings: include security holdings with a maturity of less than a 1 year plus interbank operations with NCBs (repos and security lending). Long-term security holdings: include security holdings with a maturity greater than 1 year. Deposits: include retail deposits of different maturities, external liabilities with non-euro area residents, and other liabilities. Interbank deposits refer to interbank deposits with other DTCs. Security Issuance includes the issuance of short and long-term securities plus interbank operations with NCBs.

B.2 CET 1 Capital Ratios and Buffers

Table B.2: Average capital ratios for euro area banks

	All banks	Large	Supervised
CET 1 capital ratio	15.62	13.23	14.45
CET 1 management buffer ratio	7.97	6.16	5.12

Note: All numbers are in percentage points. The first two columns correspond to the cross-sectional means of the centered distribution grouped from 2013 to 2020. *All banks* refers to all euro area banks in our sample, approximately 70+ per quarter. *Large banks* refer to banks with total assets larger than 100 billion euros. *Supervised banks* refer to significant institutions directly supervised by the ECB, 64 in our 2021.Q4 sample. *Sources:* Regulatory requirements (GSII, OSI, SRB) are obtained from the European Systemic Risk board (ESRB). Data for the Pillar 2 requirements of CET1 capital from ECB supervisory reports. Bank-level data for CET 1 ratios and Total Risk Weighted Assets from *S&P* Global.

Table B.2 reports the cross-sectional average CET1 capital ratios and capital buffers for different types of euro area banks.

The first two columns present the cross-sectional averages of the grouped distribution for a sample of euro area banks from 2013 to 2020. We construct an unbalanced bank-level panel using balance-sheet data from S&P Global, a proprietary source. Our quarterly dataset includes information on common equity tier 1 (CET1) capital levels, risk-weighted assets, and total assets. For each bank in the sample, we calculate the capital buffer as the difference between its CET1 ratio and the applicable Combined Buffer Requirement (CBR) in each quarter. The CBR is defined

are included indistinguishably in MFIs' external assets without identifying them separately.

[48]Notice that this aggregate measure of capital and reserves does not coincide with the regulatory capital that we present in Appendix B.2, which is the Core Equity Tier 1 (CET1) capital expressed as a percentage of risk-weighted assets.

as the sum of the Capital Conservation Buffer (CCoB), the Countercyclical Capital Buffer (CCyB), and the maximum of the following institution-specific components: the Systemic Risk Buffer (SRB), the Global Systemically Important Institution (G-SII) buffer, and the Other Systemically Important Institution (O-SII) buffer.

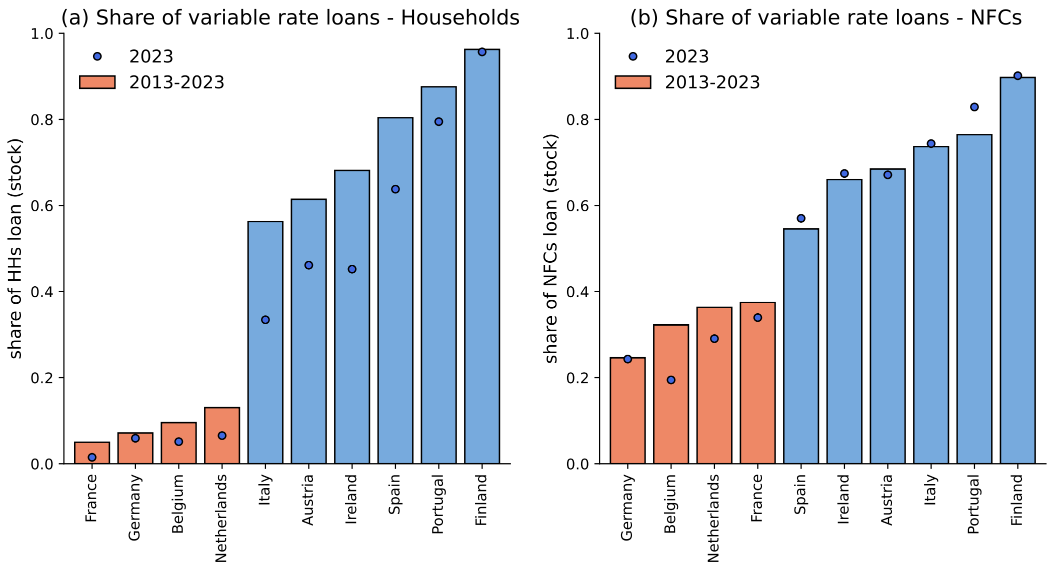
The third column presents CET1 ratios and capital buffer estimates for a sample of Supervised Banks as of 2021:Q4 reported by the European Banking Authority (EBA). These estimates incorporate bank-specific Pillar 2 requirements for CET1 capital in addition to the combined buffer requirements. As expected, the average CET1 capital buffer is slightly lower once Pillar 2 requirements are included. Nonetheless, the overall distribution retains a similar shape and statistical properties.

