The Heterogeneous Bank Lending Channel of Monetary Policy*

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May 2026

Abstract

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

*We would like to thank Volha Audzei, Frédéric Boissay, Felix Corell, Pablo D'Erasmo, Andrea Eisfeldt, Juan Pablo Gorostiaga, Tim Hagenhoff, Tommaso Monacelli, Steven Ongena, Federico Puglisi, Maximiliano San Millán, Alexi Savov, Enrico Sette, Javier Suarez, Andrea Tiseno, Antonia Tsang, Skander Van den Heuvel, and Emil Verner for their comments, as well as participants at numerous conferences and seminars. We are also deeply grateful to Hervé Le Bihan, who collaborated on an initial version of the project. AI-assisted tools were used solely for proofreading, language editing, and consistency checks. All remaining errors are ours. The views expressed in this manuscript are those of the authors and do not necessarily represent the views of the European Central Bank, the Banco de España or the Eurosystem.

1. Introduction

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

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

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

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

An implication of our irrelevance benchmark is that whether interest-rate risk exposure matters is ultimately a quantitative question: the answer depends on whether the capital distribution in the calibrated model places enough banks near the solvency threshold for failure risk to affect lending. Answering this question requires a model calibrated to a specific institutional context, with a realistic formulation of capital regulation and a good fit to both the cross-sectional distribution of bank leverage and the aggregate dynamic responses of credit to policy changes.

1. This distinction is recognized as early as in Samuelson (1945). Interestingly, Samuelson held the view that banks were advantageously exposed to interest-rate hikes because they reprice 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.

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

We find that heterogeneity is quantitatively important, but only because a substantial number of banks operate near the solvency threshold. In our model, this arises from two forces: convex loan-origination costs and idiosyncratic loan-default shocks that prevent banks from fully controlling their leverage. The mechanism operates via the asymmetric effects that monetary policy shocks have on profitability dynamics across regimes: when policy rates rise, fixed-rate banks experience net interest margin (NIM) compression—funding costs increase while income from legacy loans remains unchanged—eroding equity and pushing highly leveraged banks closer to the solvency threshold. Variable-rate banks face the opposite dynamic, with rising legacy loan rates widening margins and rebuilding capital buffers. Because funding costs and new-loan rates are common across banks within each regime, what differs is how legacy portfolio profits affect proximity to the solvency threshold—and hence both the value banks place on distant loan cash flows and the marginal solvency cost of expanding credit. Banks initially near the threshold respond sharply, contracting lending in fixed-rate economies and expanding it in variable-rate ones, driving a reallocation of credit across the capital distribution. This asymmetric pattern is consistent with the empirical evidence on interest-rate risk and monetary transmission documented by Gomez, Landier, Sraer, and Thesmar (2021).[4] In aggregate, the elasticity of new lending to monetary policy is approximately one-third larger in fixed-rate systems. The divergence between fixed- and variable-rate banks extends to financial stability: rate hikes increase the probability of bank failures in fixed-rate economies but reduce it in variable-rate systems. To isolate the quantitative force behind the lending gap, we propose a counterfactual with muted idiosyncratic risk in which the mass of banks near the threshold is largely removed. In that case, lending responses in the two economies become nearly indistinguishable, indicating that endogenous bank fragility drives the baseline fixed-rate/variable-rate lending gap.

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

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

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

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

Beyond these insights, our framework combines several features essential for this analysis: long-term loan portfolios with vintage structure, idiosyncratic default risk generating ex post leverage heterogeneity, convex loan-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 a legacy-pricing state, given by the average loan rate in the fixed-rate economy and the average contractual spread in the variable-rate economy—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. The bank lending channel emphasizes that monetary policy affects real activity by changing banks' ability or willingness to supply credit (Bernanke and Gertler, 1995).[5] Early empirical work by Kashyap and Stein (1995, 2000) establishes that the strength of the bank lending channel is heterogeneous across banks. Subsequent research has focused on two dimensions of heterogeneity. First, the transmission is stronger among banks with lower capital ratios (Jiménez, Ongena, Peydró, and Saurina, 2012; Dell'Ariccia, Laeven, and Suarez, 2017; Altavilla, Canova, and Ciccarelli, 2020).[6] Second, the transmission is also stronger among banks with greater interest-rate risk exposure (Gomez et al., 2021; Altunok, Arslan, and Ongena, 2024). Importantly, Gomez et al. (2021) provides evidence of an interaction between both the interest-rate risk exposure and risk-bearing capacity dimensions: the transmission is stronger among financially constrained banks with greater interest-rate risk exposure. These findings provide direct empirical evidence for the central mechanism in our model.

While this empirical literature identifies important differences in bank lending responses to monetary policy, structural models are essential for two complementary reasons. First, cross-sectional estimates explain differences across banks, but quantitative models are needed to translate these cross-sectional estimates into aggregate responses. Second, empirical estimates do not permit counterfactual analysis—for instance, quantifying how transmission would change with the cross-sectional distribution of bank capital. Our contribution is to provide a structural framework that speaks directly to this empirical literature.

A recent strand of the literature has developed quantitative banking models with heterogeneity to study monetary policy transmission, emphasizing different frictions. On the liability side, Leite (2025)

5. This mechanism is distinct from other channels that operate through household portfolio and savings decisions, asset revaluations, or deposit-rate pass-through.

6. Other references include Kishan and Opiela (2000), Gambacorta and Mistrulli (2004), and Holton and Rodriguez d'Acri (2018). Beutler, Bichsel, Bruhin, and Danton (2020), in particular, controls for hedging positions.

shows that banks with longer-maturity debt are partially hedged against tightening, while Bianchi and Bigio (2022) study how settlement frictions and deposit withdrawals shape the lending channel. Begenau, Landvoigt, and Elenev (2026) examine how uninsured deposit funding creates endogenous run risk after rate hikes. On the asset/risk-taking side, Coimbra and Rey (2023) show that monetary easing can destabilize the financial system by concentrating assets in the most leveraged intermediaries, while Corbae and D'Erasmo (2021, forthcoming) study how capital regulation and competition shape bank risk-taking and the size distribution. Closely related, Corbae and Levine (2025) study how bank competition and leverage shape the transmission of monetary policy.[7] Rios-Rull, Takamura, and Terajima (2023) examine the effectiveness of countercyclical capital buffers and Begenau, Bigio, Majerovitz, and Vieyra (2026) emphasize delayed loan-loss recognition. Our contribution is to study how the exposure to interest-rate risk determines the strength of the bank lending channel.

