The Heterogeneous Bank Lending Channel of Monetary Policy*

Jorge Abad[†] Saki Bigio[‡] Salomon Garcia-Villegas[$]
Joël Marbet[†] Galo Nuño[†,§]

[†]Banco de España
[‡]UCLA and NBER
[$]CUNEF University
[§]CEMFI and CEPR

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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 banks face occasionally binding capital constraints. Calibrating the model to the euro area, we show that idiosyncratic default risk pushes a substantial share of banks toward regulatory limits, 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 a neutrality result that serves as an organizing theoretical benchmark. Regardless of loan origination costs, monetary policy transmission is identical in fixed- and variable-rate banking systems in an unconstrained benchmark where banks remain away from binding capital requirements and banks and borrowers evaluate loan cash flows with aligned effective horizon weights. In turn, meaningful differences in loan discounting arise when either capital constraints matter for bank valuation or effective horizon weights cease to align.[2] This benchmark clarifies that heterogeneity in interest-rate risk exposure matters insofar as it affects the distribution of banks whose leverage is near regulatory limits.

An implication of our irrelevance benchmark is that whether interest-rate risk exposure matters is ultimately a quantitative question: the answer depends on how likely banks are to approach their regulatory constraints. Answering this question requires a model calibrated to a

[1] This distinction is recognized as early as in Samuelson (1945). Interestingly, Samuelson held the dogmatic 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.

specific institutional context, with a realistic formulation of regulatory constraints 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). Our framework, which targets calibration targets both aggregate moments and the dispersion in capital buffers across banks, provides the discipline needed to address this question.

We find that heterogeneity is quantitatively significant, but only because a substantial number of banks operate near their regulatory constraints. 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 regulatory constraints. 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 capital constraints—and hence how banks discount future loan cash flows. Banks initially near the constraint 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). 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

[3] Financing long-term loans with short-term deposits exposes banks to interest rate risk (English et al., 2018; Ampudia and den Heuvel, 2022). 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.

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 pushes banks away from regulatory constraints, 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 binding constraints.

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).[4] 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: in the unconstrained benchmark with aligned valuation weights, whether loans carry fixed or variable rates is also irrelevant for monetary policy transmission. 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 capital constraints bind or effective discounting diverges, 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 shared with Elenev et al. (2021), our model emphasizes heterogeneity, both in terms of ex ante interest-risk exposure and ex-post leverage.[5] We articulate that credit reallocation within rate-

[4] 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.

[5] 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.

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[6]; 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.[7] 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] Bellifemine et al. (2022) extends this framework with nominal frictions.

[7] 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 $t \in \{0, 1, 2, \dots\}$ 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 core of the model features a banking sector that intermediates funds from households to entrepreneurs, who undertake risky long-term projects requiring external financing. Entrepreneurs' entry decisions generate a microfounded, forward-looking demand for loans. The funding side is deliberately kept simple: the household block delivers a static deposit supply, yet remains flexible enough to match the observed dynamics of deposit rates following monetary policy shocks. This setup allows us to focus squarely on the bank lending channel.

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

The regulatory framework comprises capital requirements, which are central to banks' risk exposure. In addition, we introduce liquidity requirements and a deposit insurance scheme, which allow us to accurately capture bank funding costs. Aggregate economic activity depends on the interaction between banks' lending capacity and entrepreneurs' investment demand.

We analyze two distinct institutional arrangements regarding loan-rate fixation: one where loan contracts stipulate a fixed interest rate for the life of the loan, and another where the interest rate is variable, resetting 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 via retained earnings.

Assets. Bank assets comprise risky long-term loans and safe short-term assets, which we refer to as reserves.[8] 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.[9]

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.[10] 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

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

[9] 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.

[10] 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:

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

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^B_t. Retail deposits are one-period liabilities paying r^D_t. They provide liquidity services to depositors (which implies that, in equilibrium, $r^D_t \leq r^B_t$).

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.[11]

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 $t+1$:

$$\begin{aligned} \Pi_{jt+1} = (1-\omega_{jt+1})\left(r^L_{jt} L_{jt} + r^N_t N_{jt}\right) + r^M_t M_{jt} - r^D_t D_{jt} - r^B_t B_{jt} \\ - \lambda \omega_{jt+1}(L_{jt} + N_{jt}) - f\left(\frac{N_{jt}}{L_{jt}}\right) L_{jt} - \bar{\pi} E_{jt}. \end{aligned} \tag{5}$$

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:

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

[11] 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.2 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 constraint as capturing 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 ($r_t^D < r_t^B$). Naturally, a profit-maximizing bank will always choose to finance as much of its portfolio as possible with the cheapest source of funding. Moreover, the liquidity requirement (7) binds because the return on reserves, r_t^M, is assumed to be strictly lower than the return on loans and is never larger than the cost of any liabilities available to the bank. Consequently, the bank naturally chooses to hold as few reserves as necessary to satisfy the regulatory minimum.

Bank failure, entry, and exit. A bank fails and is resolved by the regulator if, after the realization of portfolio defaults ω_{jt+1}, its equity falls below the regulatory minimum: $E_{jt+1} < \gamma L_{jt+1}$. Upon failure, its equity is wiped out, and a deposit insurance agency seizes its assets, liquidates a fraction, 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 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. New entrants start 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. In Appendix A.5, we derive an expression for the probability $\tilde{\chi}$ that a loan is liquidated because of an exit of its financing bank.[12]

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_{jt}^L, for FR banks, or the

[12]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.

average spread s^L_{jt}, for VR banks. The bank's value function V_t satisfies:

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

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. Lemma 1 below shows that the problem can be written more parsimoniously in terms of two state variables: the bank's leverage (L_j/E_j) and either the average legacy rate (r^L_j) for FR banks, or the average legacy spread (s^L_j) for VR banks.

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 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 $\tilde{\chi}$.[13] 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.

Entrepreneurs are long-lived agents who accumulate wealth by retaining earnings from their projects and investing at the risk-free rate r^E_t. Entrepreneurial income is subject to the corporate tax rate τ, so the law of motion for entrepreneur i's wealth is given by:

$$W_{it+1} = \Upsilon_t W_{it} + (1-\tau)\Pi^E_{it+1}, \tag{10}$$

where the first term, $\Upsilon_t \equiv 1 + (1-\tau) r^E_t$, is the after-tax gross return on the entrepreneur's existing wealth W_{it}, reflecting the risk-free investment opportunity. The second term, $(1-\tau)\Pi^E_{it+1}$,

[13] 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.

represents the after-tax operating profits from the entrepreneur's active project, where Π^E_{it+1} is the pre-tax net cash flow (yield A minus interest payments). Crucially, the entrepreneur's planning horizon is explicitly tied to the bank's exit shock. The entrepreneur accumulates wealth until the exact date their originating bank exits and the loan is liquidated (probability $\tilde{\chi}$). Upon this event, the active project terminates, the loan is repaid, and the entrepreneur consumes all accumulated wealth and leaves the economy.[14]

Initiating a project requires a utility cost of $a(N_t)$, where $a(\cdot)$ is an increasing and convex 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^N_t (or spread s^N_t) for all new loans originated at time t.

The present value of a project depends on the nature of the interest rate regime, but is always evaluated using the entrepreneur's effective discounting sequence. Because entrepreneurs value cash flows based on their ability to accumulate wealth over time until they eventually consume it upon the bank-driven liquidation event, the subjective present value of a marginal unit of after-tax cash flow *conditional on the project surviving to horizon m* must account for this consumption timing.

Specifically, if the cash flow is earned at horizon m, it compounds at rate Υ until the date $k \geq m$ when the liquidation shock finally hits, causing the entrepreneur to consume their wealth. This conditional consumption event has probability $(1-\tilde{\chi})^{k-m}\tilde{\chi}$ and provides utility discounted by β^{k+1}. To evaluate the unconditional value of the loan, this utility must be multiplied by the probability that the project actually survives to horizon m. The project must avoid default (p) and maturation (δ) up to horizon m, with probability $(1-p)^{m+1}(1-\delta)^m$. Furthermore, it must also avoid the bank-driven liquidation shock $\tilde{\chi}$ up to horizon m, with probability $(1-\tilde{\chi})^m$.

Multiplying the survival probability $(1-\tilde{\chi})^m$ by the conditional consumption probability $(1-\tilde{\chi})^{k-m}\tilde{\chi}$ simplifies exactly to $(1-\tilde{\chi})^k\tilde{\chi}$. Thus, we can define a valuation kernel that absorbs both the liquidation survival risk up to horizon m and the consumption timing thereafter:

$$\Omega^E_{t,m} \equiv (1-\tau)\sum_{k=m}^{\infty}\beta^{k+1}(1-\tilde{\chi})^k\tilde{\chi}\left(\prod_{q=m+1}^{k}\Upsilon_{t+q}\right) \tag{11}$$

This valuation kernel $\Omega^E_{t,m}$ aggregates the expected future value of a dollar earned at date $t+m$. The term $(1-\tau)$ converts pre-tax cash flow to after-tax. The product $\prod_{q=m+1}^{k}\Upsilon_{t+q}$ captures the continuous compounding of this dollar at the after-tax risk-free rate from horizon m until

[14] Note that if the project terminates early due to success (δ) or failure (p), the entrepreneur *does not* exit, but rather continues to compound their accumulated wealth until the bank-level liquidation shock $\tilde{\chi}$ materializes.

a potential exit date k. The term $(1-\tilde{\chi})^k\tilde{\chi}$ effectively combines the probability of avoiding liquidation up to horizon m with the conditional probability of liquidating exactly at horizon k, at which point the accumulated balance is consumed, providing utility discounted back to date t by the subjective time preference factor β^{k+1}.

To evaluate a loan, this valuation kernel must be combined with the probability that the project actually survives to generate cash flows at horizon m. We define the entrepreneur's normalized effective discount factor for project cash flows at horizon m as:

$$\Lambda^E_{t,m} \equiv \Omega^E_{t,m}(1-p)^{m+1}(1-\delta)^m. \tag{12}$$

Here, $(1-p)^{m+1}(1-\delta)^m$ is the probability that the project successfully avoids both default (probability p per period, starting from origination) and maturation (probability δ per period, starting one period after origination) up to horizon m. This composite sequence $\Lambda^E_{t,m}$ consolidates both the objective project survival probabilities and the entrepreneur's subjective timing of consumption.[15]

For a loan originated at date t, the entrepreneur pays an interest rate $q^N_{t,m}$ in every period $t+m$, which equals r^N_t for FR banks and $r^M_{t+m}+s^N_t$ for VR banks. The net cash flow in each period is $A-q^N_{t,m}$. Equating the expected discounted value of these constant cash flows to the aggregate startup cost yields the free-entry condition $\sum_{m=0}^{\infty}\Lambda^E_{t,m}(A-q^N_{t,m}) = a(N_t)$. The implied aggregate demand for new loans is therefore:

$$N_t = a^{-1}\left(\sum_{m=0}^{\infty}\Lambda^E_{t,m}\left(A-q^N_{t,m}\right)\right). \tag{13}$$

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. The bundle combines highly liquid assets, D^H_t, with less liquid bonds, A^H_t, and the differing liquidity services of these assets generate an equilibrium spread between their returns. Highly liquid assets comprise bank deposits and short-term government paper; bonds comprise wholesale debt issued by banks, B^H_t, and longer-term government bonds, M^H_t. Within each category, the component assets are perfect substitutes from the household's perspective. Appendix A.3 details the full problem.

The core result is a canonical asset-demand system. In particular, the demands for highly

[15] Note that project survival and entrepreneur exit are independent events. The project survival probability enters $\Lambda^E_{t,m}$ multiplicatively, while the exit probability shapes the valuation kernel $\Omega^E_{t,m}$.

liquid assets and bonds are:

$$D_t^H = h^D(r_t^D, r_t^M), \tag{14}$$

and

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

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:

$$T_t + \tau\Pi_t + M_t^S + D_t^S = \left(1 + r_{t-1}^M\right) M_{t-1}^S + \left(1 + r_{t-1}^D\right) D_{t-1}^S + \Theta_t, \tag{16}$$

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.

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, reserves, and the consumption good 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.4 provides more details on all equilibrium objects and market-clearing conditions.

2.6 Discussion of modeling assumptions

It is worth discussing the key modeling features of the non-financial block. The general equilibrium structure plays a dual role. First, it delivers a loan demand and funding supply system in which the credit side is decoupled from the supply of funds, akin to the asset-demand systems used for econometric analysis (Koijen and Yogo, 2019; Diamond et al., 2024). Because the entrepreneur's problem does not interact with the household's funding decisions, the model remains computationally tractable. By construction, this decoupling strips away aggregate demand feedbacks, but it is precisely this feature that allows us to isolate the bank-lending channel. Second, unlike the partial equilibrium or ad-hoc formulations common in the literature, embedding household decisions in general equilibrium disciplines the analysis: it provides a consistent representation of funding supply and forces us to be explicit about how monetary policy is implemented.

While decoupled from one another, the loan-demand and funding-supply sides differ in their intertemporal structure. The loan-demand side is forward-looking: given the long-term nature of entrepreneurial projects, aggregate loan demand depends on the discounted present value of future loan repayments. Two simplifications discipline the credit side of the model. First, although default risk is present in the environment, it is exogenous and invariant to policy. We maintain this assumption to isolate the bank-lending channel from credit-risk feedback, and we study its robustness below. Second, interest-rate risk plays no role on the loan-demand side: there is no connection between surprises in rate changes and how the yield curve is priced (Piazzesi, 2005). Despite shutting down these two feedback channels, the evolution of bank equity retains an important role in the pricing of loans, so the model preserves a key financial-amplification force on the bank side (Brunnermeier and Sannikov, 2014).

Unlike the loan-demand side, the supply of deposits and wholesale bonds by households is static, depending only on current rates. This feature follows directly from our quasi-linear preferences—a standard assumption in new-monetarist models (Lagos and Wright, 2005; Lagos

et al., 2017) and also adopted in dynamic banking models (Bianchi and Bigio, 2022). The complementarity between deposits and wholesale bonds couples the two funding instruments into a demand system with cross-elasticities, as in other frameworks with competing monetary services (e.g., Drechsler et al., 2017; Di Tella and Kurlat, 2021).

The main text presents households as choosing between two tiers of assets—highly liquid assets (earning r^D) and less liquid bonds (earning $r^M > r^D$)—with components within each tier being perfect substitutes. While this may appear as an ad-hoc simplification, Appendix A.6 provides a deeper institutional setting from which these substitutability assumptions emerge. In that setting, money market funds act as pass-through entities that hold short-term government securities and issue liquid shares to households, making MMF shares and bank deposits perfect substitutes within the liquid tier. Similarly, a central bank facility allows banks to exchange long-term government bonds one-for-one for reserves, rendering them indifferent between the two within the bond tier. The reduced-form demand system in the main text is thus a consolidation of this richer institutional structure.