B.3 Loan Rate Pricing

We define variable-rate loans as contracts with a maturity of over one year and whose interest rate resets within the next 12 months.[49] Figure B.3 shows the share of variable rate lending broken down by credit to households and non-financial corporations, based on ECB MFI statistics. The bars display the average for our period of reference, 2013-2023. The average for most countries is close to the average for 2023 (blue circles), suggesting persistence in loan rate pricing practices.

[49]Approximating the share of variable-rate loans using loans with maturities of up to one year, yields similar results. The categorization in Figure B.3 is also consistent with the findings of Core et al. (2025), who use granular data on non-financial corporate loans in the euro area.

Figure B.3: Composition of lending stocks by interest rate fixation period.



Notes: The left panel presents the share of the stock of aggregate lending to households (including mortgage loans, consumer loans, and other loans) issued at variable rates. The right panel presents the share of stock of aggregate lending to non-financial corporations (NFCs) issued at variable rates. The bars display the average for 2013-2023. Orange bars correspond to our classification of fixed-rate countries and blue bars to variable-rate countries. Blue circles depict the average for the year 2023. Source: ECB Statistical Data Warehouse.

B.4 Estimating Local Projections

We estimate Local Projections a là Jordà (2005) and Jordà et al. (2015) to identify the responses of prices and quantities to monetary policy shocks. We build a balanced panel covering twenty euro area countries. In the baseline results, also reported in the body of the paper, we focus on the ten largest economies (Austria, Belgium, Germany, Finland, France, Italy, Ireland, Netherlands, Portugal, and Spain), as this allows us to construct a balanced panel without data gaps. Variables include lending, deposit rates, and net interest margin (NIM) rates, lending volumes, capital/equity ratios, and macroeconomic indicators (inflation rates, GDP growth, employment, among others) from 2003 to 2023.[50] All variables in the panel are consolidated at the country level, the data frequency is quarterly.

Countries are categorized as variable-raters (VR) if their share of variable-rate lending is above 50% or fixed-raters (FR) otherwise. VR countries are Spain, Portugal, Italy, Finland, Ireland, and Austria. FR countries are Germany, France, Belgium, and the Netherlands. In Appendix B.5 we present robustness checks for the extended sample with all 20 euro area countries, and

[50]Our reference sample is extended to begin in 2003, which improves the statistical power of the panel estimations and aligns the lending-volume and interest-rate series. For most euro area countries, interest rate data are consistently reported in the ECB's publicly accessible data portal starting in 2003.

for a restricted sample where we exclude a set of southern european countries. All IRFs remain qualitatively unchanged.