Bellifemine, Jamilov, and Monacelli (2025) build a heterogeneous-bank New Keynesian model in which idiosyncratic-return shocks generate a cross-sectional distribution of bank net worth that amplifies monetary transmission.[8] We share their insight that the mass of banks near the capital constraint determines the strength of the response to monetary shocks, but our paper differs in two key respects. First, banks in our model originate long-term loans, so monetary policy affects the evolution of equity via the NIM of the legacy portfolio. Second, we compare fixed- and variable-rate regimes and show that they differ not only in the magnitude of the equity response but also in its sign. As a result, the same monetary tightening amplifies the effect on credit supply in fixed-rate economies, whereas it attenuates it in variable-rate ones.

Also 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.[9] Our framework abstracts from this endogenous-exposure margin. Because the maturity structure of loan books is slow-moving and strongly shaped by institutional conventions—particularly in the euro area, where country-level loan-pricing norms are persistent—we treat interest-rate risk exposure as predetermined and ask when these ex ante differences are quantitatively important for the transmission of monetary policy.

Other recent quantitative macro-banking models, e.g., Begenau (2020), Elenev, Landvoigt, and Van Nieuwerburgh (2021) and Mendicino, Nikolov, Rubio-Ramirez, Suarez, and Supera (forthcoming), share the emphasis on capital regulation as a quantitatively important friction. The latter two include idiosyncratic default shocks, but aggregate to a representative bank.[10] Relative to these papers, we

7. Another related structural approach is Wang, Whited, Wu, and Xiao (2022), who study how bank market power affects monetary pass-through to deposit and loan rates.

8. Jamilov and Monacelli (2026) develop a Bewley-style incomplete-markets real-economy model of banks in which persistent idiosyncratic return shocks and incomplete equity markets generate precautionary capital accumulation and a stationary leverage distribution.

9. Relatedly, Di Tella and Kurlat (2021) study why banks choose to remain exposed to monetary policy shocks, while Schneider (2026) shows, in a representative-bank model, that the zero lower bound incentivizes banks to increase duration exposure.

10. These build on a broader literature that identifies intermediary net worth as a key state variable driving macroeconomic fluctuations (Gertler and Karadi, 2011; He and Krishnamurthy, 2012; Brunnermeier and Sannikov, 2014; Nuño and Thomas, 2017).

emphasize the role of bank heterogeneity and interest-rate risk exposure for the transmission of monetary policy.

A virtue of our framework is that, despite sharing the richness of other heterogeneous-bank models, it delivers a clean irrelevance result: in general equilibrium, the response of lending to monetary policy in fixed-rate and variable-rate economies is the same, provided that banks remain far from their regulatory limits and share a common discount factor with borrowers.The result is not a mere theoretical curiosity. It provides a lens through which to interpret the data: differences in transmission across rate-fixation regimes and across banks with different capital positions arise precisely *because* the irrelevance fails. As banks approach their regulatory limits, their interest-rate exposure shapes credit supply responses, generating the cross-sectional and regime-level patterns documented in the empirical literature. This result resonates with earlier irrelevance results. Kashyap and Stein (1995) show that the bank lending channel is inactive when non-deposit funding costs are independent of monetary policy—a manifestation of the Modigliani-Miller logic. Van den Heuvel (2007) establishes a further irrelevance: even if banks cannot raise equity freely, the strength of the channel can be independent of bank capital as long as banks are sufficiently far from their regulatory limits. In that case, lending depends on a present-value comparison between marginal funding costs and marginal lending revenues. Our contribution extends this irrelevance one step further: even if fixed-rate and variable-rate regimes generate different equity dynamics, the equilibrium response of lending to monetary policy can be the same across regimes as long as banks remain sufficiently capitalized.

Finally, a related strand examines monetary transmission from the borrowers' side. For example, Berger, Milbradt, Tourre, and Vavra (2021) and Eichenbaum, Rebelo, and Wong (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, Fuster, Hurst, and Vavra (2018) focus on the importance of home equity values.[11] Guren, Krishnamurthy, and McQuade (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; fixed-rate contracts partly shift interest-rate risk from borrowers to the intermediaries that retain the exposure. Hence, relative to this literature, our paper provides the banking counterpart: we study how bank-side interest-rate risk exposure shapes monetary transmission.

11. Kaplan, Moll, and Violante (2018), Auclert (2019), and Garriga and Hedlund (2020) examine monetary policy transmission in heterogeneous-agent economies. In the euro area, Corsetti, Duarte, and Mann (2021) study cross-country heterogeneity in monetary transmission, while Calza, Monacelli, and Stracca (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 banking sector intermediates funds from households to entrepreneurs, who undertake risky long-term projects that require external finance. Entrepreneurs' entry decisions generate a microfounded, forward-looking demand for loans. The funding block is intentionally parsimonious: household asset demand is static, yet remains flexible enough to match the empirical response of deposit rates to monetary policy shocks. This structure keeps the focus on the bank lending channel.

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

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

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

2.1 Banks

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

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

Assets. Bank assets comprise risky long-term loans and safe short-term assets, which we refer to as reserves.[12] 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.

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

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.[13]

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.[14] 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 law of motion:

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

Liabilities. The bank's assets are funded with a combination of wholesale debt B_{jt}, retail deposits D_{jt}, and equity E_{jt}. Wholesale debt is a one-period liability that pays a net interest rate r_t^B. Retail deposits are one-period liabilities paying r_t^D. They provide liquidity services to depositors (which implies that, in equilibrium, $r_t^D \le r_t^B$). Furthermore, 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.[15]

13. 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.

14. 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.

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

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:

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

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

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

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

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

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

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

Additionally, banks face an independent exogenous exit shock with probability $\chi \in (0,1)$ each period. Exiting banks repay liabilities and distribute remaining equity as dividends. To maintain a constant mass of banks, each exiting bank is replaced by a new entrant, which starts with an exogenous amount of equity $\bar{E}_t$ and a random amount of legacy loans that ensures that the leverage distribution of new banks is the same as that of surviving banks. These exit and entry dynamics ensure a stationary distribution of bank sizes. Loans in the legacy loan portfolio of exiting banks at $t+1$ that are not distributed among new banks are liquidated. Appendix A.6 derives the implied probability $\tilde{\chi}$ that a loan is liquidated because its financing bank exits.[16]

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

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

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

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

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

so optimal policy rules are size-independent. They depend only on leverage and the average legacy rate/spread, not on the bank's absolute size. The legacy pricing state x_{jt} then evolves according to (2) in

16. 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.

the FR economy and (3) in the VR economy. Hence the individual bank problem has two state variables—leverage and the average legacy rate/spread—and one choice, the new-lending-to-equity ratio. Appendix A.2 provides the formal derivation.