A novel aspect of our formulation is that monetary policy shocks induce changes in two rates simultaneously. As is known from the literature, the pass-through from policy rates to deposit rates is non-linear (Drechsler et al., 2017) and time-varying—a feature that is challenging to replicate in models without additional state variables on the household side (Eichenbaum et al., 2025). Our setup sidesteps this difficulty: government bond supply shocks, occurring contemporaneously with monetary policy shocks, allow both the deposit rate and the rate on reserves to follow their observed empirical trajectories, while the loan rate responds endogenously. This flexibility to match the empirical path of funding costs, while preserving endogenous loan pricing, is key to accurately capturing banks' cost of funds.

All in all, the setup isolates the bank-lending channel from three potential confounds: aggregate demand feedbacks (through the decoupling of loan demand from funding supply), credit-risk feedbacks (through the exogeneity of default), and the deposit-passthrough channel (through the modeling of government bond supply).

2.7 Characterization

This section shows how to reduce the dimensionality of the bank's problem. We then demonstrate an irrelevance result which helps us clarify when is it that heterogeneity matters.

Collapsing the bank problem. A key feature of the model is that, despite its complexity, it has a transparent representation in terms of a dynamic programming problem with two states and one choice. This is possible thanks to two properties. First, as we showed above, because the constraints on reserve holdings, deposit constraints, and the period budget constraints hold,

we can substitute out three variables: D_{jt}, B_{jt}, M_{jt} and express all of these in terms of D_{jt}, B_{jt}. Second, the banks' optimal policies exhibit size independence, substantially simplifying the analysis while preserving the relevant heterogeneity in leverage and portfolio composition. Because returns, costs, and regulatory constraints all scale proportionally with bank size, decision rules can be expressed independently of the current level of equity. Specifically, factoring out equity leaves leverage $l_{jt} \equiv L_{jt}/E_{jt}$ and the average legacy rate r^L_{jt} (for FR banks) or spread s^L_{jt} (for VR banks) as the sole relevant state variables for individual bank decisions.

Lemma 1 (Size independence)**.** *The bank's value function $V_t\big(L_{jt}, E_{jt}, x_{jt}\big)$, which solves (9), is linear in equity E_{jt}, i.e., $V_t\big(L_{jt}, E_{jt}, x_{jt}\big) = v^B_t\big(l_{jt}, x_{jt}\big)\, E_{jt}$. The value per unit of equity, v^B_t, solves:*

$$v^B_t(l,x) = \max_{n \geq 0} \beta\big(1-\phi(l,x,n)\big)\, \mathbb{E}\Big[\, g(l,x,n;\omega)\big[(1-\chi)\, v^B_{t+1}(l',x') + \chi\big] \,\Big|\, \omega < \bar{\omega}(l,x,n)\Big], \tag{17}$$

with laws of motion for the state variables:

$$l' = (1-\omega)\,\frac{(1-\delta)(l+n)}{g(l,x,n;\omega)}, \quad x' = \frac{r^L(x)\, l + r^N_t\, n}{l+n}. \tag{18}$$

Equity growth is $g(l,x,n;\omega) = 1 + (1-\tau)\,\pi(l,x,n;\omega)$ where $\pi(l,x,n;\omega) = r^E(l,x,n) - \omega\,\mathscr{L}(l,x,n)$ are the profits per unit of equity. Here, r^E is the deterministic levered return on equity,

$$r^E(l,x,n) = \big(r^L(x) - r^M_t\big)l + \big(r^N_t - r^M_t\big)n + r^M_t + \alpha(r^M_t - r^D_t)l - f\big(\tfrac{n}{l}\big)\, l - \bar{\pi}, \tag{19}$$

and $\mathscr{L}$ is the loss upon default,

$$\mathscr{L}(l,x,n) = \big(r^L(x)\, l + r^N_t\, n\big) + \lambda(l+n). \tag{20}$$

The failure threshold shock, $\bar{\omega}$, solves

$$\bar{\omega}(l,x,n) = \frac{1 + (1-\tau)\, r^E(l,x,n) - \gamma(1-\delta)(l+n)}{(1-\tau)\,\mathscr{L}(l,x,n) - \gamma(1-\delta)(l+n)}, \tag{21}$$

and the failure probability is $\phi(l,x,n) \equiv 1 - F\big(\bar{\omega}(l,x,n)\big)$.

Proof. See Appendix A.6.

Homogeneity in equity arises because interest income, funding costs, and operating costs all scale linearly, while regulatory constraints are proportional to loans and liabilities, respectively. Consequently, bank growth rates depend on leveraged returns and the realization of idiosyncratic shocks, not absolute scale. Thus, conditional on leverage and the average rate on their loans, which is encoded in x, all banks are scaled replicas.

The Bellman equation (17) has a natural interpretation: The bank survives to the next period with probability $1-\phi$, which depends on the leverage at the beginning of the next period, after the shock. Conditional on survival, $\omega < \bar{\omega}$, the bank computes its value, which multiplies the equity growth times the change in the value per unit of equity to compute its continuation value. The following period's value per unit of equity is v^B_{t+1} if the bank continues with probability $1-\chi$ or 1 if it exits (with probability χ).

Notice how the deterministic levered return on equity, r^E, aggregates the spread income on legacy loans $(r^L(x) - r^M_t)l$, the spread on new loans $(r^N_t - r^M_t)n$, the return on reserves r^M_t, and the deposit franchise $\alpha(r^M_t - r^D_t)l$, net of origination costs and fixed costs. The stochastic component $\omega\mathscr{L}$ captures losses from default: foregone interest income on the loan portfolio plus the loss-given-default on principal.

The bank's lending decision n shapes the future state through two channels. First, it determines next-period leverage l': more lending raises the loan stock but also affects equity growth through profits, with the net effect on leverage depending on the realization of ω. Second, it alters the average portfolio rate x' by diluting the legacy rate $r^L(x)$ toward the new-loan rate r^N_t. Both channels feed back into future failure probabilities, since ϕ depends on the state (l, x) through the failure threshold $\bar{\omega}$.

We characterize the economy by tracking the joint distribution of leverage and the average loan rate. This simplification reduces the dimensionality of the problem considerably, while preserving the key interactions: highly leveraged banks are more likely to become insolvent, and their distance from insolvency determines how loan-pricing conventions affect monetary transmission.

Irrelevance of interest-rate risk exposure. We now turn to a central question: under what conditions does the distinction between FR and VR loan pricing matter for monetary policy transmission? A central theme of this paper is that this distinction matters only insofar as it interacts with the banks' failure risk. In turn, heterogeneity in loan-default risk is key to this interaction.

To establish the benchmark result, we derive the supply of loans when the loan default rate is deterministic, that is, $\omega_t = p$ for all t, and capital constraints are slack along the paths being compared. Deterministic default removes unexpected losses on existing portfolios; the slack-capital assumption shuts down endogenous bank failure and isolates the pure pricing benchmark.

It is instructive to derive the supply for new loans by bank j at time t in either type of economy. This supply is obtained by taking the first-order condition with respect to new loans, applying the envelope condition, and iterating forward. The supply of new loans depends on the net-present

value representation of income from loans and expenditures in both economies—see Appendix A.6:

$$N_{j,t} = (f')^{-1}\left(\sum_{m=0}^{\infty} \Lambda^B_{t,m} q^N_{t,m} - \Gamma_{j,t}\right) L_{j,t},. \tag{22}$$

Recall that $\Lambda^B_{t,m} \equiv \frac{\Omega^B_{t,m}}{\Omega^B_{t,0}}(1-p)^{m+1}(1-\delta)^m$ is the bank's normalized effective discounting alongside the deterministic loan probabilities. This discount factor is applied to $q^N_{t,m}$, the cashflow associated with a loan at horizon m which equals r^N_t in the FR economy and $s^N_t + r^M_{t+m}$ in the VR. In turn, $\Gamma_{j,t}$ consolidates all terms that are independent of the loan fixation: the loan origination costs and the marginal cost of funds at each date:

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

with $\Phi_t \equiv \alpha(r^M_t - r^D_t) - \lambda p - r^M_t$.

Notice that the supply schedule (22) is linear in individual loans with the same coefficient across all banks within the same economy. Hence, both economies admit aggregation. Thus, in both economies, the loan market clearing condition, (13), imposes the following general equilibrium condition:

$$a^{-1}\left(A\sum_{m=0}^{\infty}\Lambda^E_{t,m} - \underbrace{\sum_{m=0}^{\infty}\Lambda^E_{t,m}q^N_{t,m}}_{\text{NPV entrepreneur}}\right) = (f')^{-1}\left(\underbrace{\sum_{m=0}^{\infty}\Lambda^B_{t,m}q^N_{t,m}}_{\text{NPV bank}} - \Gamma_t\right)L_t.$$

Thus, market clearing in both economies reduces to one equation in two interrelated valuation objects: the NPV of loan cash flows discounted at the entrepreneur's and banker's effective horizon weights. When those horizon weights are proportional across borrowers and banks, the same pricing relation equalizes the FR and VR present values on both sides of the market, as we formalize in the following proposition:

Proposition 1 (Irrelevance of interest-rate risk exposure)**.** *Consider an FR and VR economy starting from the same aggregate legacy loan portfolio L_0 and facing the same sequences of policy rates $\{r^M_t\}_{t\geq 0}$ and deposit rates $\{r^D_t\}_{t\geq 0}$. Assume further that capital constraints are slack along the compared paths and that, for each date t, there exists a scalar $c_t > 0$ such that*

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

Then there exists a pricing relation between the fixed loan rate r^N_t in the FR economy and the

spread s_t^N in the VR economy given by

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda_{t,m}^B r_{t+m}^M}{\sum_{m=0}^{\infty} \Lambda_{t,m}^B},$$

where the last term is the discounted average of future policy rates under the bank's effective horizon weights. Under this relation, the equilibrium path of aggregate new lending $\{N_t\}_{t\geq 0}$ is identical in the two economies.

Proof. See Appendix A.7.

The logic underlying Proposition 1 mirrors that of the classical Modigliani-Miller Theorem (Modigliani and Miller, 1958, , henceforth, MMT) with some important differences. The MMT establishes that, when equity holders and its financiers share a common valuation of future cash flows, the structuring of liabilities does not affect firm value. If that is the case, investment is independent of financing.

Our result is not a direct application of the MMT because the bank has financial constraints and faces loan origination costs. Moreover, the statement is not about the level of lending, but the about the change in the level of lending as policy changes. However, our result offers an analogous irrelevance in the unconstrained benchmark: when banks and entrepreneurs assign aligned effective horizon weights to future loan cash flows, the allocation of interest rate risk between them—determined by whether loans carry fixed or variable rates—does not affect aggregate bank lending. Thus, as long as marginal funding costs are the same in both economies, lending must respond in the same way. The result is intuitive: in the FR economy, the entrepreneur pays a fixed rate r_t^N each period until maturity. In the VR economy, the entrepreneur pays a variable rate $r_{t+m}^M + s_t^N$ in period $t+m$. When entrepreneurs and banks value these two payment streams with proportional horizon weights, market clearing requires the NPV of the two structures to move together. While the timing of interest rate payments can differ, the relevant present value cannot.

In our setting, aligned horizon weights require that banks and entrepreneurs face the same effective taxation, that exit and liquidation hazards satisfy $\chi = \tilde{\chi}$, and that the two retained-cash-flow compounding factors coincide, $\Upsilon_t^E = \Upsilon_t^B$ for all t.[16] Under $r_t^B = r_t^M$ and with the operating-cost term retained in the bank problem, we have $\Upsilon_t^B = 1 + (1-\tau)(r_t^M - \bar{\pi})$, so the primitive alignment condition becomes $r_t^E = r_t^M - \bar{\pi}$. Under our calibration, these benchmark conditions do not hold exactly: there is an entrepreneur-return wedge relative to $r_t^M - \bar{\pi}$ and an exit/liquidation wedge between χ and $\tilde{\chi}$. In Section 4, we show that reducin idiosyncratic

[16] Appendix A.7 shows that, under these primitive restrictions, the entrepreneur's and bank's valuation kernels are proportional horizon by horizon.

risk nonetheless makes the quantitative differences between FR and VR economies negligible, underscoring that bank failure risk is the key driver of differences in the responses in both economies.

Heterogeneous responses. We now depart from the benchmark conditions in Proposition 1 and consider the general case with idiosyncratic loan-default risk. When default rates are stochastic, banks face endogenous failure probabilities that vary with their leverage, and the irrelevance result breaks down.

To see why, define

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

as the probability that bank j survives from the end of period t through period $t+k$, and let $\tilde{\mathbb{E}}_{j,t,k}[\cdot]$ denote expectations conditional on survival through period $t+k+1$. Iterating on the value function yields the representation:

$$V_{jt} = \sum_{k=0}^{\infty} \beta^{k+1} (1-\chi)^k \chi S_{j,t,k+1} \tilde{\mathbb{E}}_{j,t,k}\left[E_{jt+k+1}\right]. \tag{23}$$

This expression makes clear that the bank's value is a weighted sum of future equity values, where the weight on equity k periods ahead is proportional to the cumulative survival probability $S_{j,t,k+1}$. This object is bank-specific: a more leveraged bank sits closer to its failure threshold, faces a higher failure probability ϕ_{jt} at each horizon, and therefore places lower weight on future payoffs. It is in this sense that highly levered banks discount future cash flows by more than well-capitalized ones.

Taking the first-order condition with respect to $N_{j,t}$ in (23), we isolate two distinct channels through which idiosyncratic risk shapes lending decisions. The first is a *discounting channel*: a higher failure probability reduces the effective weight placed on future loan income, compressing the present value of new lending. The second is a *precautionary channel*: the bank internalizes that lending decisions today affect its equity path, and therefore its survival probabilities, at every future date. Specifically, differentiating the cumulative survival term $S_{j,t,k+1}$ with respect to $N_{j,t}$ generates additional terms in the first-order condition reflecting the option value of remaining solvent. A bank near its failure threshold will curtail lending not only because it discounts the future more heavily, but also because additional lending today increases leverage at future dates and thereby lowers the probability of collecting returns on its existing portfolio.

Applying Leibniz's rule to account for the dependence of future failure thresholds on current

lending yields a bank-specific supply condition:

$$N_{j,t}^{x} = L_{j,t}(f')^{-1}\left(\sum_{m=0}^{\infty} \tilde{\Lambda}_{j,t,m}^{B,x}\, q_{t,m}^{N,x} - R_{j,t} - \tilde{\Gamma}_{j,t}^{x}\right), \qquad x \in \{FR, VR\}, \tag{24}$$

where $q_{t,m}^{N,FR} = r_t^N$ and $q_{t,m}^{N,VR} = s_t^N + r_{t+m}^M$. The bank-specific effective weights $\tilde{\Lambda}_{j,t,m}^{B,x}$ combine the bank's survival-adjusted valuation kernel with the conditional expected repayment path of a marginal loan, while $\tilde{\Gamma}_{j,t}^{x}$ collects current expected credit losses, marginal funding costs, future origination-cost terms, and a marginal-risk penalty reflecting the effect of current lending on future failure probabilities. Appendix A.8 derives (24) and defines these objects formally.