Interest rates. We estimate the following local projection specification:

$$r_{c,t+h} = \alpha_{c,h} + \beta_{1h}\varepsilon_t^{MP} + \beta_{2h}\left[\varepsilon_t^{MP} \times I_c^{FR}\right] + \Gamma_h X_{c,t} + e_{c,t+h} \tag{B.1}$$

where $r_{c,t+h}$ denotes the variable of interest (lending rates, deposit rates, NIM rates) at time t, and horizon h ranging from 0 to 16 quarters. The variable ε_t^{MP} denotes the change in the deposit facility rate (DFR) at time t, which we instrument– in a first stage– with the *(median) monetary policy component* from Jarociński and Karadi (2020). I_c^{FR} is a dummy variable that takes the value of one when a country belongs to the FR category.

$X_{c,t}$ represents the set of controls. As it is common in the literature, we include the first lag of the dependent variable and the first lag of the deposit facility rate as controls. We also use the contemporaneous and the first lag of inflation and the quarterly growth rate of the industrial production index. As well as the first lag of the yield on a BBB corporate bond index for the euroarea, and the first lag of the yield on the one-year German government debt bond since these variables have been found relevant for the euro area (Jarociński and Karadi (2020)).

Quantities. In a similar fashion, our econometric specification for the volume of lending:

$$\log Y_{c,t+h} = \alpha_{c,h} + \beta_{1h}\epsilon_t^{MP} + \beta_{2h}\left[\epsilon_t^{MP} \times I_c^{FR}\right] + \Gamma_h X_{c,t} + e_{c,t+h}. \tag{B.2}$$

For these specifications, we use the monetary surprises (i.e., the *(median) monetary policy component*, ϵ_t^{MP}, from Jarociński and Karadi (2020)) without instrumenting the DFR since for log-volumes the monetary surprise series yields smoother IRFs. The set of controls is the same used for interest rates but expressing variables in logarithms: first lag of the dependent variable $\log Y_{c,t-1}$. The contemporaneous and the first lag of HICP and the log of the industrial production index. We also include the first lag of the yield on a BBB corporate bond index for the euroarea, and the first lag of the yield on the one-year German government debt bond.