2.2 Entrepreneurs: Loan demand microfoundation

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

An active project yields A units of the final good per period. At the end of period t, the project 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, an active loan may be liquidated because its financing bank is resolved or exits, with probability $\tilde{\chi}$.[17] If the project is completed or the loan is liquidated, the principal is repaid in full to the bank. If the project fails, the bank recovers only $1-\lambda$ of the principal. For a loan originated at date t, the repayment stream in period $t+m$ is

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

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

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

Entrepreneurs are long-lived agents who accumulate wealth by retaining earnings from their projects and investing at the rate r_t^E. In the baseline, we assume $r_t^E = 0$, but we revisit the possibility of a non-zero rate in Proposition 1 below. The net cash flow in each period is project surplus net of interest payments, $A - q_{t,m}^N$. Entrepreneurial income is subject to the corporate tax rate τ, and accumulated wealth accrues pre-tax net returns r_t^E per period, so the law of motion for entrepreneur i's wealth is given by:

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

The entrepreneur consumes accumulated wealth when the lending relationship is liquidated. If the project matures or defaults before this event, the lending relationship ends, but retained wealth remains invested at r_t^E and is paid out when at the same hazard rate $\tilde{\chi}$.[18]

Initiating a project requires a utility cost of $a(N_t)$, where $a(\cdot)$ is an increasing function of N_t, the aggregate volume of new projects. This cost generates an upward-sloping supply curve for new projects, which captures aggregate decreasing returns to scale for the entrepreneurial sector. Free entry implies

17. We distinguish the bank's exogenous exit probability, χ, from the resulting loan-liquidation probability, $\tilde{\chi}$. The latter is the probability that a surviving loan is liquidated rather than transferred to an entrant. It can be strictly smaller than the bank exit rate χ if only a fraction of an exiting bank's loan portfolio is liquidated while the remainder is transferred to newly entering banks.

18. After project maturity or default, $\tilde{\chi}$ should be read as a payout hazard rate for retained entrepreneurial wealth. This convention preserves the valuation kernel below, separates project termination from the entrepreneur's consumption date, and allows us to state the conditions for the irrelevance benchmark in Section 3.

that, in equilibrium, the expected lifetime value of a new project at origination must exactly equal this startup cost. This zero-profit condition determines a uniform interest rate r_t^N (or spread s_t^N) for all new loans originated at time t.

It is convenient to write the entrepreneur's problem recursively. Let $V_{t,m}^E$ denote the date-t value of a project that remains active at horizon m. Conditional on reaching horizon m, the entrepreneur receives the operating payoff $A-q_{t,m}^N$ provided the project does not default, and continuation requires that the project neither defaults nor matures.

The Bellman equation is therefore

$$V_{t,m}^E = (1-p)\left[\Omega_{t,m}^E\left(A-q_{t,m}^N\right)+(1-\delta)V_{t,m+1}^E\right], \tag{11}$$

where $\Omega_{t,m}^E$ is the date-t value of one unit of pre-tax cash flow received at horizon m, taking into account that entrepreneurial earnings are retained and reinvested until the payout event governed by $\tilde{\chi}$ materializes:

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

The factor $(1-\tilde{\chi})^k\tilde{\chi}$ combines the probability that the active loan is not liquidated before horizon m with the probability that retained wealth is paid out at horizon k. Forward iteration of (11) yields the value of a newly originated project, $V_{t,0}^E$, as the discounted sum of future operating payoffs. This motivates the entrepreneur's effective discount factor:

$$\Lambda_{t,m}^E \equiv \Omega_{t,m}^E(1-p)^{m+1}(1-\delta)^m. \tag{13}$$

The term $(1-p)^{m+1}(1-\delta)^m$ is the probability that the project remains active long enough to deliver cash flow at horizon m. Thus, $\Lambda_{t,m}^E$ combines project survival with the entrepreneur's valuation of when that cash flow is eventually consumed.[19]

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

$$N_t = a^{-1}\left(\sum_{m=0}^{\infty}\Lambda_{t,m}^E\left(A-q_{t,m}^N\right)\right). \tag{14}$$

2.3 Households: Supply of bank funds

Households have quasi-linear preferences over two consumption goods—one entering with curvature, the other linearly—and derive additional utility from holding a bundle of monetary assets. These assets are grouped into highly liquid assets, D_t^H, and less liquid bonds, A_t^H, so differences in liquidity services generate an equilibrium spread between their returns. The liquid assets D_t^H consist of bank deposits D_t and short-term government paper D_t^S, which pay the deposit rate r_t^D. The less liquid bonds A_t^H consist of bank wholesale debt, B_t^H, and central bank reserves, M_t^H, which pay the policy rate r_t^M. From the

19. Project survival and entrepreneur payout are independent. Project survival enters through $(1-p)^{m+1}(1-\delta)^m$, while payout timing is captured by $\Omega_{t,m}^E$.

household's perspective, assets within each tier are perfect substitutes. Appendix A.3 presents the full problem in detail.[20]

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

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

and

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

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

2.4 Consolidated government

The consolidated government includes a central bank and a fiscal authority. As is standard, the central bank supplies reserves to implement the policy rate r_t^M. The fiscal authority raises taxes from banks, entrepreneurs, and households and manages the deposit insurance scheme. In addition, the government issues short-term paper that, from the household's perspective, is a perfect substitute 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:

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

where T_t denotes lump-sum taxes paid by households, Π_t^B and Π_t^E aggregate pre-tax profits of banks and entrepreneurs, respectively, 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.*

20. Appendix A.4 derives this representation from a richer institutional environment. In that environment, money market funds hold short-term government bonds and issue liquid shares, making those shares and bank deposits perfect substitutes within the liquid tier. Households do not literally hold central bank reserves; the reduced-form object M_t^H represents policy-rate government claims that are equivalent to reserves in the bond tier because a central bank facility allows banks to exchange government securities one-for-one for reserves, making those assets equivalent within the bond tier. The demand system in the main text is the reduced-form counterpart of that richer structure.

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

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

4. *The government budget constraint holds.*

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

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

Appendix A.5 provides more details on all equilibrium objects and market-clearing conditions.

2.6 Discussion of modeling assumptions

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

The two sides of the non-financial block nonetheless differ in their intertemporal structure. Loan demand is forward-looking because entrepreneurial projects are long lived, so borrowing depends on the discounted value of future repayments. Two additional restrictions keep this block focused. First, default risk is exogenous and policy invariant, which shuts down credit-risk feedbacks from monetary policy.[21] Second, interest-rate risk does not operate on the demand side through term-structure pricing (e.g., Piazzesi, 2005). These assumptions remove two transmission channels, but they do not eliminate financial amplification: bank equity still matters for loan pricing, so the model retains the bank-side mechanism emphasized by, e.g., Brunnermeier and Sannikov (2014).