Relative to Proposition 1, two new features appear. First, the effective weights $\tilde{\Lambda}_{j,t,m}^{B,x}$ are now bank-specific, because they inherit the entire path of survival probabilities. Second, the residual term $\tilde{\Gamma}_{j,t}^{x}$ contains a precautionary component that depends on the sensitivity of future survival probabilities to current lending. Both objects depend on the bank's leverage and on the loan-pricing regime through its effect on the path of retained earnings, making the supply schedule a nonlinear function of individual bank characteristics rather than a linear function of portfolio size.

In Proposition 1, the supply schedule (22) was linear in $L_{j,t}$ with a coefficient common across all j, so summing across banks was immediate and the economy could be fully characterized by aggregate quantities alone. Here, aggregation fails for two compounding reasons. First, the bank-specific effective weights $\tilde{\Lambda}_{j,t,m}^{B,x}$ cannot be factored out of the cross-sectional sum, so aggregate new lending depends not only on total legacy loans L_t but on the full distribution of leverage across banks. Second, the precautionary wedge depends on each bank's distance to the failure threshold, a bank-level state variable that cannot be summarized by any aggregate moment. As a result, the cross-sectional distribution of leverage is itself a state variable of the aggregate economy, and we must track it explicitly to characterize equilibrium. The mean leverage of the banking sector is insufficient; what matters is how leverage is distributed.

This failure of aggregation is not a technical inconvenience but the economic heart of the framework. Consider two banks with identical leverage and facing identical idiosyncratic default shocks, one in each regime. A contractionary monetary policy shock affects their equity differently: in the FR economy, legacy loans continue paying a fixed rate while funding costs rise, compressing the net interest margin and eroding equity; in the VR economy, legacy loans reprice upward, protecting margins and preserving equity. The same bank, facing the same default realization, therefore ends up at a different point in the leverage distribution depending on the regime it operates in.

The distribution of leverage translates this bank-level divergence into an aggregate difference in lending. Banks whose equity is most eroded by the shock, those with the greatest exposure

to legacy fixed-rate portfolios, face the sharpest rise in failure probabilities, amplifying both the discounting and precautionary channels and forcing them to curtail lending. At the same time, banks with sufficient risk-bearing capacity, those far from the failure threshold, exploit the higher lending margins that the shock generates and expand their loan supply. The aggregate lending response is therefore shaped by the interaction between the cross-sectional distribution of leverage and the regime-specific effect of monetary policy on equity accumulation, a margin of adjustment that is absent when banks are homogeneous. We study how these forces play out in the quantitative analysis.

2.8 Solution method

To solve the model, we use a value function iteration algorithm for the bank problem defined in Appendix A.6 and keep track of the bank distribution over log-equity $\log(E_{jt})$, leverage $l_{jt} = \frac{L_{jt}}{E_{jt}}$, and the loan rate/spread x_{jt} using the method of Young (2010). The steady state can then be found in an iterative procedure where, for a given guess of the loan rate r^N, we first solve for the policy functions using value function iteration and then compute the bank distribution using those policy functions. During this procedure, the guess for the loan rate is adjusted until an equilibrium in the loan market is found. The transitional dynamics after an MIT shock are computed similarly to Boppart et al. (2018). For a guess of a transition path for the loan rate $\{r_t^N\}_{t=0}^T$, we make a backward pass along the transition to compute the policy functions, followed by a forward pass to compute the distribution along the transition. Similar to our steady state algorithm, we adjust the transition path for the loan rate $\{r_t^N\}_{t=0}^T$ until the loan market clears in each period. Appendix C provides more details on the solution algorithm.

3. Calibration and model fit

We calibrate the model to the euro area economy at quarterly frequency. Subsection 3.1 presents the functional forms and parameter values adopted in the calibration, while subsections 3.2 and 3.3 evaluate the model's fit along the cross-sectional and time-series dimensions, respectively.

3.1 Functional forms and parameter values

The calibration follows a two-step procedure. In the first step, we fix several parameters based on values from the existing studies or on their observed regulatory counterparts. In the second step, the remaining parameters are jointly calibrated to match a set of empirical moments using euro area data.

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 0.05×4, 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.[17]

Policy parameters are set based on Basel III regulatory levels. The capital requirement γ encompasses the minimum Common Equity Tier 1 (CET1) requirement of 4.5% plus the capital conservation buffer of 2.5%, both of which must be maintained with CET1 capital. The parameter α in equation (8), which determines the ratio of deposits to legacy loans on a bank's balance sheet, is set to match the observed deposits-to-loans ratio of 0.89 in the consolidated balance sheet of euro area monetary financial institutions (MFIs). Similarly, the liquidity requirement θ is set to match the reserves-to-total-debt ratio of 0.118.[18] The steady-state policy rate r^M—the rate of remuneration on central bank reserves—is set to 1%, matching the average deposit facility rate in the euro area over 1999–2019. The steady-state deposit rate r^D is set to 0.5%, based on the average overnight deposit rate over 2003–2023.

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) single risk-factor model:[19]

$$F_j(\omega) = \Phi\left(\frac{\sqrt{1-\rho}\Phi^{-1}(\omega) - \Phi^{-1}(p)}{\sqrt{\rho}}\right), \tag{25}$$

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, which governs the volatility of a bank's portfolio default rate. To discipline the calibration of ρ, we target the average failure probability of 0.66% for European banks reported by Mendicino et al. (2020).

We assume that banks face a convex loan origination cost:

$$f(N_{jt}/L_{jt}) = \eta\left(\frac{N_{jt}}{L_{jt}}\right)^2, \tag{26}$$

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

[18] See Appendix B, Figure B.2, for a composition of MFIs and a description of the time series used.

[19] See Appendix A.1 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).

Table 1: Parameter values

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	Avg. EA deposit facility rate, 1999-2019.
r^D	Steady-state deposit rate (%)	0.5	Avg. EA overnight deposit rate, 2003-2023.

Jointly calibrated parameters

	Parameter	Value	Target	Data	Model
β	Subjective discount factor	0.933	Banks' return on equity (%)	6.4	6.4
ρ	Loan default correlation	0.51	Bank failure probability (%)	0.66	0.66
η	Loan origination cost	0.22	Voluntary capital buffer (%)	5.1	4.8
ζ_1	Ent. entry cost (level)	5.78	Avg. lending rates (%)	3.0	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 (%)	0.34	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.

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

$$a(N_t) = \zeta_1 N_t^{\zeta_2}, \tag{27}$$

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 jointly calibrated to match (i) the historical average loan rate of 3%, (ii) the peak response of log new lending to a 100 basis-point monetary policy shock, equal to -0.38, and (iii) the average voluntary capital buffer of 5.1 percentage points, consistent

with the mean CET1 buffer in 2021Q4 for banks supervised by the ECB.[20]

Finally, the discount factor β, the fixed operating cost parameter $\bar{\pi}$, and the exit rate χ are disciplined by jointly targeting banks' return on equity (ROE), the average ratio of non-interest expenses to assets, and the tail coefficient (slope) of the log-log asset-size distribution. As discussed in Section 3.2, this last target allows the model to replicate the power-law distribution of bank sizes observed in the data.

Ex-ante heterogeneity: FR and VR economies. As anticipated above, we study two versions of the model: one with FR loans and one with VR loans. This modeling choice is motivated by cross-country institutional variation within the euro area. Figure 1 presents the share of VR loan contracts in each country. VR loans are defined as those with original and remaining maturity over 1 year and interest rate reset within the next 12 months.[21] We observe that in a first group of countries—Germany, France, Belgium, and the Netherlands—approximately 80% of outstanding loans are fixed-rate contracts. In contrast, in a second group—Finland, Portugal, Spain, Ireland, Italy, and Austria—more than 60% of outstanding loans are variable-rate contracts.[22] We label the first and second groups as FR and VR countries, respectively, and use these definitions in Section 4, where we study the aggregate responses of bank balance-sheet variables to monetary shocks across country groups.

3.2 Cross-sectional validation

We validate the model by comparing untargeted cross-sectional moments to their empirical counterparts.

Bank balance sheet composition. begin by comparing the consolidated balance sheet of monetary financial institutions (MFIs) in the euro area to its model counterpart.[23] Table 2 shows that the model's steady-state consolidated balance sheet closely matches the composition of assets and liabilities observed in the data. Asset-side ratios are directly targeted in the calibration,

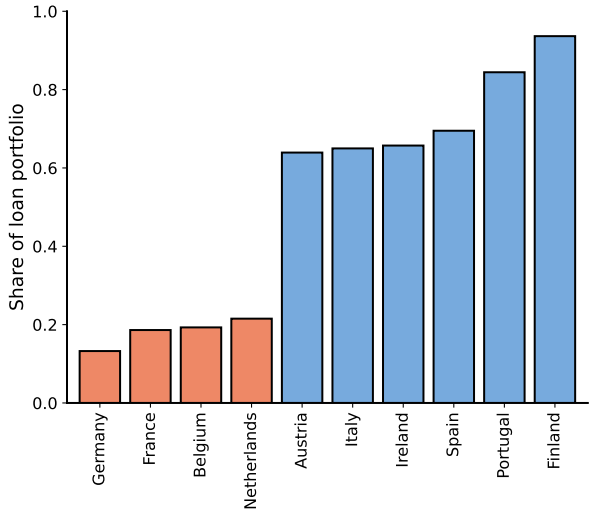
[20] We calibrate the model based on CET1 data for ECB-supervised banks, which provide the most accurate available estimates of capital buffers. See Appendix B.3 for a comparison of different CET1 ratio and buffer estimates.

[21] At the country-consolidated level, loan time series are categorized primarily by maturity rather than by interest-rate fixation. As an alternative, we approximate the share of variable-rate loans using loans with maturities up to one year, which yields similar results. The categorization in Figure 1 aligns with results reported by Core et al. (2025) using granular data on non-financial corporate loans in the euro area.

[22] Appendix B.4 provides additional analysis of this categorization. In particular, we show that these patterns have remained stable and extend across loan categories, affecting both loans to households and to non-financial corporates.

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

Figure 1: Share of variable-rate loans.



Note: Average share of total outstanding loans issued at variable rates, 2014–2020. 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.

but on the liability-side only deposits are targeted.[24]

Table 2: Consolidated bank balance sheet: Model vs. data (2013–2023)

Assets			**Liabilities**		
	Model	Data		Model	Data
Loans	89%	88%	Deposits	81%	78%
ST 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. *ST 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).

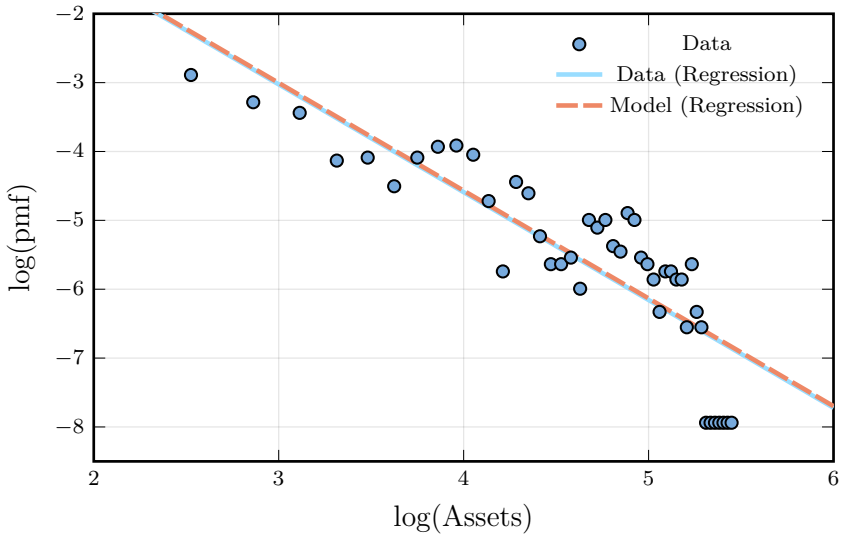
Asset-size distribution. The model generates a steady-state distribution of bank assets that closely mirrors the empirical distribution observed for euro area banks.[25] Figure 2 compares

[24]Note that 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.

[25]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

the right tails of the model and empirical asset distributions in log-log space, illustrating the substantial heterogeneity in bank sizes produced by the model. 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).

Figure 2: Bank asset size distribution: Tail behavior.



Note: Blue dots represent equally spaced bins in the right tail of the empirical asset distribution. *Data (Regression)*: We fit a power-law distribution of the form $f(x) = \bar{A}x^{\psi}$, where ψ captures the tail behavior; it equals the slope of a log-log regression of the density 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. To ensure comparability, we scale asset values so that means match in the model and the data.

Capital ratio distribution. Table 3 reports the distribution of capital ratios in the data and in the model's steady state.[26] The model distribution captures its empirical counterpart well. The capital ratio at the first percentile is 9.7% in the model and 9.4% in the data, both slightly above the regulatory minimum of 7%. In both the model and the data, a substantial share of the mass lies close to the regulatory constraint, reflecting banks' incentive to operate with a buffer to avoid supervisory intervention. At the 40th percentile, the capital ratio is 12.7% in the model versus 13.5% in the data. For banks in the upper half of the distribution, the average capital ratio is 13.1% in the model and 18.7% in the data, indicating that the model underestimates the mass of banks with high capital ratios (i.e., low leverage).

To understand this discrepancy, we compare the model distribution with that of large banks, defined as those with assets exceeding €100 billion (second column of Table 3). For this subsam-

information on CET1 capital levels, risk-weighted assets, and total assets. See Appendix B.3 for details.

[26] Since the gradual implementation of Basel III beginning in 2013, capital ratios for euro area banks have increased steadily, introducing spurious dispersion into the pooled distribution. To adjust for this time trend, we demean capital ratios period by period and re-center the distribution using the mean capital ration in 2019.

Table 3: 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.

ple, the model's fit improves across the entire distribution. The average capital ratio for banks in the upper half, for instance, falls to 14.7% in the data (compared with 13.1% in the model). We attribute the remaining gap partly to additional regulatory constraints that our model does not capture. In particular, banks must satisfy a Minimum Requirement for Own Funds and Eligible Liabilities (MREL).[27] While larger banks typically issue contingent convertible liabilities to satisfy MREL, smaller banks often do so by holding additional CET1 capital, which may explain CET1 ratios well above 15% observed in the data

In any case, the underestimation of the right tail is inconsequential for our results. Banks far from the regulatory constraint behave nearly homogeneously, so aggregate dynamics are driven by the left tail of the capital distribution rather than the right.