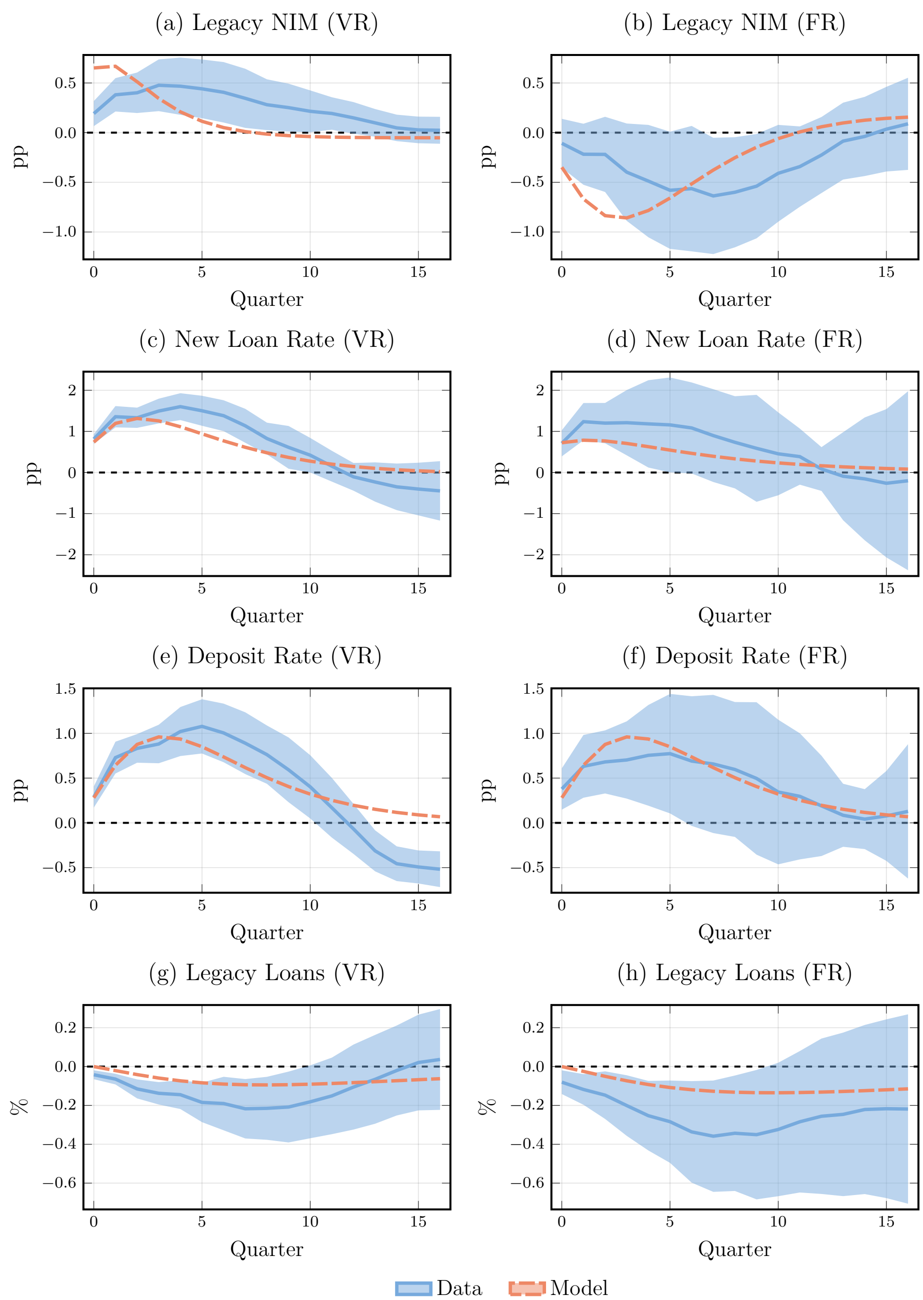
Figure 4 (in the main text) shows the estimated IRFs for interest rates, and lending volumes. In each Figure, the left Panel depicts the sequence of estimated dynamic coefficients $\{\beta_{1h}\}_{h=0}^{h=16}$ of the monetary policy shock as a solid blue line together with 95% confidence bands. This represents the average effect across VR countries. The right Panel depicts the sequence of estimated dynamic coefficients $\{\beta_{1h} + \beta_{2h}\}_{h=0}^{h=16}$ of the monetary policy shock as a solid blue line together with 95% confidence bands. This represents the average effect across FR countries.

B.5 Robustness for Local Projections

Panel of 20 euro area countries. Figure B.4 presents robustness estimations for an extended sample including all 20 euro area countries, where Germany, France, Belgium, the Netherlands, and Slovakia are classified as operating under a fixed rate regime (FR). Portugal, Spain, Finland, Ireland, Austria, Italy, Estonia, Croatia, Cyprus, Greece, Latvia, Lithuania, Malta, Luxembourg, and Slovenia are classified as operating under a variable rate regime (VR).