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

A useful feature of the setup is that monetary policy shocks move two rates simultaneously. Empirically, pass-through from policy rates to deposit rates is nonlinear and time varying (Drechsler et al., 2017), which is difficult to reproduce in models without additional household-side state variables see, (e.g., Eichenbaum, Puglisi, Rebelo, and Trabandt, 2025). Our setup sidesteps this difficulty by allowing contemporaneous

21. We explore the effects of relaxing this assumption in a robustness exercise presented in Section 5.

government bond-supply shocks to move the deposit rate together with the policy rate, while the loan rate remains endogenous. This flexibility allows the model to match the empirical path of funding costs without altering the core bank-lending mechanism while preserving endogenous loan pricing.

3. Benchmark irrelevance and the role of heterogeneity

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

3.1 A benchmark irrelevance result

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

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

$$\Lambda_{t,m}^E = c_t \Lambda_{t,m}^B \qquad \text{for all } m \geq 0,$$

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

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

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

where the last term is the average of future policy rates weighted by the bank's effective discount factor.

Proof. See Appendix A.7.

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

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

Proportional effective discounting places restrictions on effective taxation, exit and liquidation risk, and reinvestment returns across the two sides of the credit relationship, detailed in Appendix A.7. While these conditions do not hold in the quantitative model, Section 5 shows that when idiosyncratic risk is muted enough to keep banks away from the solvency threshold, the remaining differences between FR and VR economies become quantitatively small.

3.2 Monetary policy transmission

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

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

where Γ_t collects the marginal costs, including funding, of originating one extra unit of loans.[22] Because the coefficient on $L_{j,t}$ is common across banks, supply aggregates linearly. A monetary tightening raises banks' funding costs, summarized by a higher Γ_t. For any given loan repayment stream $q^{N}_{t,m}$, the term in parentheses falls, so banks are willing to supply fewer loans, and the supply schedule shifts inward. On the demand side, equation (14) is downward sloping in the repayment stream because higher promised repayments reduce the value of entry for entrepreneurs. Equilibrium therefore moves to a lower quantity of new loans and a higher loan rate in the FR economy, or, given the policy-rate path, a higher spread in the VR economy. This is the benchmark transmission mechanism.

3.3 Why heterogeneity matters

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

22. Appendix A.7 derives this supply condition formally.

therefore consequential only when banks differ in their distance to the solvency threshold—the margin that the irrelevance benchmark shuts down.

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

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

where $\tilde{\Lambda}^{B,x}_{j,t,m}$ are bank-specific effective discount factors, and $\Xi^x_{j,t}$ is a bank-specific marginal-cost term collecting the components of the cost of new lending that do not operate through the discounted repayment stream. Appendix A.8 derives the exact bank-specific supply condition.

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

Once aggregation fails, the full leverage distribution then matters for the transmission of monetary policy because banks nearest the solvency threshold respond the most and do so differently under FR and VR contracting. Following a monetary tightening, any effect of the shock on banks' net interest margins changes net worth and therefore banks' distance to the solvency threshold. Through the discount-factor channel, this changes the weight banks place on distant loan cash flows. Through the precautionary channel, it changes the marginal solvency cost of expanding credit today. The sign and quantitative importance of both forces, therefore, depend on how monetary policy affects net interest margins, and hence bank capitalization, under each contract structure. Because these mechanisms operate through banks' capitalization, their aggregate implications depend on how the shock reshapes the cross-sectional distribution of bank capitalization relative to the solvency threshold. Sections 5 and 6 quantify those effects and show when they amplify or dampen the benchmark transmission mechanism.

4. Calibration and quantitative discipline

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

4.1 Functional forms and identification of parameter values

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

The calibrated model departs from the conditions required for the irrelevance benchmark in Proposition 1 to hold. In particular, the effective discount factors with which banks and entrepreneurs value the same loan cash flows are not proportional, reflecting differences in survival risk, subjective discounting, and reinvestment or exit timing.

Table 1: Parameter values and calibration targets

Pre-set parameters

	Parameter	Value	Target/Source
p	Loan default rate, mean (ann., %)	2.65	Mendicino, Nikolov, Suarez, and Supera (2020)
λ	Loan loss-given-default	0.30	Mendicino et al. (2020)
δ	Loan maturity (ann.)	0.20	Cortina, Didier, and Schmukler (2018)
τ	Corporate tax rate	0.20	Avg. European banks' effective tax rate.
γ	Min. capital requirement (%)	7.0	Basel III CET1 + capital conservation buffer.
θ	Liquidity requirement (%)	11.8	Avg. euro area reserves-to-total-debt ratio.
α	Deposits-to-legacy-loans ratio	0.97	Avg. euro area deposit-to-total-loans ratio.
r^M	Steady-state policy rate (%)	1.0	Avg. euro area deposit facility rate.
r^D	Steady-state deposit rate (%)	0.5	Avg. euro area overnight deposit rate.

Jointly calibrated parameters

	Parameter	Value	Target	Data	Model
β	Subjective discount factor	0.933	Avg. euro area banks' return on equity (%)	6.41	6.41
ρ	Loan default correlation	0.51	Avg. euro area bank failure probability (%)	0.66	0.66
η	Loan origination cost	0.22	Avg. euro area voluntary capital buffer (%)	5.12	4.79
ζ_1	Ent. entry cost (level)	5.78	Avg. euro area loan rate (%)	3.13	3.00
ζ_2	Ent. entry cost (power)	0.50	Avg. euro area response of new lending (%)	-0.38	-0.37
$\bar{\pi}$	Fixed operating cost	0.012	Avg. euro area non-interest expenses to assets (%)	0.29	0.22
χ	Bank's exit rate	0.02	Slope of log-log euro area bank assets distribution	-1.56	-1.56

Note: Interest rates and probabilities are reported in annualized terms. For p and δ, the quarterly model probabilities are chosen so that their annualized counterparts match the reported values.