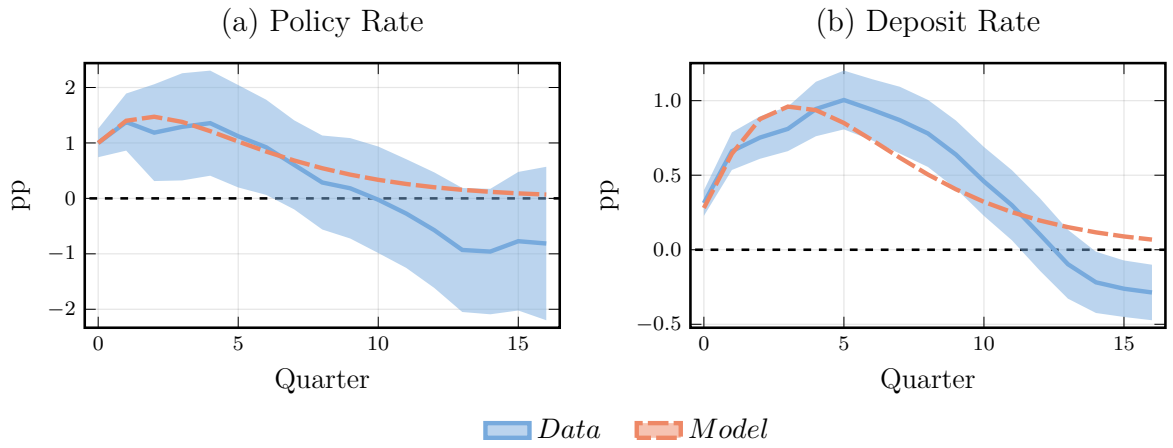
3.3 Time-series moment fit

Responses to a monetary tightening. Our primary interest is in how heterogeneous banks respond to monetary policy shocks. To evaluate the model's ability to capture the the transmission of monetary policy shocks to bank lending, we compare model-generated impulse response functions (IRFs) to their empirical counterparts. We estimate all empirical IRFs using a local projections approach (Jordà, 2005; Jordà et al., 2015).[28]

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

[28] We estimate empirical impulse responses using a balanced panel comprising the ten largest euro area countries, which allows us to construct a dataset without gaps. We classify a country as VR if its share of variable-rate lending exceeds 50%, and as FR otherwise. The VR group includes Spain, Portugal, Italy, Finland, Ireland, and Austria; the FR group consists of Germany, France, Belgium, and the Netherlands. Appendix B.5 provides details on the local projection estimation, and Appendix B.6 shows that extending the panel to all twenty euro area countries yields

Figure 3: Targeted 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 responses of the policy rate and the deposit rate, respectively. See Appendix B.5 for details.

To compute the model's response of new loans to an unexpected increase in the policy rate r^M, we solve for the transitional dynamics following an unanticipated (MIT) shock, using an algorithm similar to Boppart et al. (2018).[29] Loan rates and quantities in the model are determined in equilibrium through market clearing. As explained in Section 2.4, the deposit side is calibrated to induce deposit-rate paths similar to those observed empirically. Thus, for new loans, quantities and prices are jointly determined by supply and demand; for deposits, rates are effectively exogenous, with quantities determined by banks' funding demand. The model takes as exogenous inputs the projected paths of both the policy rate and the deposit rate following a 100 basis-point increase in r^M, estimated from the data.

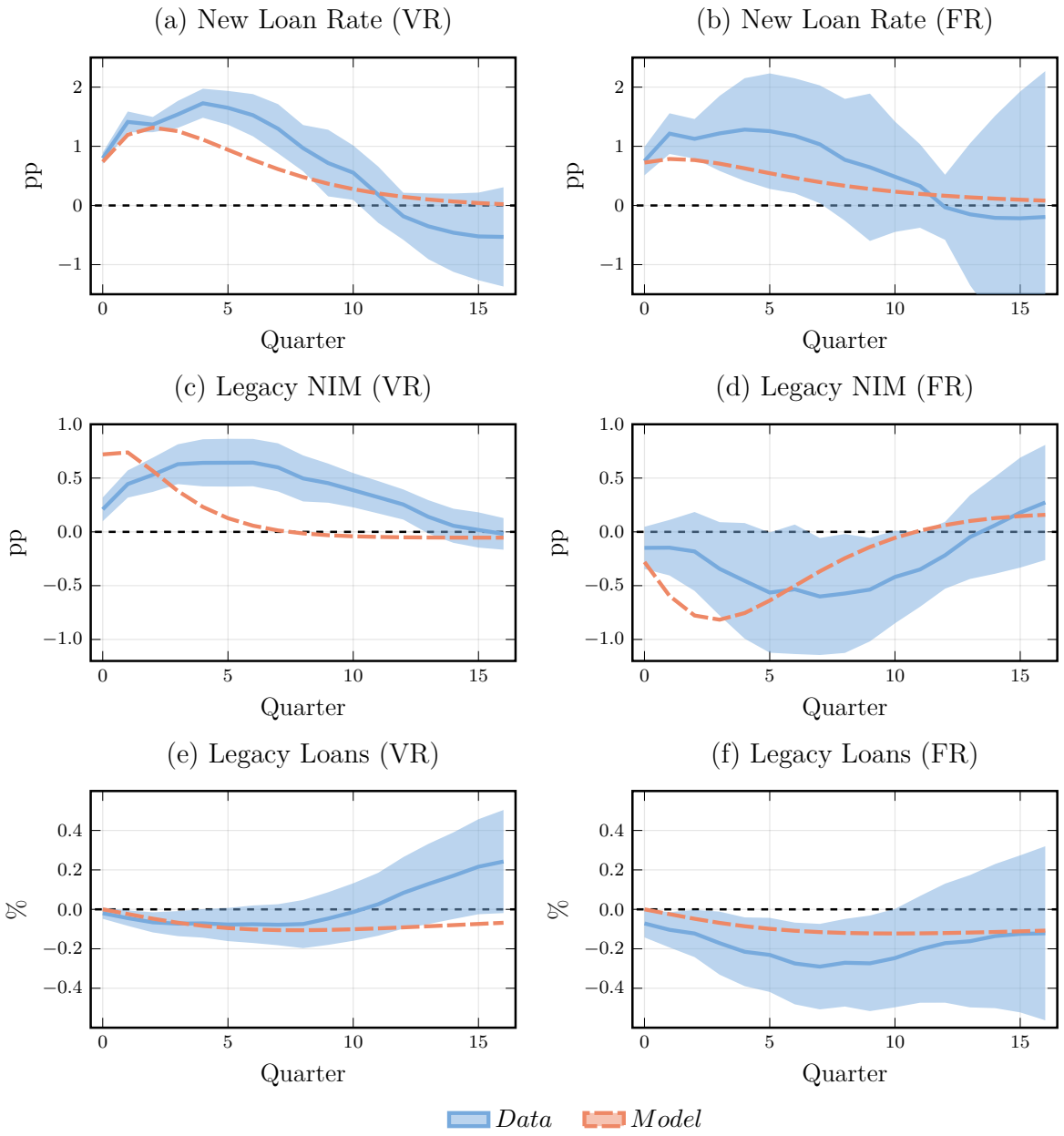
Figure 3 presents the IRFs of the exogenous rate processes. Panel (a) displays the estimated trajectory of the policy rate, and Panel (b) shows the corresponding path for the deposit rate. Solid blue lines and shaded bands correspond to point estimates and 95% confidence intervals from the empirical IRFs; dashed red lines show the exogenous rate paths fed into the model. The figure illustrates how the shock paths are calibrated to approximately match the empirical dynamics.

Figure 4 further analyzes the IRFs of variables that are not calibration targets, allowing us to assess the model's fit for additional bank balance-sheet variables. The left panels correspond to VR countries, while the right panels correspond to FR countries. The model fits the data well

similar results.

[29] This is equivalent to solving a model with aggregate risk by a first-order perturbation method. See Appendix C for details on the solution algorithm.

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.5 for details.

for both the rate charged on new loans and the volume of legacy loans. It captures the fact that pass-through to new loan rates is higher in VR economies than in FR ones (panels a and b), as well as the larger and more persistent decline in legacy loan volumes in FR economies (panels e and f). Regarding the net interest margin (NIM; panels c and d), the response is positive for VR countries and negative for FR ones, both in the data and in the model—a pattern we explain in the next section. The model-generated NIM responses are of similar magnitude to those in the data but miss the persistence observed empirically.[30]

In summary, the model simultaneously captures several demanding qualitative and quantitative features of the data. First, it reproduces the opposite-signed responses of the NIM of legacy loans across banking systems—expanding in VR economies while compressing in FR economies—while inducing positive responses of the new loan rate in both regimes. Second, 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.

4. Inspecting the mechanism

In this section, we inspect the qualitative and quantitative differences in transmission of interest-rate shocks to bank lending in FR vs. VR economies.

The aggregate facts. We begin by discussing outcomes for a broader set of variables than those considered in the validation results of Figure 4. Figure 5 presents the aggregate responses to the one-percentage-point monetary tightening discussed above. Both economies face the same path of funding costs, which, by construction, replicate the empirical counterparts in Figure 3. Wholesale funding rates correspond to the path of policy rates, whereas pass-through to deposit rates remains more gradual. While the paths of funding costs are the same, the response of asset-side variables differs sharply across regimes.

In VR economies, loan rates rise quickly in response to the policy shock for both new and legacy loans (Panels a and b). Because loan rates on legacy loans rise with the policy rate while deposit rates adjust more sluggishly, the NIM on the legacy portfolio expands (as already seen in Figure 4). This increase in legacy NIM generates higher profits, which, through retained earnings, boost equity accumulation and capital ratios (Panels g and h).

In FR economies, new loan rates rise quickly, but loan rates on the legacy portfolio remain

[30] 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.

fixed at the time of the shock. The gradual rise in the average legacy loan rate shown in Panel (b) reflects only the inflow of new loan vintages, not the repricing of existing loans. This gradual increase is insufficient to offset rising deposit rates, so the NIM on the legacy portfolio compresses. As a result, retained earnings decline, eroding equity and capital ratios.

The divergence in legacy NIM is at the heart of the transmission differences. As noted above, the model matches the divergent NIM patterns shown in Figure 4, but also rationalizes a seeming paradox: in VR economies, new loan rates rise by more than in FR economies, yet the stock of lending declines by less—approximately one-third less (Panels d and e).

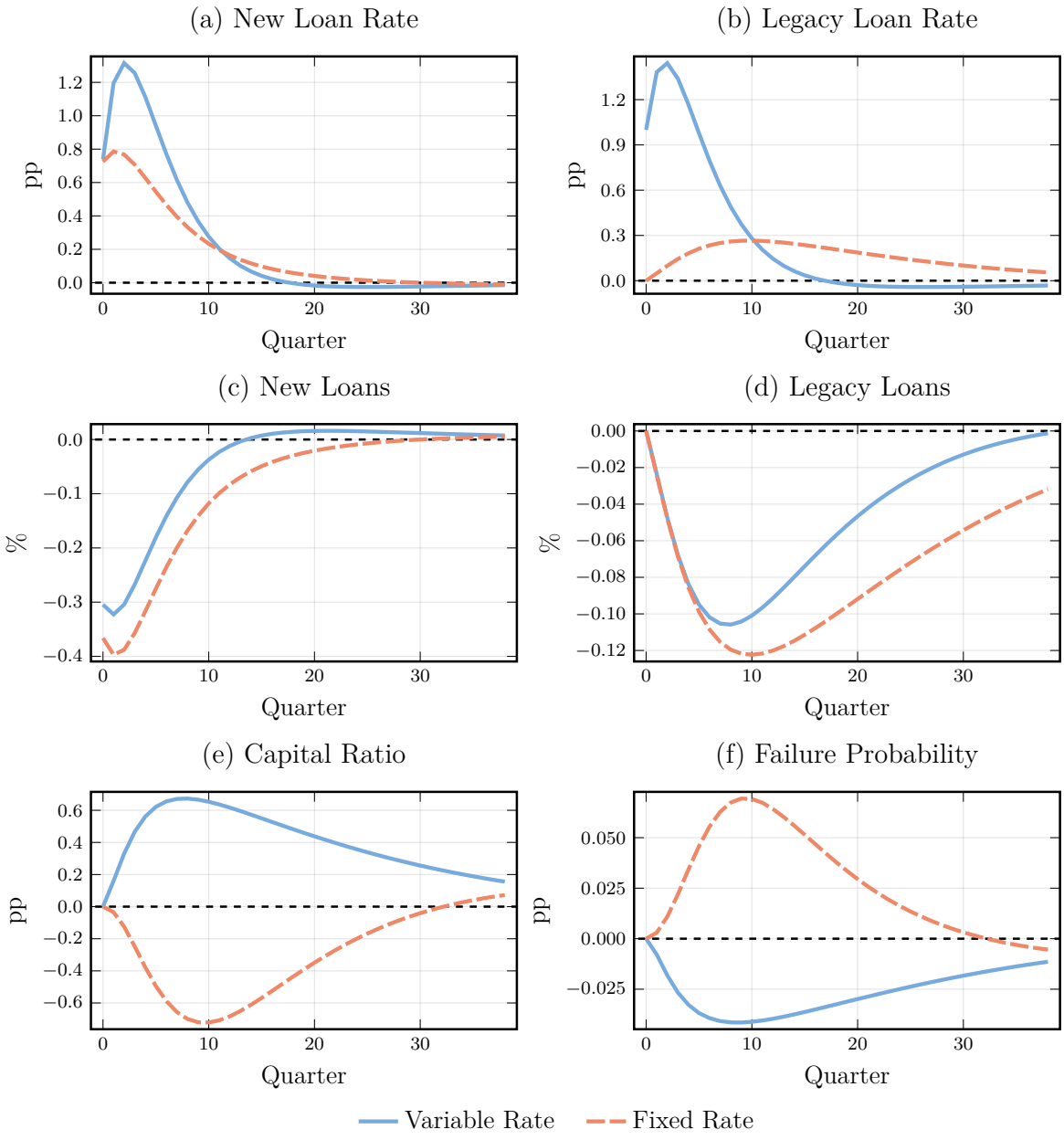
Rationalizing why new loan rates rise by more while lending declines by less is not immediate. Both loan demand and loan supply are forward-looking, reflecting discounted future cash flows. Hence, quantity responses cannot be read directly off new loan rates, which are, in any case, general equilibrium objects. Instead, we must understand how banks discount loan cash flows while anticipating mean reversion in policy rates and, crucially, how the path of the NIM on legacy loans impacts their capital buffers and failure rates.

What makes matters more complex is that, while all banks within a regime face the same NIM dynamics, they differ in their exposure—through leverage—and in their capacity to bear losses—through their proximity to regulatory constraints. These differences in exposure and bearing capacity, which we flesh out below, ultimately shape the aggregate lending response. We now look under the hood.

Comparison with the homogeneous bank economy. A useful starting point for fleshing out how heterogeneity within a regime shapes differences in responses between regimes is to compare baseline responses to a counterfactual scenario in which idiosyncratic loan-default risk is significantly reduced, from $\rho = 0.51$ in the baseline to $\rho = 0.1$, rendering all banks, de facto, homogeneous. Figure 6 presents this comparison: solid lines show the baseline responses to a one-percentage-point monetary tightening (as done for Figure 4), while dotted lines show the homogeneous-bank counterparts.