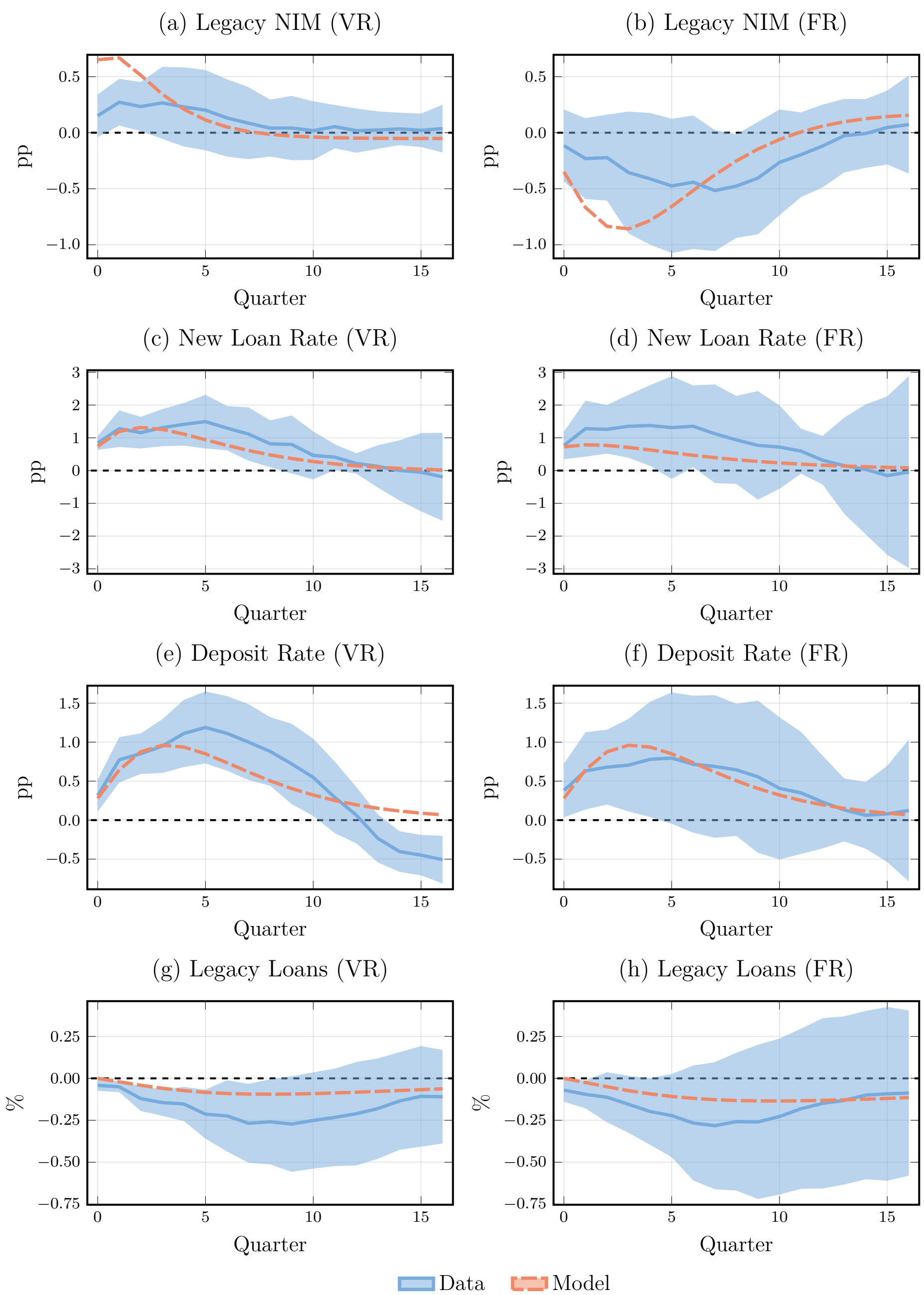
Panel of 20 euro area countries excluding periphery countries. Figure B.5 shows that our estimated empirical responses are not driven by a core-periphery classification. We present robustness estimates for the extended sample excluding a set of periphery countries: Spain, Portugal, Italy, and Ireland. This exclusion reduces the set of countries categorized as VR to Finland, Austria, Estonia, Croatia, Cyprus, Greece, Latvia, Lithuania, Malta, Luxembourg, and Slovenia. The set of FR countries is Germany, France, Belgium, the Netherlands, and Slovakia.

Figure B.4: Local Projections. Panel of 20 euro area countries.



Note: Solid blue lines show the empirical impulse responses to a monetary policy shock and dashed red lines compute the model counterparts. Light blue bands show the 95% confidence intervals. Panels on the left report the response across VR countries, while right Panels report the response across FR countries in the data and in the model. See Appendix B.4 for estimation details.

Figure B.5: Local Projections. Panel excluding periphery euro area countries.