Pre-set parameters. The first block of Table 1 corresponds to the pre-set parameters. These parameters pin down the institutional environment and steady-state rate levels. We follow Mendicino et al. (2020) and set the average loan default rate p so that its annualized value is 2.65% and the loan loss given default λ to 0.3. The loan maturity parameter δ is set so that the implied annualized maturity rate is 0.2, corresponding to 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.[23]

23. See http://www.stern.nyu.edu/~adamodar/pc/datasets/taxrateEurope.xls.

On the regulatory side, the model's minimum capital requirement γ is set to 7%, equal to the Basel III CET1 minimum of 4.5% plus the capital conservation buffer of 2.5%. Bank-specific requirements can exceed this level; those additional requirements enter the empirical measurement of voluntary capital buffers in Appendix B.1. The deposit-to-loan ratio $\alpha = 0.97$ and the liquidity requirement $\theta = 11.8\%$ are set to match the observed deposit-loan mix and liquid-asset share in the consolidated balance sheet of euro area monetary financial institutions (MFIs) over for the reference period 2013–2023.[24] Finally, the steady-state policy rate r^M and deposit rate r^D are set to 1% and 0.5%, respectively, roughly matching their euro area time-series averages.[25]

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:

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

where $\Phi(\cdot)$ is the CDF of a standard normal, $\Phi^{-1}(\cdot)$ denotes its inverse, and $\rho \in [0,1]$ is the loan correlation parameter.[26] This parameter governs the dispersion of bank portfolio default rates and, therefore, the bank failure rate. We choose it to match the average annualized failure probability of 0.66% for European banks reported by Mendicino et al. (forthcoming).

We assume that banks face a convex loan-origination cost:

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

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

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

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

The parameters ζ_1, ζ_2, and η are calibrated to match three moments central to the transmission mechanism:[27] (i) the average loan rate of 3.13% over 2013–2023, sourced from the ECB's MFI Interest Rate (MIR) statistics; (ii) the peak response of log new lending to a 100 basis-point monetary policy shock,

24. Appendix B.2 reports the balance-sheet construction in detail.

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

26. See Appendix A.9 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).

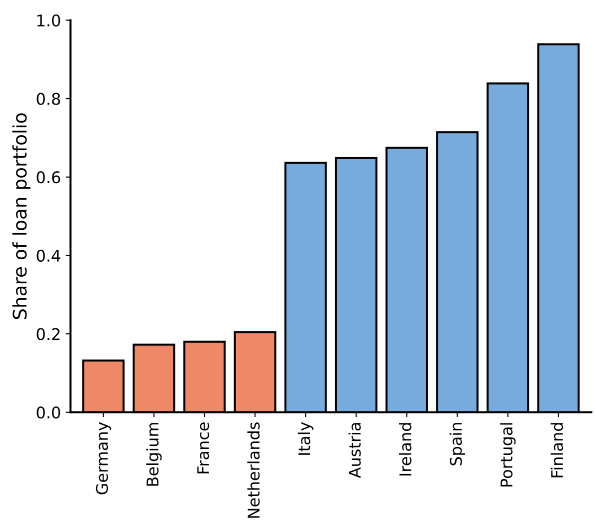
27. Though all the parameters in this group are jointly calibrated, some subgroups are more relevant for certain subsets of moments.

equal to −0.38 (computed using the local projection methodology detailed in subsection 4.3); and (iii) the average voluntary capital buffer of 5.12 percentage points, consistent with the mean CET1 voluntary buffer in 2021.Q4 for banks supervised by the ECB.[28]

Finally, the value of the subjective discount factor β, the fixed operating cost parameter $\bar{\pi}$, and the exit rate χ are pinned down by three moments: the average ROE of European banks from Mendicino et al. (forthcoming); the average non-interest-expense-to-asset ratio in the ECB's Consolidated Banking Data (CBD2) over 2013—2023; and the log-log tail coefficient of the bank asset-size distribution (Figure 2).[29] This last target allows the model to replicate the power-law distribution of bank sizes observed in the data, as discussed in Section 4.2.

Ex ante heterogeneity: FR and VR economies. We compare two counterfactual economies: one in which all loans are fixed-rate and one in which all loans are variable-rate (FR and VR economies, respectively). Figure 1, which presents the share of VR loan contracts in each country, shows that this distinction maps naturally into the euro area. We define VR loans as contracts with a maturity over one year and whose interest rate resets within the next 12 months.[30] The cross-country dispersion is large and persistent: in Belgium, France, Germany, and the Netherlands, approximately 80% of outstanding loans are fixed-rate,

Figure 1: Share of variable-rate loans.



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

28. We calibrate the model based on CET1 data for ECB-supervised banks, which provide the most accurate available estimates of capital buffers. For the supervised-bank target, the voluntary buffer is measured as the CET1 ratio net of the applicable combined buffer requirement and bank-specific Pillar 2 CET1 requirements. Appendix B.1 compares alternative CET1 ratio and buffer estimates.

29. Our approach to disciplining the model to fit characteristics of the cross-sectional bank-size distribution aligns with recent studies (Corbae and D'Erasmo, 2021; Jamilov and Monacelli, 2026).

30. The categorization in Figure 1 also aligns with results reported by Core, Marco, Eisert, and Schepens (2025) using granular data on non-financial corporate loans in the euro area.

whereas in Austria, Finland, Ireland, Italy, Portugal, and Spain, more than 60% are variable-rate.[31] We use these two country groups when comparing empirical and model responses to monetary shocks below.

4.2 Cross-sectional validation

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

Capital ratio distribution. Table 2 reports the distribution of capital ratios in the data and in the model's steady state.[32] The model reproduces the left tail of the distribution well. The capital ratio at the first percentile is 9.7% in the model and 9.4% in the data, both only modestly above the regulatory minimum of 7%. More generally, the model places substantial mass close to the requirement: at the 40th percentile, the capital ratio is 12.7% in the model versus 13.5% in the data. This is the region of the distribution that matters for the mechanism, as shown in the bank-level responses in Section 5, because banks near the solvency threshold are the ones whose lending choices are most sensitive to equity losses.

The model is less successful in the right tail. For banks in the upper half of the distribution, the average capital ratio is 13.1% in the model versus 18.7% in the full sample. The calibration is designed to discipline the left tail of the capital-ratio distribution. For our purposes, this is the relevant margin, because banks far from the solvency threshold behave nearly homogeneously in the model. The fit improves when the comparison is restricted to large banks, for which the average capital ratio in the upper half of the distribution falls to 14.7% in the data. Part of the remaining gap likely reflects regulatory margins outside the model, notably the Minimum Requirement for Own Funds and Eligible Liabilities (MREL), which smaller banks often satisfy with extra CET1 capital rather than with bail-inable liabilities.[33]

Bank balance sheet composition. We compare the consolidated balance sheet of monetary financial institutions (MFIs) in the euro area to its model counterpart.[34] Table 3 shows that the model's steady-state consolidated balance sheet closely matches the composition of assets and liabilities observed in the data. This matters because the mechanism operates through maturity transformation: banks fund a large stock of long-duration loans with deposits, wholesale debt, and a relatively small amount of equity and liquid

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

32. Since the gradual implementation of Basel III beginning in 2013, capital ratios for euro area banks have trended upward over time. To adjust for this time trend, we demean capital ratios period by period and recenter the pooled distribution using the 2019 mean capital ratio. See Appendix B.1 for further details.