Two takeaways from this figure clarify the source of FR vs. VR differences. First, as idiosyncratic risk is shut down, the lending responses in FR and VR economies become nearly identical (Panels a and b). This feature is consistent with the logic of Proposition 1, which is an unconstrained benchmark: when capital constraints remain slack and banks and borrowers evaluate loan cash flows with aligned effective horizon weights, loan-rate fixation is irrelevant for the flow of new lending even though the equilibrium paths of rates can differ across regimes. In the low-risk exercise, no bank approaches the regulatory threshold, and failure probabilities are essentially zero throughout (Panel d), so the first ingredient of the benchmark is restored directly. The second ingredient is not imposed exactly, because the model retains small wedges

Figure 5: Aggregate impulse response functions



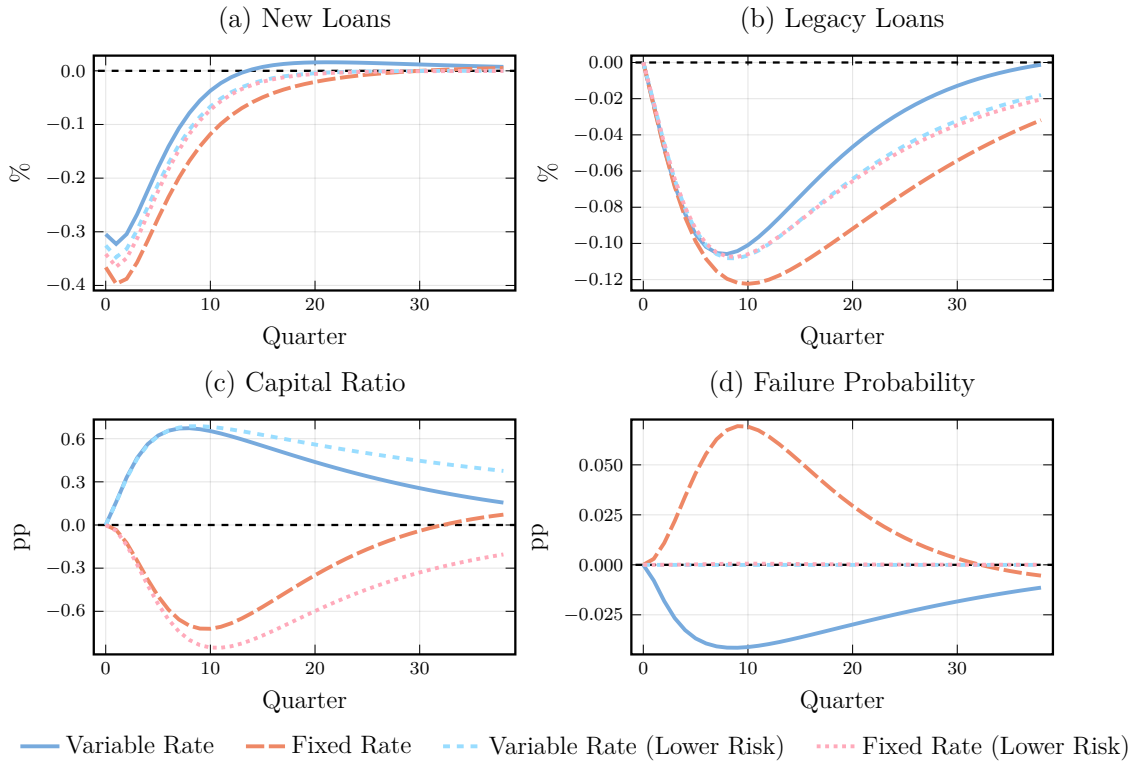
Note: Impulse responses to a 1 percentage point increase in the policy rate. Solid blue lines correspond to the variable-rate (VR) economy; dashed red lines correspond to the fixed-rate (FR) economy.

between the bank and entrepreneur valuation kernels. Nonetheless, the FR/VR differences become negligible, indicating that those residual wedges are quantitatively minor relative to the role played by endogenous proximity to capital constraints.

The second takeaway follows directly: If eliminating idiosyncratic risk eliminates FR/VR differences, then idiosyncratic risk must be what generates differences in responses across regimes.

Idiosyncratic risk does so by inducing a distribution of bank leverage, pushing some institutions toward regulatory constraints and raising their failure probability, which endogenously changes how they discount future cash flows. Highly levered banks, therefore, discount future cash flows by more than unconstrained banks—and differently across regimes. In the FR economy, the NIM on legacy loans compresses, eroding profits and depleting capital (Panel c). Banks closer to the constraint must deleverage, amplifying the lending contraction. In the VR economy, the NIM expands, capital ratios rise, and constraints remain slack. The divergent paths of capital ratios—rather than differences in interest rates, NIM, and the average capital ratio—explain why FR and VR economies respond differently to monetary policy.

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. The low-idiosyncratic-risk counterfactual establishes that binding capital constraints drive the divergence between FR and VR economies. Yet aggregate responses mask the substantial heterogeneity in behavior across banks with different capital ratios within each regime, a key dimension of the heterogeneous bank lending channel. We now ask: how do banks within the same economy respond differently depending on their capital ratios? The

answer explains the aggregate response and further clarifies how differences in transmission across economies arise.

Figure 7 presents impulse responses for banks at different percentiles of the steady-state capital-ratio distribution, with lighter shades representing more highly leveraged institutions. A key feature to bear in mind is that, within each economy, all banks face identical funding conditions and the same loan demand curve. Yet their lending responses differ dramatically (Panels a and b). With identical rate paths, we should expect identical quantity responses unless loan valuations reflect differences in discounted future cash flows. This heterogeneity in effective discounting drives the cross-sectional dispersion in lending.

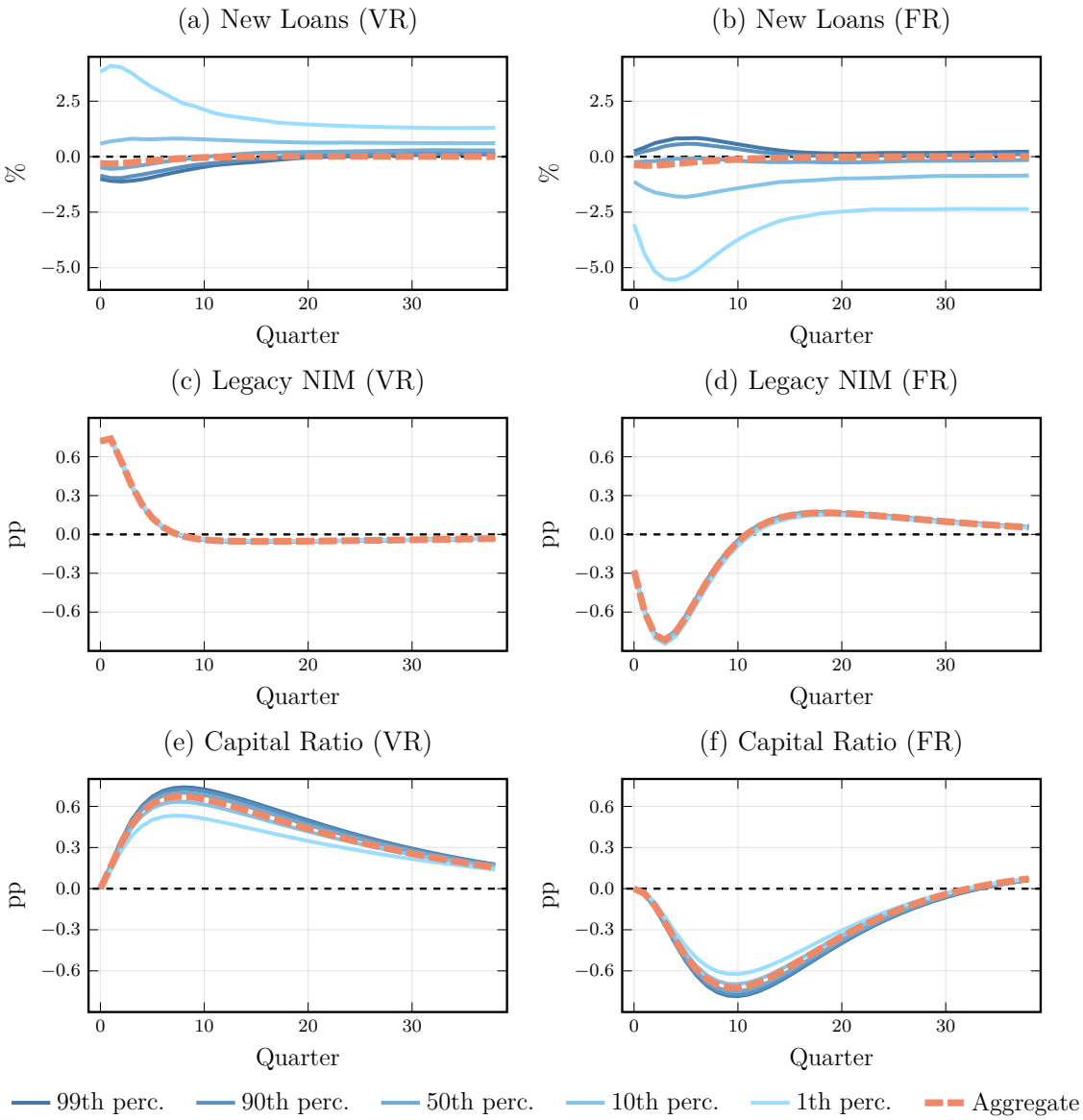
Naturally, banks near regulatory constraints discount those flows more heavily when their capital is at risk or when the risk of regulatory non-compliance and subsequent failure is substantial. When a policy shock hits, the effect on banks' legacy NIM varies with their leverage. The divergence in lending responses across banks within a regime results from a tension between two forces. The first is the rate on new loans, which rises on impact and moves identically across all banks within a regime. The second is the accumulation of profits from legacy portfolios, which is heterogeneous and affects banks' discounting differently within the same regime.

In FR economies, equity erodes, and erodes faster for highly leveraged banks. For banks already near regulatory limits, this equity erosion sharply increases their effective discounting—leaving them with heightened insolvency risk and forcing them to curtail lending even as the rate on new loans rises. Well-capitalized banks, by contrast, remain far from the constraint; their discounting is largely unaffected, and they expand lending to exploit a higher NIM, thus absorbing the slack left by constrained institutions.

In VR economies, the reallocation operates in reverse. The NIM on both new and legacy loans expands, boosting profit accumulation and strengthening equity. Banks near the constraint anticipate that rising profits will rebuild their capital buffers, lowering their effective discount rate and encouraging them to lend more aggressively. Well-capitalized banks, whose effective discounting was already unaffected by under-capitalization risks, do not change it with the profit windfall. While the loan rate on new loans rises on impact, it is expected to fall, reducing the willingness to lend. In equilibrium, high-leverage banks expand and gain market share in the loan market.

The key takeaway is that high-leverage banks are the most sensitive margin of transmission, though they move in opposite directions across regimes: expanding lending most strongly in VR economies and contracting most sharply in FR economies (Panels a and b). This generates substantial credit reallocation—constrained banks gain market share in VR economies while ceding it in FR economies. In VR economies, the aggressive expansion by constrained banks partially offsets the muted response of well-capitalized banks, producing a smaller aggregate

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 constraint in the steady state); darker shades correspond to higher percentiles.

contraction. In FR economies, the reallocation works in reverse, amplifying the aggregate decline despite smaller rate increases. Because loan demand and supply are forward-looking, what matters is how the path of equity across the capital distribution affects discounting. This is why loan rates can rise by more in VR economies while lending contracts 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, 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.[31] 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

[31] 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.

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).[32] A richer model would be needed to fully assess such non-linearities; we keep this exercise purposely simple to preserve focus on the core mechanism.

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.

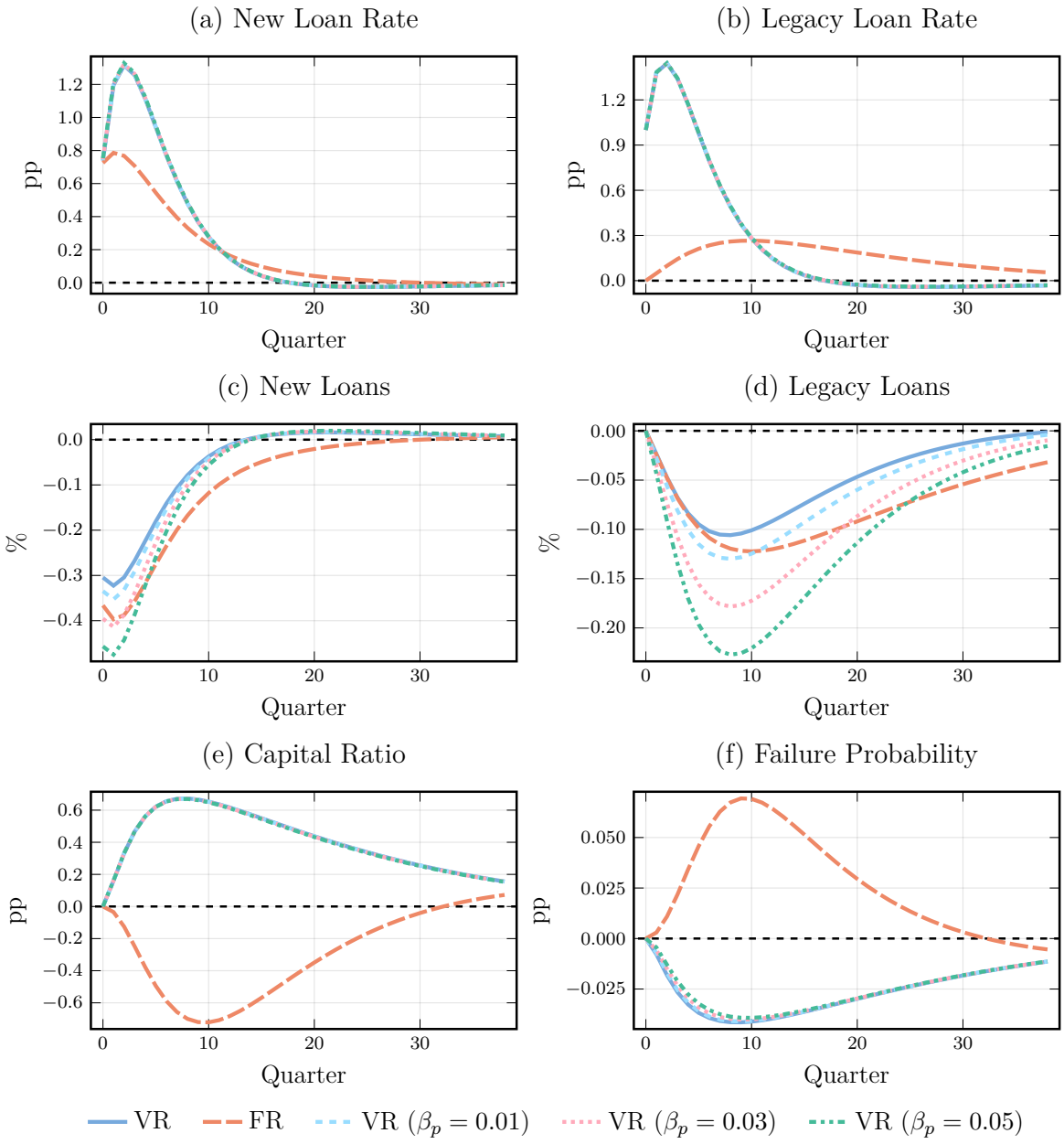
These findings align closely with recent cross-sectional evidence in Gomez et al. (2021), who study how banks' interest-rate risk exposures shape the transmission of monetary policy. They document that banks with larger interest-rate risk exposure experience NIM compression when rates rise, and that 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 (Section 4), the effect operates only when it interacts with binding capital constraints (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).[33]

The credit reallocation we document—toward constrained banks in VR economies, away

[32] Moreover, we apply the same default-probability rule to both new and legacy loans, though in practice legacy borrowers facing higher variable rates are more likely to default than new borrowers underwritten at current rates.