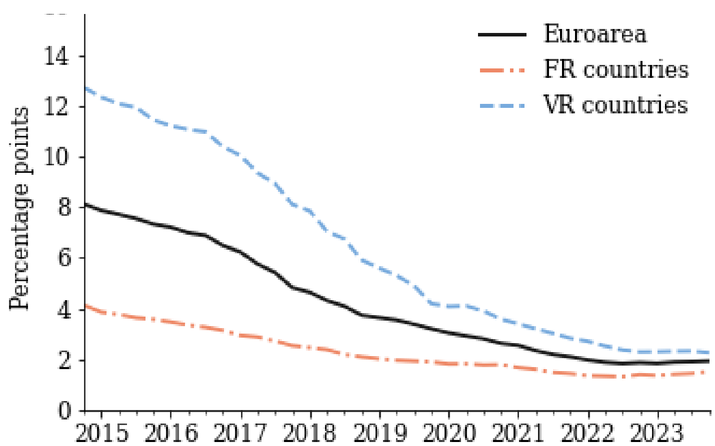


Note: Solid blue lines show the empirical impulse responses to a monetary policy shock and dashed red lines compute the model counterparts. Light blue bands show the 95% confidence intervals. Panels on the left report the response across VR countries, while right Panels report the response across FR countries in the data and in the model. See Appendix B.4 for estimation details.

B.6 Credit risk in the euro area

This section examines credit risk dynamics across euro area countries using time-series data on non-performing loans (NPLs) from the ECB's Consolidated Banking Data (CBD2) dataset. The dataset covers the period from 2014 to 2023.[51] As before, we focus on the ten largest euro area economies, grouped by their share of variable-rate lending. FR countries: Belgium, France, Germany, and the Netherlands, and VR countries: Austria, Finland, Ireland, Italy, Portugal, and Spain.

Figure B.6: Average non-performing loans (NPLs).



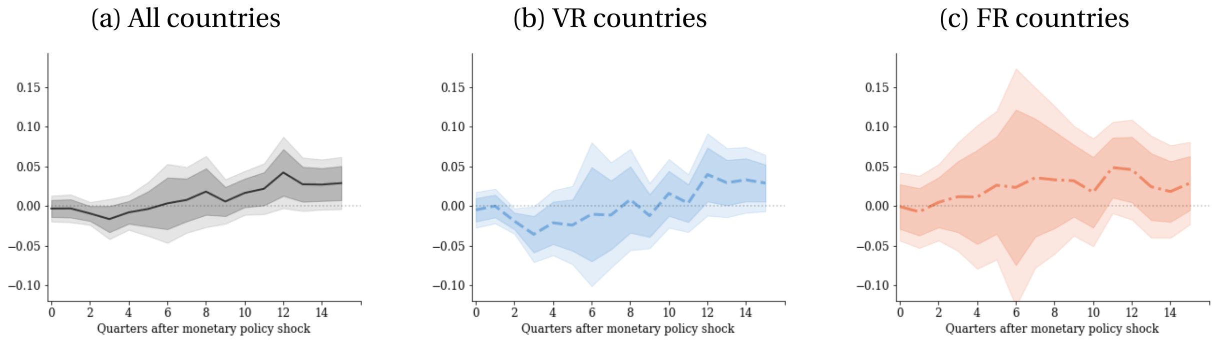
Note: NPLs are defined as the volume of non-performing loans and advances divided by the total volume of loans and advances. The data is from the European Central Bank's country *Consolidated Banking Data* dataset. The country sample covers the ten largest euro area economies, grouped by their share of variable-rate lending. FR countries: Belgium, France, Germany, and the Netherlands, and VR countries: Austria, Finland, Ireland, Italy, Portugal, and Spain.