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

34. Appendix B.2 details the composition of MFIs and the time series used.

Table 2: Capital-ratio distribution

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

Source: S&P Global and ESRB supervisory data on European banks' capital requirements. *Note*: Capital ratios are defined as CET1 capital divided by risk-weighted assets. The sample covers approximately 70 euro area banks per quarter from 2013 to 2020. *Large banks* refers to banks with assets exceeding €100 billion.

assets. Asset-side ratios are directly targeted in the calibration, but on the liability side only deposits are targeted.[35]

Asset-size distribution. The model also reproduces the heavy right tail of the bank asset-size distribution observed in the data.[36] Figure 2 compares the right tails of the model and empirical asset distributions in log-log space. The model reproduces the power-law behavior observed in the data, which emerges endogenously from the combination of size-independent growth rates and stochastic exit, consistent with Gabaix (2009). This regularity is well documented empirically, both for U.S. banks (Janicki and Prescott, 2006) and across European banking systems (Bremus, Buch, Russ, and Schnitzer, 2018).

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

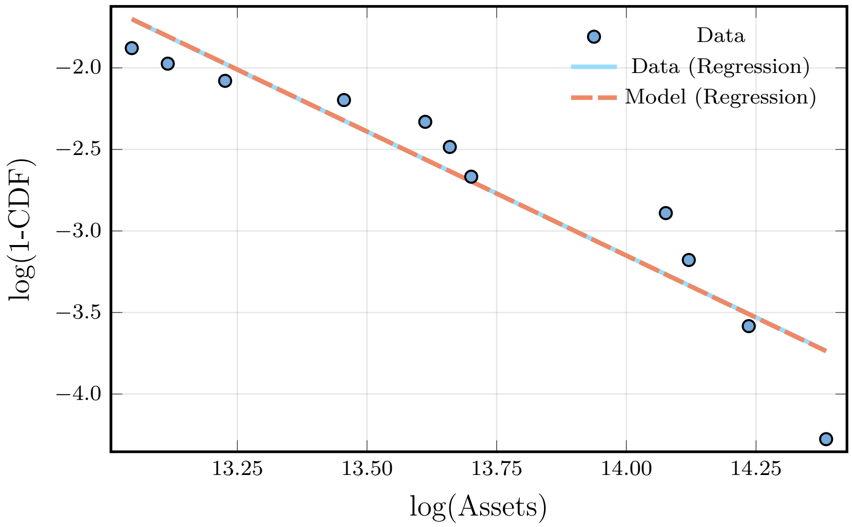
Assets			**Liabilities**		
	Model	Data		Model	Data
Loans	89%	88%	Deposits	81%	78%
Short-term securities and reserves	11%	12%	Wholesale funding	9%	14%
			Equity capital	10%	8%

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

35. 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.

36. We characterize the distribution of bank assets using a quarterly dataset covering more than 70 euro area banks from 2013 to 2020 and including information on CET1 capital levels, risk-weighted assets, and total assets. See Appendix B.1 for details.

Figure 2: Bank asset size distribution: Tail behavior.



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

4.3 Time-series validation

We examine whether the calibrated model reproduces the response patterns that motivate the paper. We estimate empirical impulse responses using local projections (Jordà, 2005; Jordà, Schularick, and Taylor, 2015) on a balanced panel of the ten largest euro area countries over 2003–2019, grouped into FR and VR systems using the classification above.[37] We then feed the model the empirical paths of the policy rate and the deposit rate following a 100 basis-point monetary tightening. Model transitional dynamics are computed following an unanticipated (MIT) shock, using an algorithm similar to Boppart, Krusell, and Mitman (2018).[38]

Exogenous rate paths. Figure 3 reports the policy-rate and deposit-rate paths used in the experiment. The rate paths are exogenous inputs to the quantitative experiment. This allows us to focus on whether, given a common tightening in policy and funding costs, the model reproduces the relative responses of lending-side variables across FR and VR country groups in the data and the corresponding model economies.

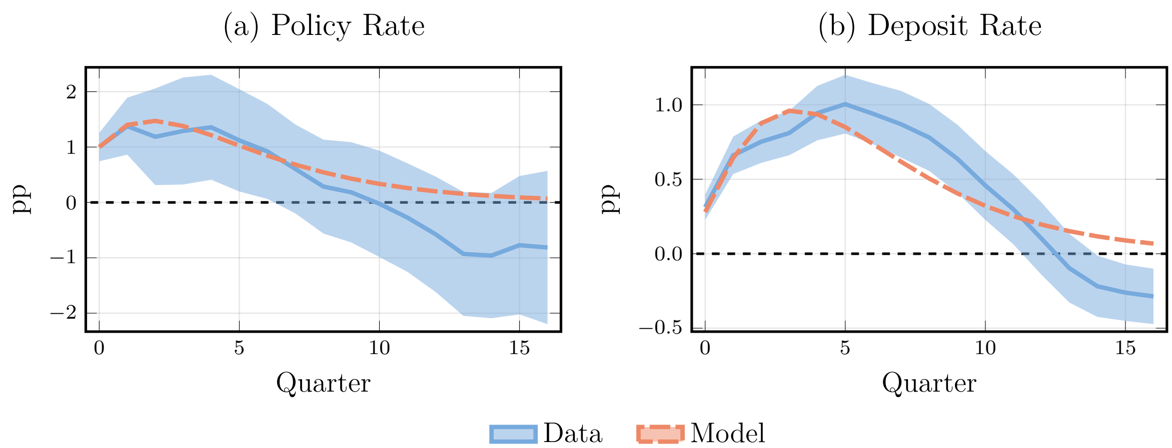
We approximate these empirical impulse responses using AR(2) processes for r^M and r^D so that the quantitative exercise isolates the bank lending channel rather than the pass-through from monetary

37. We exclude the COVID-19 period to keep the local projections in a regime where monetary surprises elicit approximately linear responses. Appendix B.4 reports the local projection estimation details, Appendix B.5 shows robustness to using all twenty euro area countries, and to the extended sample period 2003–2023. Both yield qualitatively similar results.

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

policy to deposit rates.[39] Given those inputs, loan prices and quantities are determined endogenously in equilibrium.