[33] 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.

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.

from them in FR economies—raises questions beyond monetary transmission. In VR economies, credit shifts toward less well-capitalized institutions during tightening cycles, potentially increasing aggregate credit risk even as bank failure rates fall. We explore some implications for financial stability trade-offs next.

5. 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 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.

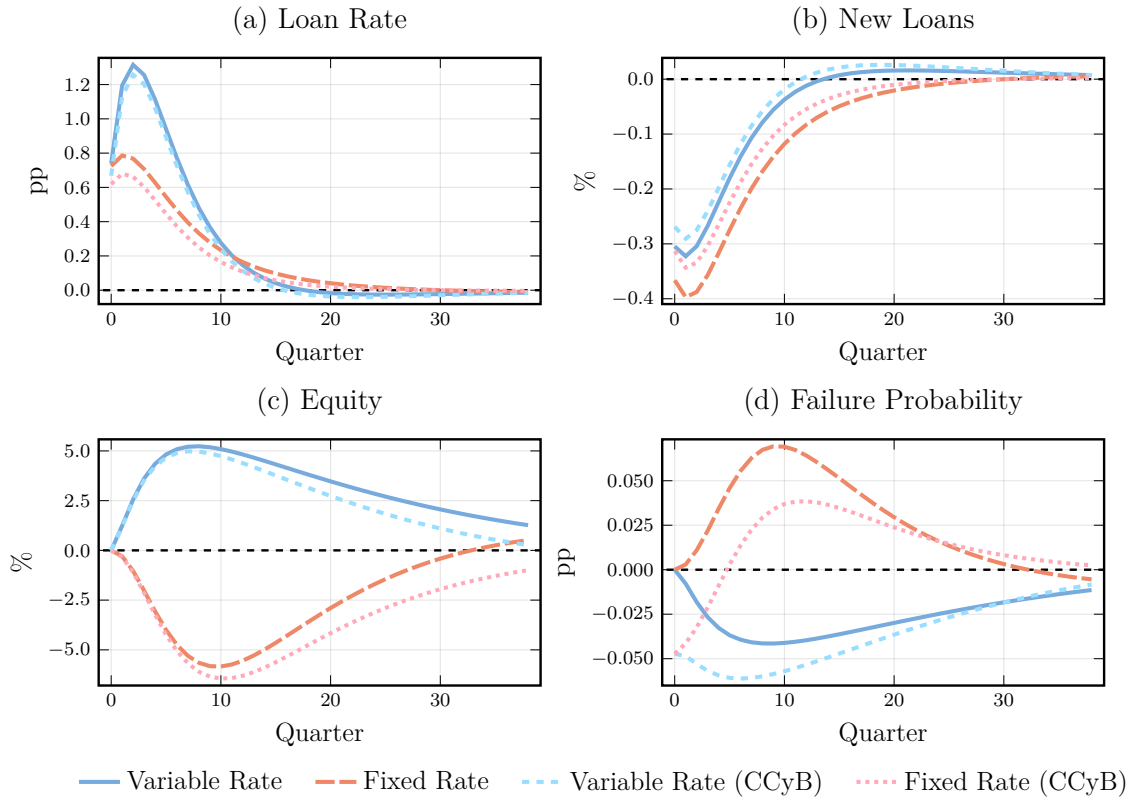
Countercyclical capital regulation. A prominent macroprudential tool is the countercyclical capital buffer (CCyB). The CCyB requires banks to build additional capital during credit expansions. The objective is to build resilience during booms and support credit supply during downturns, thereby dampening 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 VR (solid blue line) and FR (dashed red line) economies when the CCyB is released by 1 percentage point.

The key 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 the distance to the regulatory constraint 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 affected by a binding constraint differ across systems: FR banks lose equity and drift toward the constraint, while VR banks gain equity and move away from it. By shifting the constraint 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 less binding capital constraints are, 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 regulatory 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 constraint.

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.

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 binding constraints precisely when interest-rate risk exposure is generating the largest differences in equity dynamics, magnifying the gap that Proposition 1 identifies. This interaction is especially relevant for monetary unions, where a single policy rate coexists 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 the regulatory constraint 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.[34] The 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

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

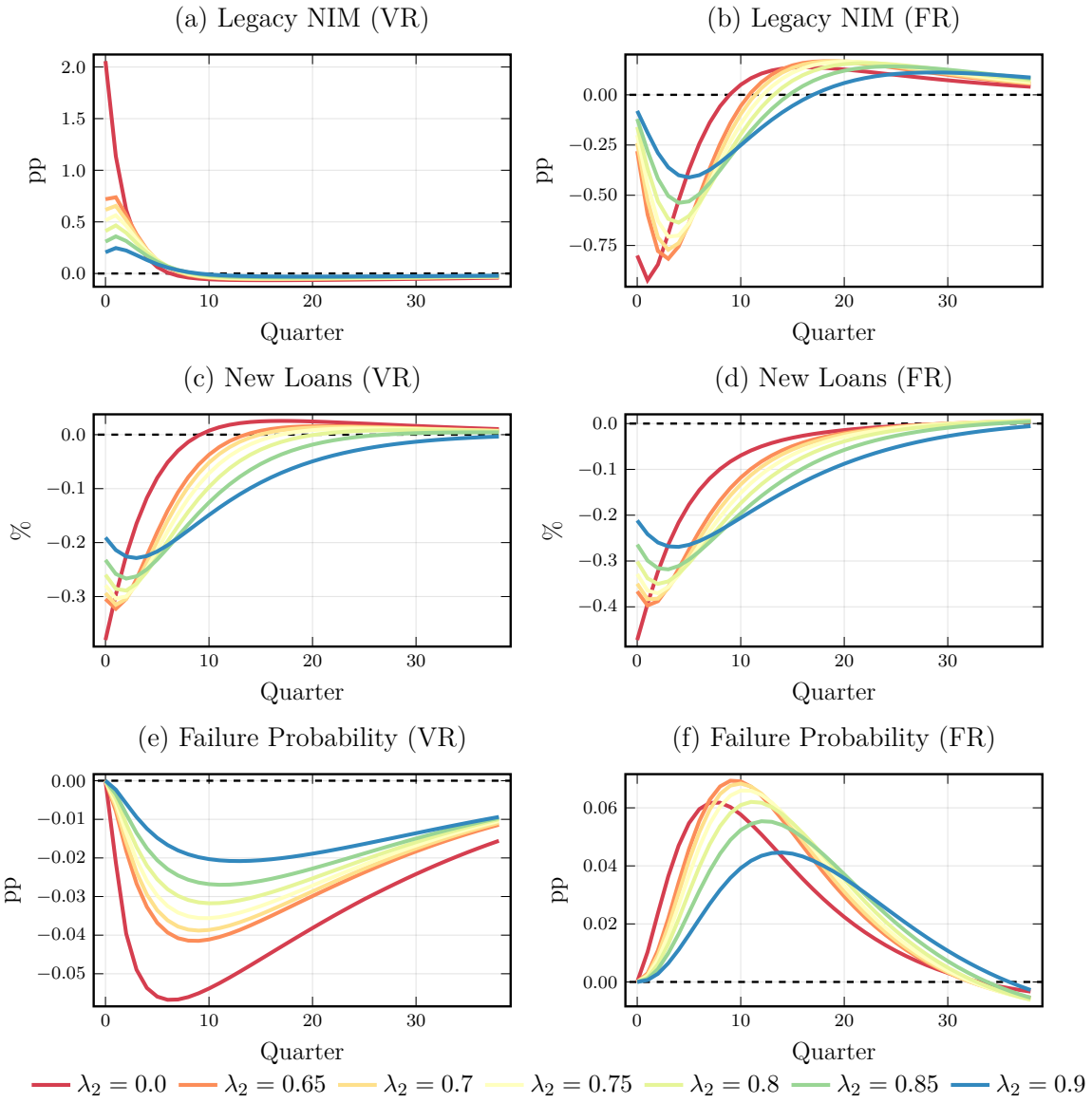
Fixing μ_1 at its baseline value, we generate more gradual policy paths with the same cumulative stance by increasing μ_2 while reducing σ proportionally, so that the area under the IRF remains unchanged.

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

[34] To see this, note that the 3-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 $\hat{r}_t \equiv i_t - \mathbb{E}_t(\pi_{t+1}) - r_t^n$, 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.

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 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 binding capital constraints 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 binding constraints 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.[35]

6. Conclusion

This paper achieves three objectives. First, it delivers a heterogeneous-bank model to analyze how the credit 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 impact the distribution of banks near their capital constraint 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 credit channel in isolation. The model is portable enough to admit those extensions with ease.

[35] Drechsler et al. (ming) formalize how rising interest rates simultaneously increase the value of the deposit franchise and the unrealized losses on long-duration assets. Notably, their framework also prescribes gradualism. Begenau et al. (2024) also studies the financial stability implications of interest-rate risk when banks rely on uninsured deposit funding.

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Appendices

A. Model derivations

A.1 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 failure of the loan i from bank j is driven by the realization of a latent random variable:

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

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.1) 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

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

A.2 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.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_t^M and r_t^D 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_t^H, and from holding a bundle of assets. The household solves the

following recursive problem:

$$V_t^H(A_{t-1}^H, D_{t-1}^H) = C_t^H + U\left(C_t + \ell(A_{t-1}^H, D_{t-1}^H)\right) + \beta V_{t+1}^H(A_t^H, D_t^H),$$

subject to the budget constraint:

$$C_t + C_t^H + \underbrace{B_t + M_t^H}_{=A_t^H} + D_t^H + \Xi_t = (1 + r_{t-1}^B)B_{t-1} + (1 + r_{t-1}^M)M_{t-1}^H + (1 + r_{t-1}^D)D_{t-1}^H + \Pi_t^E - T_t.$$

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: $A^H = B + M^H$ (wholesale debt + gov't bonds)	

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:

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

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:

$$U'\left(C_t + \ell(A_{t-1}^H, D_{t-1}^H)\right) = 1. \tag{A.2}$$

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

$$-1 + \beta V_{A,t+1}^H(A_t^H, D_t^H) = 0, \tag{A.3}$$

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.2) 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.2):

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

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:

$$\ell_D(A_t^H, D_t^H) = \frac{1}{\beta} - (1 + r_t^D) := s_t^D, \tag{A.5}$$

where s_t^D denotes the corresponding spread for deposits.

Given the functional forms in (A.2), we compute the partial derivatives:

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

$$\ell_D(A_t^H, D_t^H) = \frac{(1-\nu)\kappa\left[\left(A_t^H\right)^\nu \left(D_t^H\right)^{1-\nu}\right]^{1-\vartheta}}{D_t^H}. \tag{A.7}$$

Dividing (A.6) by (A.7) and using the first-order conditions (A.4) and (A.5):

$$\frac{\nu}{1-\nu}\frac{D_t^H}{A_t^H} = \frac{s_t^M}{s_t^D}. \tag{A.8}$$

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.4):

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

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.8), we have:

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

Substituting into (A.9), we obtain the demand for bonds:

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

Similarly, the demand for deposits satisfies:

$$D_t^H = \left(\frac{(1-\nu)\kappa\left[\frac{\nu s_t^D}{(1-\nu)s_t^M}\right]^{\nu(1-\vartheta)}}{s_t^D}\right)^{\frac{1}{\vartheta}}. \tag{A.10}$$

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:

$$D_t^H = D_t + D_t^S \tag{A.11}$$

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

Market clearing in the reserve market requires:

$$M_t^S = M_t^H + M_t, \tag{A.12}$$

where M_t^S denotes the reserve supply by the central bank, M_t^H is household demand for bonds, and M_t is bank demand for reserves.

The key feature is that the CB has two instruments, $\{D_t^S, M_t^S\}$, 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 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.[36] 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

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

Table A.2: 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.2):

$$\begin{aligned} C_t + C_t^H + B_t + M_t^H + D_t^H + \Xi_t &= (1 + r_{t-1}^B) B_{t-1} + (1 + r_{t-1}^M) M_{t-1}^H \\ &\quad + (1 + r_{t-1}^D) D_{t-1}^H + \Pi_t^E - T_t, \qquad \text{(HHs BC)} \\ T_t + \tau\Pi_t + M_t^S + D_t^S &= \left(1 + r_{t-1}^M\right) M_{t-1}^S + \left(1 + r_{t-1}^D\right) D_{t-1}^S + \Theta_t, \qquad \text{(Gov BC)} \end{aligned}$$

where

$$\begin{aligned} \Theta_t &= \int \int_{\bar{\omega}}^{1} \Big[\left(1 + r_{t-1}^D\right) d_{t-1}(l,x) + \left(1 + r_{t-1}^B\right) b_{t-1}(l,x) \\ &\quad - \bar{v}_t(l,x,\omega) \Big] e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e), \qquad \text{(DIS \& bank resolution)} \\ \Xi_t &= \bar{\mathscr{F}}_{t-1} \bar{E}_t - \chi \int \int_0^{\bar{\omega}} g_t(l,x,\omega) e \, \mathrm{d}F(\omega) \mathrm{d}H_{t-1}(l,x,e), \qquad \text{(Net equity injections)} \\ \Pi_t^E &= (1-p) \left((A - \bar{r}_{t-1}^{L*}) L_{t-1} + (A - r_{t-1}^N) N_{t-1} \right), \qquad \text{(Entrepreneurs' profits)} \\ Y_t &= (1-p) A (L_{t-1} + N_{t-1}). \qquad \text{(Aggregate output)} \end{aligned}$$

The expression for the mass of failing banks $\bar{\mathscr{F}}_{t-1}$ is derived in Appendix A.9.