Figure B.6 shows the average ratio of NPLs— defined as the volume of non-performing loans and advances divided by the total volume of loans and advances —across FR, VR, and all euro area countries. There are clear differences in levels across country groups: VR countries feature historically higher NPLs than their FR counterparts. However, over the last decade, VR countries have seen their NPL ratios decline, converging to levels similar to those seen for FRs. Using granular credit registry data, Core et al. (2025) documents similar patterns in non-financial corporation's default rates across fixed- and variable-rate economies in the Euro Area. Bandoni et al. (2025) document a similar declining pattern for mortgage default rates computed from a sample of securitized mortgages in Spain, Portugal, Ireland, and Italy.[52]

[51] This time series is available starting the fourth quarter of 2024.

[52] Core et al. (2025) use Anacredit loan level data in December 2021, they find that the 1-year probability of default (PD) on fixed-rate loans averaged 6.26% with a 19.64% standard deviation, and 9.52% with a standard deviation of 25.05% for variable-rate loans. Using loan-level data on securitized mortgages from the European Data Warehouse

Figure B.7: Local Projections on NPLs



Note: NPLs are defined as the volume of non-performing loans and advances divided by the total volume of loans and advances. The data is from the European Central Bank's country *Consolidated Banking Data* (CBD2) dataset. The country sample covers the ten largest euro area economies, grouped by their share of variable-rate lending. FR countries: Belgium, France, Germany, and the Netherlands, and VR countries: Austria, Finland, Ireland, Italy, Portugal, and Spain.

Figure B.7 shows the responses of NPLs to a monetary surprise estimated by Local Projections. We estimate the same specification used for interest rates, see Appendix B.4. Panel (a) shows the average response across all countries. Panels (b) and (c) show the responses for VR and FR countries, respectively. Responses do not differ significantly across country group types.[53]

for 2014 to 2019, Bandoni et al. (2025) estimate an average mortgage default rate of 0.9% across countries.

[53] Our estimates capture the responses of the credit risk stock, since NPLs are a slow-moving measure of credit risk (stock). Understanding the responses of flow measures, such as defaults at 60 or 90 days, would require using granular credit registry data, as no country-consolidated series are available.

C. Solution algorithm

Preliminaries. For the solution algorithm, we define a new choice variable

$$k_t^{gap} = 1 - \gamma(l_t + n_t)\,,$$

which measures the end-of-period distance from the capital requirement. Using the choice variable k_t^{gap} and the state l_t, we can then compute n_t as

$$n_t = \frac{1 - \gamma l_t - k_t^{gap}}{\gamma}$$

Given the expression for n_t, all other model variables can be computed using the expressions presented in the main text and the appendix.

The solution algorithm then aims to find a policy function for k_t^{gap} that maximizes the value function such that $n_t, d_t \geq 0$. Note that the constraint on d_t is always satisfied since $l_t \geq 0$ and $d_t = \alpha l_t$. Therefore, we only need to ensure

$$n_t = \frac{1 - \gamma l_t - k_t^{gap}}{\gamma} \geq 0\,.$$

The constraints, thus, define a maximum feasible value for k_t^{gap}

$$k_t^{gap,max} = 1 - \gamma l_t \geq k_t^{gap}\,,$$

In the implementation of Algorithm 1, it is ensured that this constraint is not violated.

Steady State. Solving for the model's steady state comprises two main steps: First, solving for the individual bank policy functions using value function iteration. Second, computing the steady-state bank distribution over equity E_t, leverage l_t, and the average loan rate/spread x_t^L using the method of Young (2010). These steps must then be executed iteratively to find the equilibrium loan rate r^L which clears the loan market.

We discretize the state space for $l_t \in [0, 1/\gamma]$, $x_t^L \in [x^L - \sigma, x^L + \sigma]$, where σ is the size of the MIT shock, and $\log(E_t) \in [\log(0.13), \log(3000)$ using equally spaced grids.[54] Algorithm 1 describes the value function iteration algorithm used to solve the problem of an individual bank which, due to size-independence, only depends on (l_t, x_t^L). Algorithm 2 describes the algorithm to compute

[54]Note that, technically, there is no need for the x^L grid in the steady state, since it stays constant for all banks. However, computing the steady-state policies for $x_t^L \neq x^L$ is required when computing the transition after an MIT shock, such that bank behavior is well-defined when interest rates are back at their steady-state value, even if the average loan rate/spread at individual banks x_t^L has not yet converged back to the steady state.

the bank distribution. Finally, Algorithm 3 describes the complete algorithm used to solve for the steady state.