Figure 3: Exogenous rate paths after a monetary shock



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

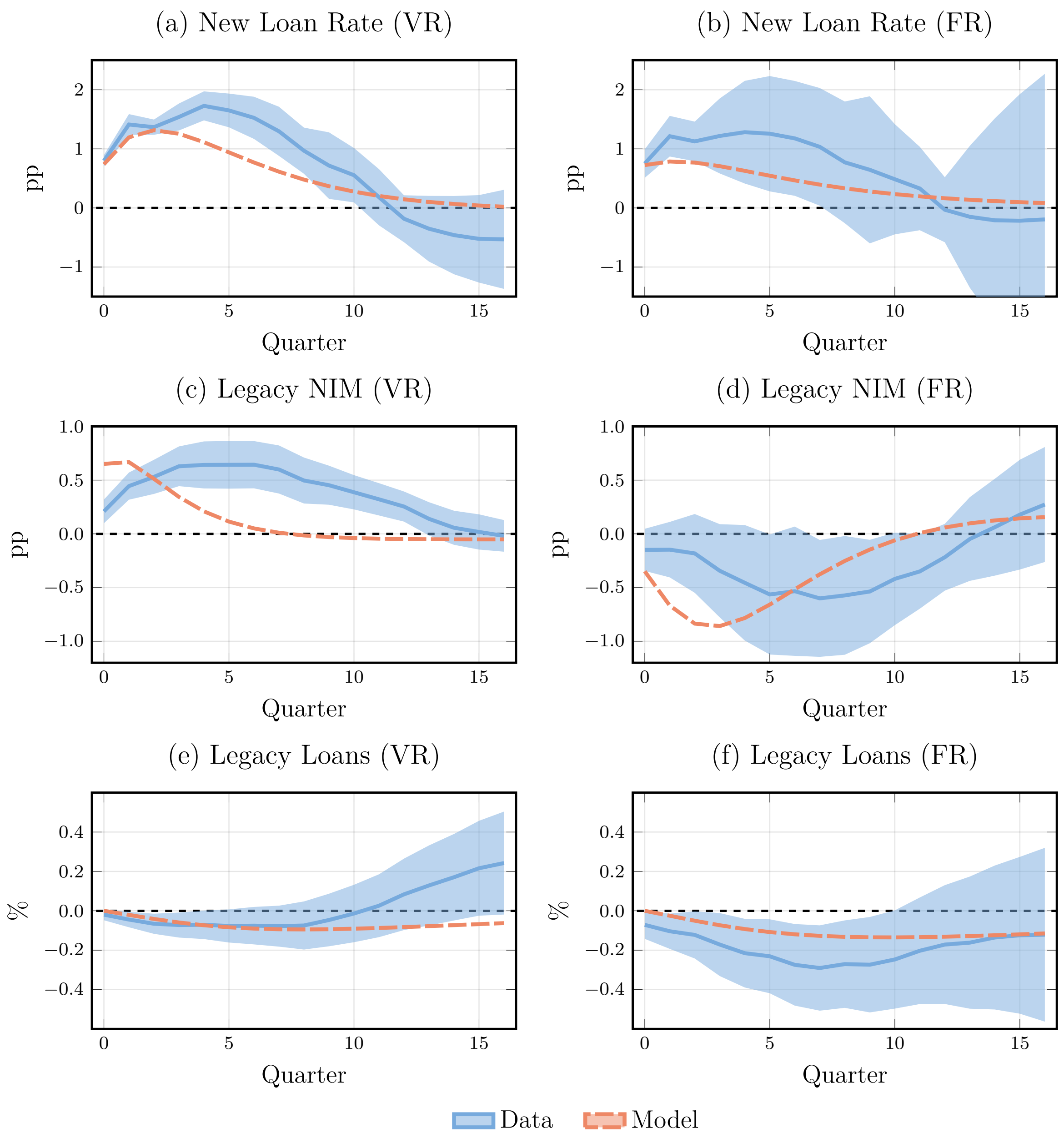
Untargeted impulse responses. Figure 4 shows the dynamic responses of the key objects of interest: loan rates, net interest margins on legacy loans, and legacy loan volumes. Although the calibration uses the average response of new lending as a target, it does not target the regime-specific responses of these variables. The left panels correspond to VR countries, while the right panels correspond to FR countries. The model matches three central patterns. First, pass-through to new loan rates is stronger in VR economies than in FR ones (Panels a and b). Second, the NIM on legacy loans rises in VR economies but falls in FR economies (Panels c and d).[40] Third, legacy loan volumes decline more, and more persistently, in FR economies (Panels e and f).

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

39. See Section 6 below for details on the AR(2) representation.

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

Figure 4: Untargeted impulse responses



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

5. Quantitative results

We now compare the transmission of interest-rate shocks to bank lending in FR vs. VR economies. Under the same path of funding costs, lending declines by substantially more in the FR economy because legacy NIM dynamics move the distribution of bank capital in opposite directions across regimes. We first present aggregate impulse responses and then test the role of heterogeneity by lowering default-rate dispersion until the solvency threshold is nearly irrelevant. We next examine bank-level responses to show that banks closest to the solvency threshold drive the aggregate divergence. Finally, we discuss the robustness of the baseline results to borrower-side credit-risk feedbacks.