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:

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

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:

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

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

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

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

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

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

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

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

$$C_t + C_t^H + L_t + N_t = E_{t-1} + D_{t-1} + B_{t-1} - M_{t-1} + \Pi_t^E + (1-p)(\bar{r}_{t-1}^{L*}L_{t-1} + r_{t-1}^{N}N_{t-1}) - RC_t.$$

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.5 Derivation of Loan Liquidation Probability

As in Appendix A.4, 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

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

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.9, 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.6 Proof of Lemma 1

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

$$
\begin{aligned}
V_t^B(L_{jt}, E_{jt}, x_{jt}^L) = \mathbf{1}_{\{E_{jt} \geq \gamma L_{jt}\}} \Bigg[\max_{\{N_{jt}, M_{jt}, D_{jt}, B_{jt}\}} \beta \int_0^{\overline{\omega}_{jt+1}} \Big[(1-\chi) V_{t+1}^B(L_{jt+1}, E_{jt+1}, x_{jt+1}^L) \\
+ \chi E_{jt+1} \Big] \mathrm{d}F(\omega_{jt+1}) \Big]
\end{aligned}
$$

$$
\begin{aligned}
\text{s.t.} \quad B_{jt} &= L_{jt} + N_{jt} + M_{jt} - D_{jt} - E_{jt}\,, && \text{(Balance sheet identity)} \\
D_{jt} &\leq \alpha L_{jt}\,, && \text{(Deposits constraint)} \\
L_{jt+1} &= \left(1 - \omega_{jt+1}\right)(1-\delta)\left(L_{jt} + N_{jt}\right), && \text{(Loan LOM)} \\
E_{jt+1} &= E_{jt} + (1-\tau)\Pi_{jt+1}\,, && \text{(Equity LOM)} \\
E_{jt} &\geq \gamma\left(L_{jt} + N_{jt}\right), && \text{(Capital requirement)} \\
M_{jt} &\geq \theta(D_{jt} + B_{jt})\,, && \text{(Reserve requirement)}
\end{aligned}
$$

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 failure 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

$$v_t^B(l_{jt}, x_{jt}^L) = \mathbf{1}_{\{1 \geq \gamma l_{jt}\}} \left[\max_{\{n_{jt}\}} \quad \beta \int_0^{\overline{\omega}_{jt+1}} g_{jt+1} \left[(1-\chi) v_{t+1}^B(l_{jt+1}, x_{jt+1}^L) + \chi \right] \mathrm{d}F(\omega_{jt+1}) \right],$$

$$\begin{aligned}
\text{s.t.} \quad b_{jt} &= l_{jt} + n_{jt} + m_{jt} - d_{jt} - 1, && \text{(Balance sheet identity)} \\
d_{jt} &= \alpha l_{jt}, && \text{(Deposits constraint)} \\
l_{jt+1} &= (1-\omega_{jt+1}) \frac{(1-\delta)(l_{jt} + n_{jt})}{g_{jt+1}}, && \text{(Loans LOM)} \\
g_{jt+1} &= 1 + (1-\tau)\pi_{jt+1}, && \text{(Equity growth LOM)} \\
1 &\geq \gamma(l_{jt} + n_{jt}), && \text{(Capital requirement)} \\
m_{jt} &= \theta(d_{jt} + b_{jt}), && \text{(Binding liq. requirement)}
\end{aligned}$$

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

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

with

$$
\pi_{jt+1} = (1-\omega_{jt+1})(r_{jt}^L l_{jt} + r_t^N n_{jt}) + r_t^B - \left[r_t^B(1-\alpha) + r_t^D \alpha \right] l_{jt} - r_t^B n_{jt} - \lambda \omega_{jt+1}(l_{jt}+n_{jt}) - f\left(\frac{n_{jt}}{l_{jt}}\right) l_{jt} - \overline{\pi},
$$

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

A.7 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) capital constraints are slack along the paths being compared; (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

$$
\begin{aligned}
L_{j,t+1} &= (1-p)(1-\delta)(L_{j,t}+N_{j,t}),\\
E_{j,t+1} &= E_{j,t} + (1-\tau)\Pi_{j,t+1},\\
r^L_{j,t+1} &= \frac{r^L_{j,t}L_{j,t} + r^N_t N_{j,t}}{L_{j,t}+N_{j,t}},\\
\Pi_{j,t+1} &= (1-p)\left(r^L_{j,t}L_{j,t} + r^N_t N_{j,t}\right) + r^M_t M_{j,t} - r^D_t D_{j,t} - r^B_t B_{j,t}\\
&\qquad - \lambda p(L_{j,t}+N_{j,t}) - f\left(\frac{N_{j,t}}{L_{j,t}}\right)L_{j,t} - \bar{\pi}E_{j,t},\\
L_{j,t}+N_{j,t}+M_{j,t} &= D_{j,t}+B_{j,t}+E_{j,t},\\
D_{j,t} &\le \alpha L_{j,t}, \qquad M_{j,t} \ge \theta(D_{j,t}+B_{j,t}).
\end{aligned}
$$

In any equilibrium with $r^D_t < r^B_t$ and $r^B_t \ge r^M_t$, 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

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

Compact equity recursion and bank valuation kernel. After substituting the binding constraints, ant 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

$$
\begin{aligned}
\Phi_t &\equiv \alpha(r^B_t - r^D_t) - \lambda p - r^M_t,\\
\Psi_t &\equiv (1-p)r^N_t - \lambda p - r^M_t.
\end{aligned}
$$

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. Solving for current origination gives the FR supply schedule

$$N^{FR}_{j,t} = L_{j,t}(f')^{-1}\left(\sum_{m=0}^{\infty}\Lambda^B_{t,m}r^N_t - \Gamma_{j,t}\right), \tag{A.13}$$

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

$$N^{VR}_{j,t} = L_{j,t}(f')^{-1}\left(\sum_{m=0}^{\infty}\Lambda^B_{t,m}(s^N_t + r^M_{t+m}) - \Gamma_{j,t}\right). \tag{A.14}$$

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

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda_{t,m}^B r_{t+m}^M}{\sum_{m=0}^{\infty} \Lambda_{t,m}^B}. \tag{A.15}$$

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

$$\Omega_{t,m}^E = (1-\tau) \sum_{k=m}^{\infty} \beta^{k+1} (1-\tilde{\chi})^k \tilde{\chi} \left(\prod_{q=m+1}^{k} \Upsilon_{t+q}^E \right), \qquad \Upsilon_t^E \equiv 1 + (1-\tau) r_t^E, \tag{A.16}$$

and the corresponding effective horizon weights are

$$\Lambda_{t,m}^E = \Omega_{t,m}^E (1-p)^{m+1} (1-\delta)^m.$$

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

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda_{t,m}^E r_{t+m}^M}{\sum_{m=0}^{\infty} \Lambda_{t,m}^E}. \tag{A.17}$$

Primitive sufficient conditions for aligned horizon weights. For (A.15) and (A.17) to describe the same pricing relation for every horizon, it is sufficient that the entrepreneur and bank horizon weights be proportional:

$$\frac{\Lambda_{t,m}^E}{\Lambda_{t,0}^E} = \frac{\Lambda_{t,m}^B}{\Lambda_{t,0}^B} \qquad \text{for all } m \geq 0. \tag{A.18}$$

A primitive sufficient set of restrictions is: symmetric taxation, $\chi = \tilde{\chi}$, and $\Upsilon_t^E = \Upsilon_t^B$ for all t. Under those restrictions, the summands in $\Omega_{t,m}^E$ and $\Omega_{t,m}^B$ coincide term by term, so $\Omega_{t,m}^E = \Omega_{t,m}^B$ for all t and m. Since the same project-survival term $(1-p)^{m+1}(1-\delta)^m$ multiplies both kernels, the two effective horizon-weight sequences are proportional. Under $r_t^B = r_t^M$, this primitive restriction implies

$$r_t^E = r_t^M - \bar{\pi}.$$

□

A.8 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

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

Let

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

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

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

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

$$\begin{aligned}\tilde{\Lambda}^{B,x}_{j,t,0} &\equiv 1 - \tilde{\omega}^x_{j,t+1},\\ \tilde{\Lambda}^{B,x}_{j,t,m} &\equiv \frac{\tilde{\Omega}^{B,x}_{j,t,m}}{\tilde{\Omega}^{B,x}_{j,t,0}}\tilde{\varrho}^{path,x}_{j,t,m}, \qquad m \geq 1,\end{aligned} \tag{A.19}$$

and

$$\tilde{\Gamma}^{x}_{j,t} \equiv \lambda\tilde{\omega}^{x}_{j,t+1} + \mu_t + \mathscr{R}^{x}_{j,t} - \sum_{m=1}^{\infty} \frac{\tilde{\Omega}^{B,x}_{j,t,m}}{\tilde{\Omega}^{B,x}_{j,t,0}} \tilde{\mathbb{E}}_{j,t,m}\left[\left(\prod_{i=1}^{m}(1-\omega_{j,t+i})(1-\delta)\right)\left(\Phi_{t+m}(\omega_{j,t+m+1}) - \Xi\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right)\right]. \tag{A.20}$$

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.9 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 $t+1$.[37] We can write the law of motion of equity as

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

[37] 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.

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

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

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

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

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

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

A.10 Microfoundation for the asset structure

This subsection 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:

$$M = B^{bg}. \tag{A.21}$$

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.[38]

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

$$D^H = D + D^S, \tag{A.22}$$

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

$$A^H = B^H + B^{hg}, \tag{A.23}$$

where B^H is bank wholesale debt and B^{hg} are long-term government bonds. Table A.3 displays the balance sheet.

The household problem yields static demand functions:

$$D^H = h^D(r^D, r^M), \tag{A.24}$$

$$A^H = h^A(r^D, r^M). \tag{A.25}$$

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

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

Table A.3: 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}	

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.

Table A.4: 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.4 and the market clearing condition is $S^g = D^S$

Government. The Government budget constraint is

$$T_t + \tau\Pi_t + B_t^g + S_t^g = (1 + r_{t-1}^M)B_{t-1}^g + (1 + r_{t-1}^D)S_{t-1}^g + \Theta_t. \tag{A.26}$$

The Government's balance sheet can be found in Table A.5.

A.11 Market clearing condition for bond markets

Long-term bonds:

$$B^g = B^{hg} + B^{bg}, \tag{A.27}$$

Table A.5: Consolidated Government Balance Sheet

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

where B^{hg} is held by households and B^{bg} is held by banks (exchanged for reserves at the central bank).

Short-term bonds:

$$S^g = D^S, \tag{A.28}$$

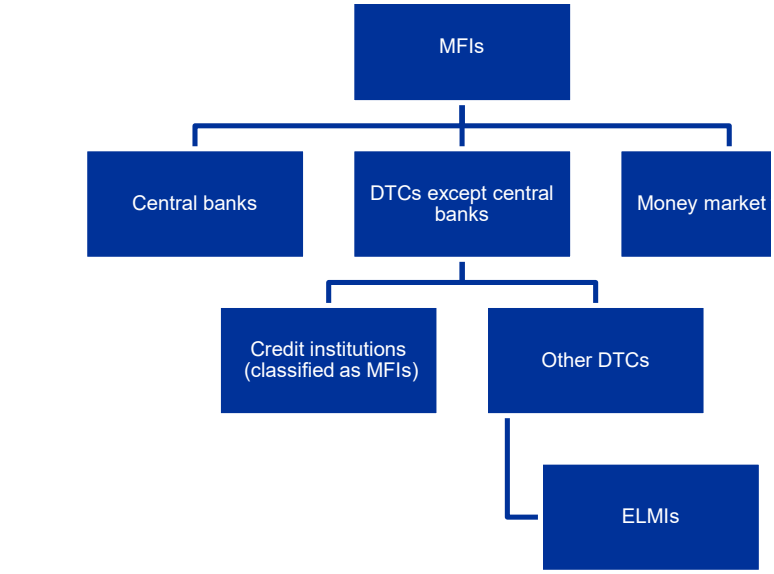
held entirely by MMFs.

B. Empirical Appendix

B.1 Consolidated banks balance sheet: Data sources

This section explains how we map the Consolidated Balance Sheet of the Euro Area MFIs (excluding the Eurosystem) to the banks' balance sheet in the model.

Figure B.1: Components of the MFIs sector



Note: DTC stands for deposit-taking corporation. ELMI stands for electronic money institution.

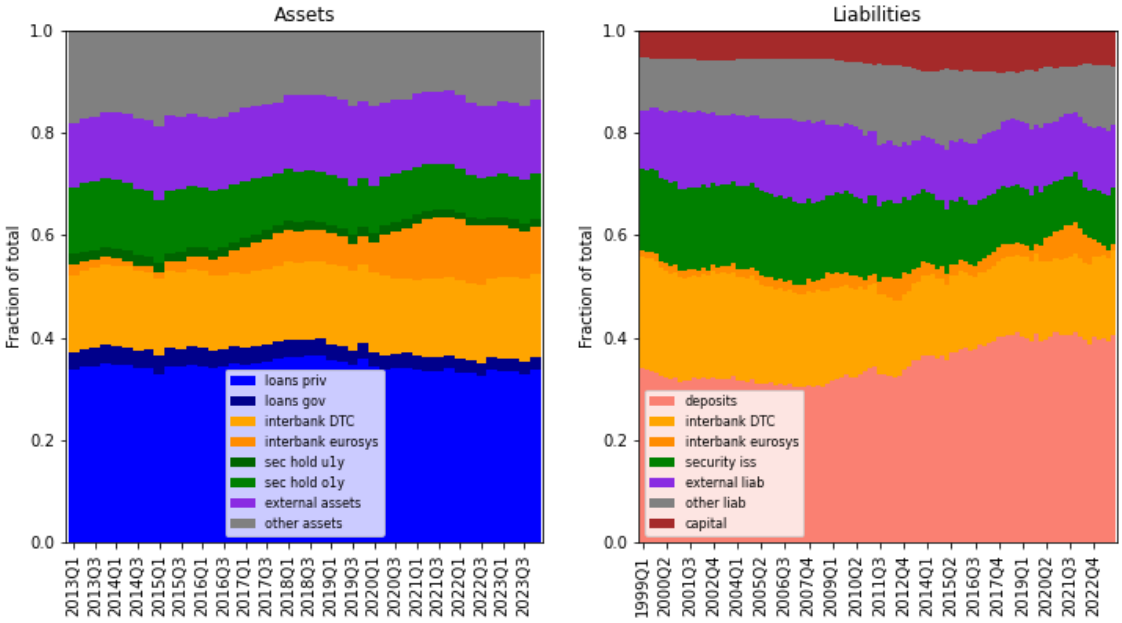
The main source is the Statistical Data Warehouse (SDW) of the ECB. We use monthly or quarterly data subject to availability and transform the series to quarterly frequency. The period of analysis starts corresponds to 01/1999 - 01/2024. Datasets:

- 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. 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

B.2 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.[39] These MFIs include deposit-taking institutions (banks), and money market funds (MMFs). 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.

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 from 1999 to 2023, 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.

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

Security holdings, both short and long-term, account for the remaining 23%.[40] On the liabilities side, most liabilities (60%) are deposits and interbank deposits (17%). The remaining liabilities are securities (16 %) and capital (7%).[41] See the breakdown below in the Table B.1.

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.3 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.

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

[41] Notice that this aggregate measure of capital and reserves does not coincide with the regulatory capital that we present in Appendix B.3, which is the Core Equity Tier 1 (CET1) capital expressed as a percentage of risk-weighted assets.