Algorithm 1 (Individual Problem)**.**

1. *Make a guess for the capital gap policy function* $k_0^{gap}(l, x^L)$ *and the value function* $V_0(l, x^L)$.

2. *Taking the value function for next period* $V_i(l, x^L)$ *as given, use an optimization routine to find the value of* $k_{i+1}^{gap}(l, x^L)$ *that maximizes todays value* $V_{i+1}(l, x^L)$ *for each grid point* (l, x^L). *Note that we use cubic interpolation to interpolate the value function if* (l_{t+1}, x_{t+1}^L) *are off-grid.*

3. *Optional "Howard Improvement": Keeping the capital gap policy function* $k_{i+1}^{gap}(l, x^L)$, *update the value function by iterating on it* N *times.*

Iterate on steps 2 & 3 until the maximum absolute difference between $V_{i+1}(l, x^L)$ *and* $V_i(l, x^L)$ *is less than a given degree of precision.*

Algorithm 2 (Bank Distribution)**.**

1. *Make a guess for the bank distribution* $H(l, x^L, \log(E))$ *in the form of a matrix* $\mathcal{H}_0$ *where each element corresponds to the mass associated with a particular grid point* $(l, x^L, \log(E))$.

2. *Given the individual policy function and the distribution* $\mathcal{H}_i$, *determine the closest grid points to which banks move in the next period and redistribute mass using the method of Young (2010) yielding* $\mathcal{H}_{i+1}$.

Iterate on steps 2 until the maximum absolute difference between $\mathcal{H}_{i+1}$ *and* $\mathcal{H}_i$ *is less than a given degree of precision.*

Algorithm 3 (Steady State)**.**

1. *Make an initial guess for the loan rate* r^N.

2. *Solve the individual bank problem as described in Algorithm 1.*

3. *Solve for the bank distribution as described in Algorithm 2.*

4. *Check whether* r^N *clears the loan market. If the loan market does not clear, update the guess for* r^N *and go to step 2.*

Transition. We use an algorithm similar to the one described in Boppart et al. (2018) to solve for the transitional dynamics after an MIT shock. The approach is similar in spirit to the steady-state algorithm presented above. However, in this case, we are not trying to find a single value for the loan rate r^N to clear the loan market but a path $\{r_t^N\}_{t=1}^{T-1}$ to clear the loan market in each period.

Algorithm 4 (Transition)**.**

1. *Choose a time T at which the economy is assumed to have reached the steady state.*
2. *Guess a path for the loan rate $\{r_t^N\}_{t=1}^{T-1}$.*
3. *Solve the value and policy functions backward from $t = T-1, \dots, 1$ assuming that time T value and policy functions correspond to the ones in the steady state.*[55]
4. *Update the paths for the distribution $\{\mathscr{H}_t(l, x^L, \log(E))\}_{t=1}^{T-1}$ by iterating forwards from $t = 1, \dots, T-1$ using the updated path of policy functions from the previous step.*
5. *Given the path for the distribution, the policy functions, and the loan demand schedule, compute the implied path for the loan rate.*
6. *Compute the maximum difference between the implied paths for $\{r_t^N\}_{t=1}^{T-1}$ and its guess. Stop the algorithm if the maximum difference is less than a given degree of precision.*
7. *Update the guess $\{r_t^N\}_{t=1}^{T-1}$ by taking a weighted average of the old guess and the implied paths. Go to step 3.*

[55]This part of the algorithm proceeds analogously to solving for the steady state.