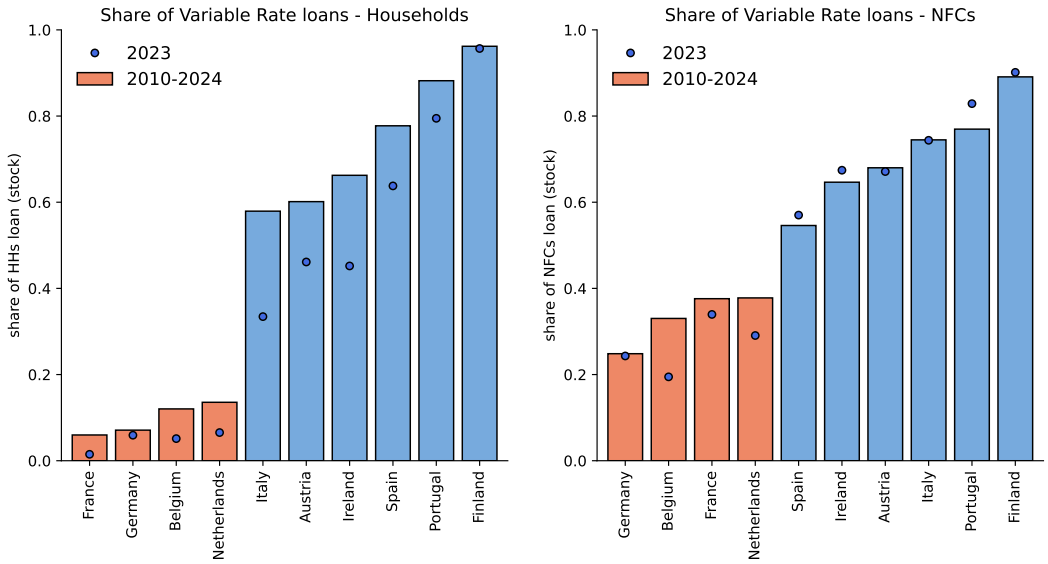
The first two columns present the cross-sectional averages of the grouped distribution for a sample of euro area banks from 2013 to 2020. We construct an unbalanced bank-level panel using balance-sheet data from S&P Global, a proprietary source. Our quarterly dataset includes information on common equity 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 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 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.4 Loan Rate Pricing

Figure B.3 shows the share of variable rate lending broken down by credit to households and non-financial corporations. The bars display the average for 2010Q1-2024Q1, which, for most countries, is close to the average for 2023 (blue circles), suggesting persistence in loan rate pricing practices.

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



Data sources: ECB Statistical Data Warehouse. 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 issued at variable rates. The bars display the average for 2010Q1-2024Q1. Orange bars corresponds to our classification of fixed-rate countries and blue bars to variable-rates. Blue circles depict the average for the year 2023.

B.5 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 2000 to 2023. 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.6 we present robustness checks for the extended sample with all 20 euro area countries, and 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:

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

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. The sample period is 2003 to 2019.[42] In each Figure, the left Panel depicts the sequence of

[42]The estimates for the sample period 2003 to 2023 are qualitatively similar.

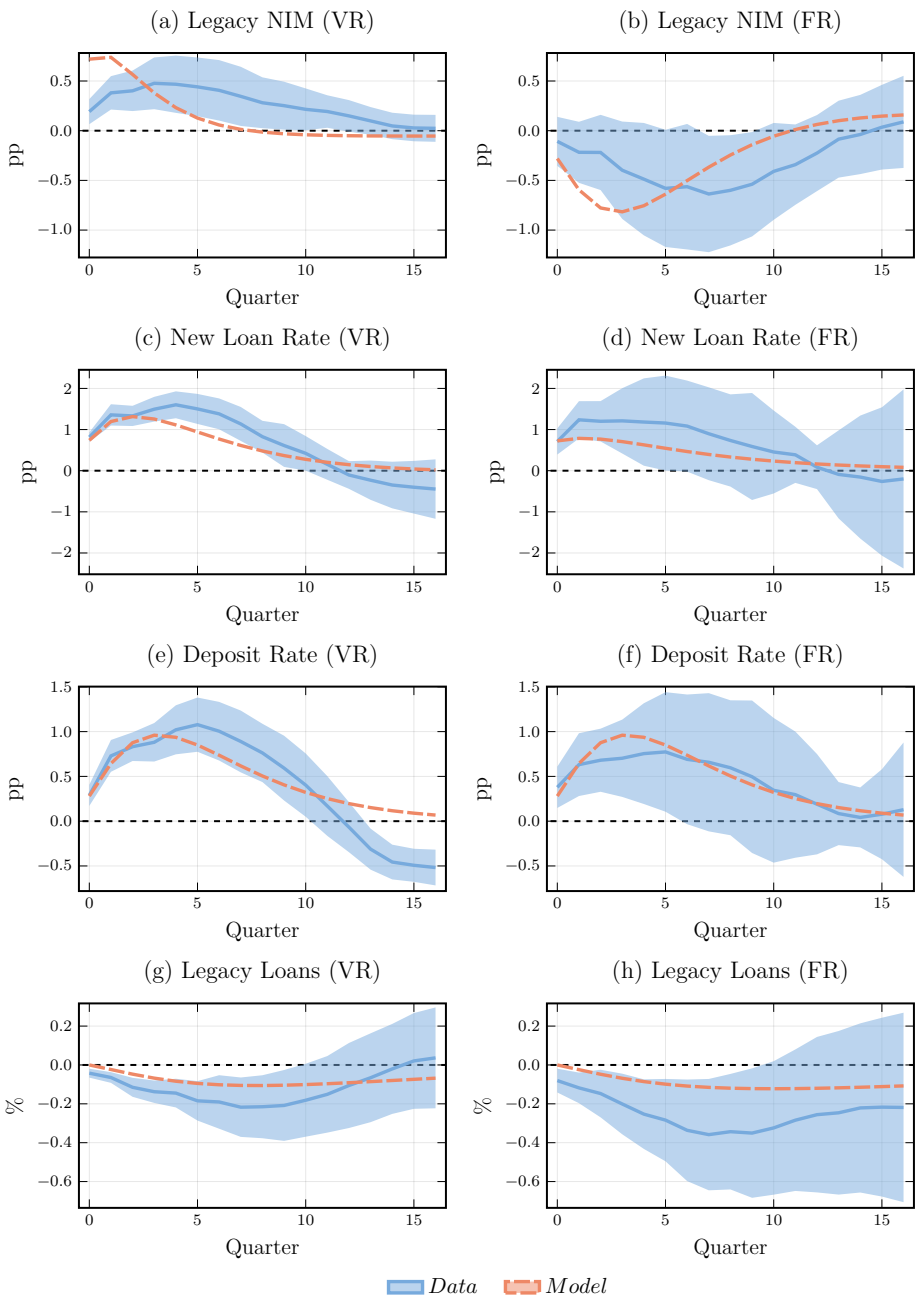
estimated dynamic coefficients $\{\beta_{1h}\}_{h=0}^{h=16}$ of the monetary policy shock as a solid blue line together with 95% confidence bands. This represents the average effect across VR countries. The right Panel depicts the sequence of estimated dynamic coefficients $\{\beta_{1h}+\beta_{2h}\}_{h=0}^{h=16}$ of the monetary policy shock as a solid blue line together with 95% confidence bands. This represents the average effect across FR countries.

B.6 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, 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).

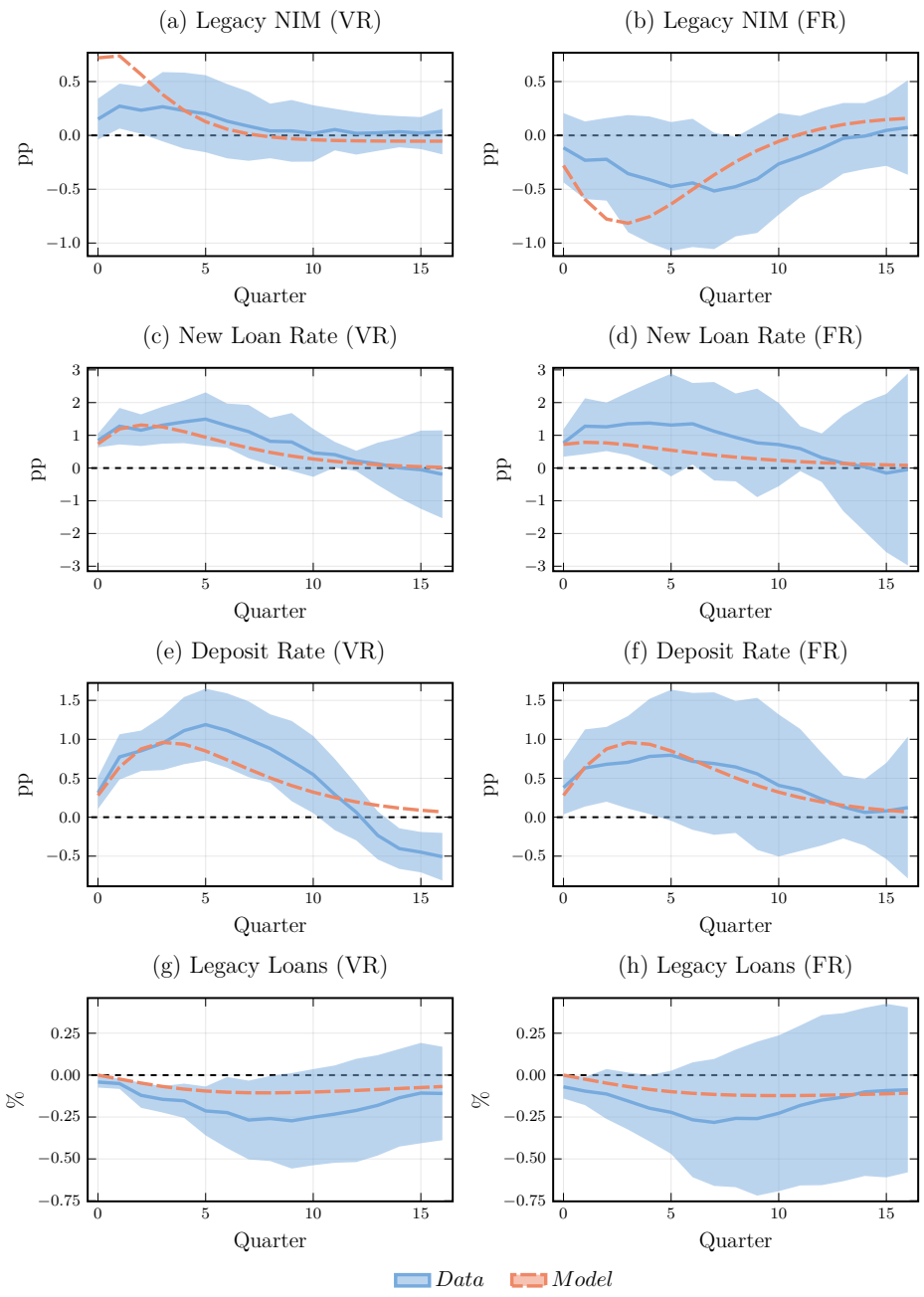
Panel of 20 euro area countries excluding periphery countries. Figure B.5 shows that our estimated empirical responses are not driven by a core-periphery classification. We present robustness estimations for the extended sample of 20 euro area countries but excluding a set of periphery countries: Spain, 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, 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.5 for estimation details.

Figure B.5: Local Projections. Panel of 20 euro area countries excluding periphery countries.

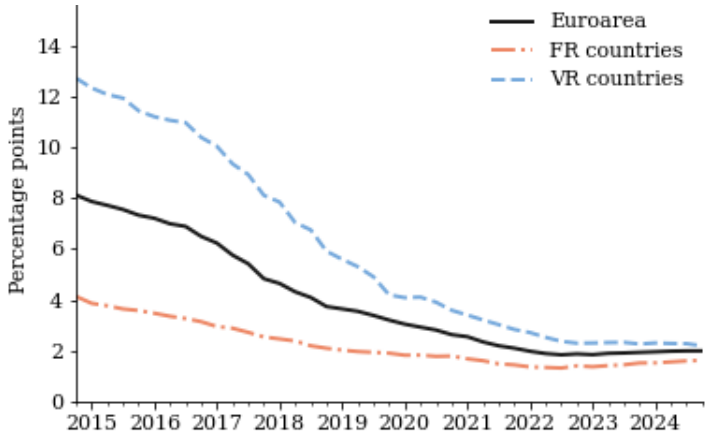


Note: Solid blue lines show the empirical impulse responses to a monetary policy shock and dashed red lines compute the model counterparts. Light blue bands show the 95% confidence intervals. Panels on the left report the response across VR countries, while right Panels report the response across FR countries in the data and in the model. See Appendix B.5 for estimation details.

B.7 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 Q1 to 2024 Q1. 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).

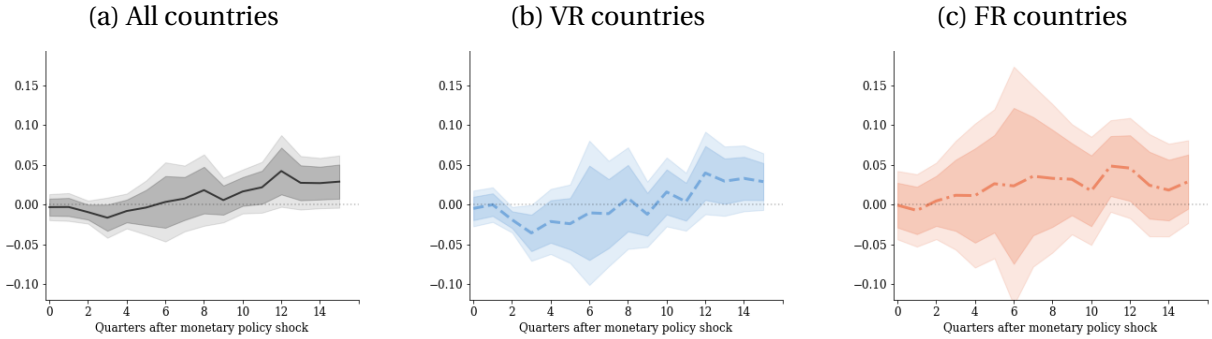


Note: NPLs are defined as the volume of non-performing loans and advances divided by the total volume of loans and advances. The data is from the European Central Bank's country *Consolidated Banking Data* (CBD2) dataset. The country sample covers the ten largest euro area economies, grouped by their 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.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.[43]

[43] 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. Bandoni et al. (2025) use loan-level data on securitised mortgages from the European DataWarehouse (EDW). For the period 2014 to 2019, they estimate an average mortgage default rate of 0.9% across

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.5. 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.[44]

countries.

[44] 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 captures how slack the capital constraint is at the end of the period. 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.[45] 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

[45] 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* $\mathscr{H}_0$ *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* $\mathscr{H}_i$*, determine the closest grid points to which banks move in the next period and redistribute mass using the method of Young (2010) yielding* $\mathscr{H}_{i+1}$.

Iterate on steps 2 until the maximum absolute difference between $\mathscr{H}_{i+1}$ *and* $\mathscr{H}_i$ *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 $t = T-1, \ldots, 1$ assuming that time T value and policy functions correspond to the ones in the steady state.*[46]
4. *Update the paths for the distribution $\{\mathscr{H}_t(l, x^L, \log(E))\}_{t=1}^{T-1}$ by iterating forwards from $t = 1, \ldots, T-1$ 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.*

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