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

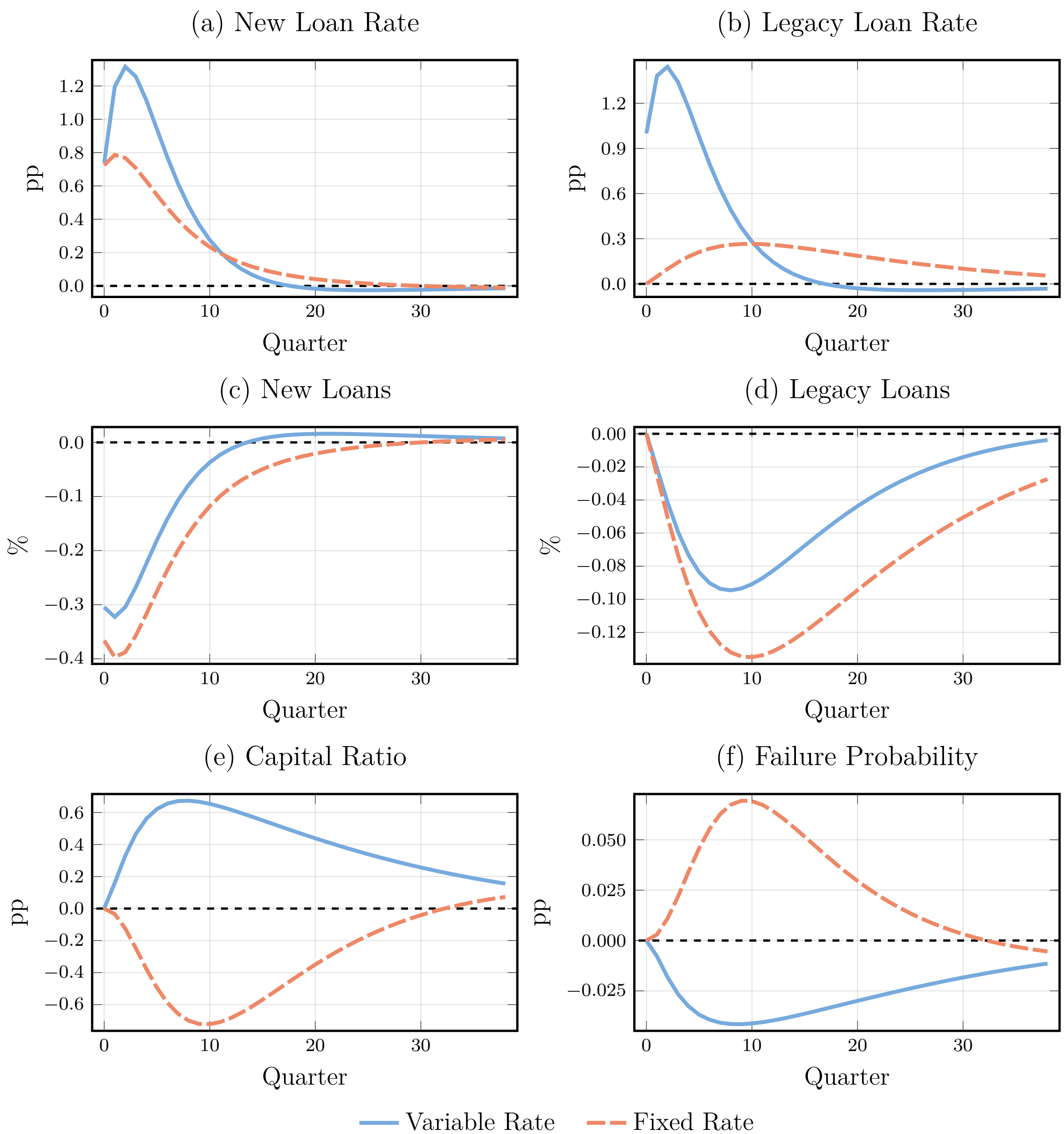
If the conditions of Proposition 1 held, these diverging NIM paths would be irrelevant for aggregate credit supply. They would merely represent different intertemporal transfers of surplus between banks and borrowers, all perfectly offset by equilibrium pricing of new loans. However, idiosyncratic default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

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

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

Restoring the benchmark. We test this implication by lowering the default-correlation parameter from $\rho = 0.51$ in the baseline to $\rho = 0.1$, holding the mean loan-default probability p fixed. This reduces the cross-sectional dispersion of realized bank portfolio default rates. This counterfactual does not

Figure 5: Aggregate impulse response functions

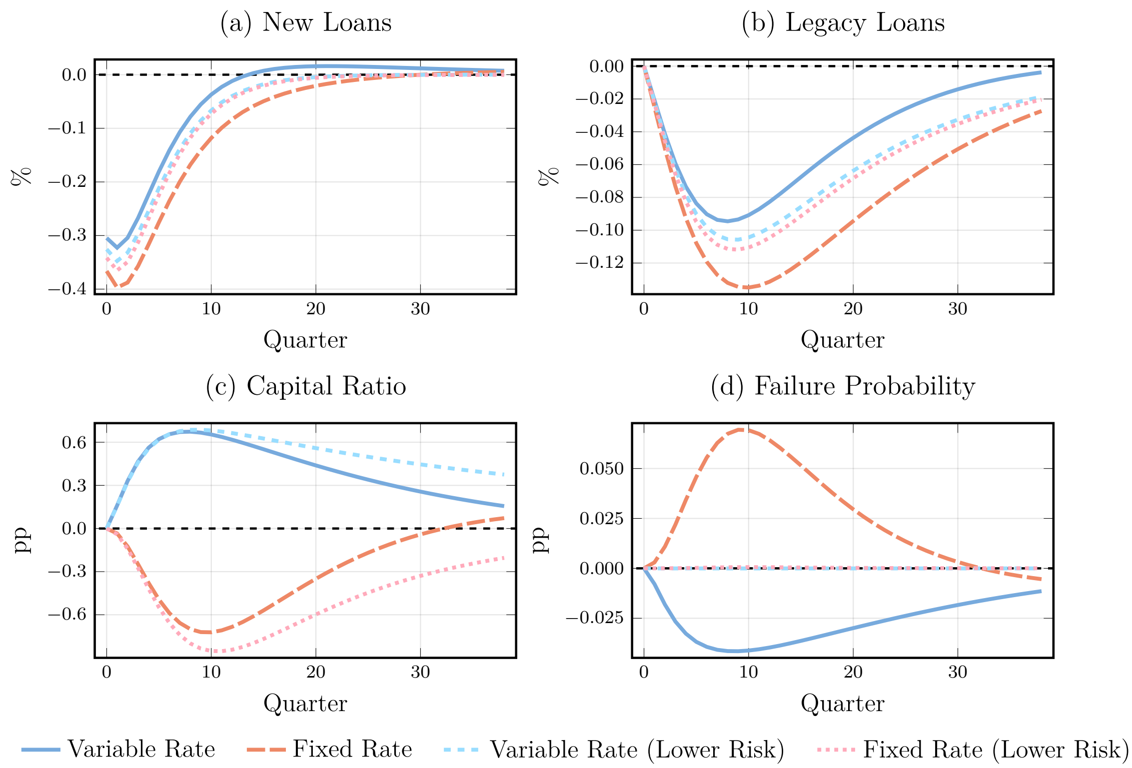


Note: Impulse responses to a 1 percentage point increase in the policy rate. Solid blue lines correspond to the variable-rate (VR) economy; dashed red lines correspond to the fixed-rate (FR) economy.

impose the conditions of Proposition 1 exactly—banks and entrepreneurs still discount future repayments differently—but it keeps banks away from the regulatory threshold and makes insolvency risk negligible, thereby nearly restoring the benchmark condition that the threshold does not affect continuation values.

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

Figure 6: Impulse response functions — Lower idiosyncratic default-rate dispersion

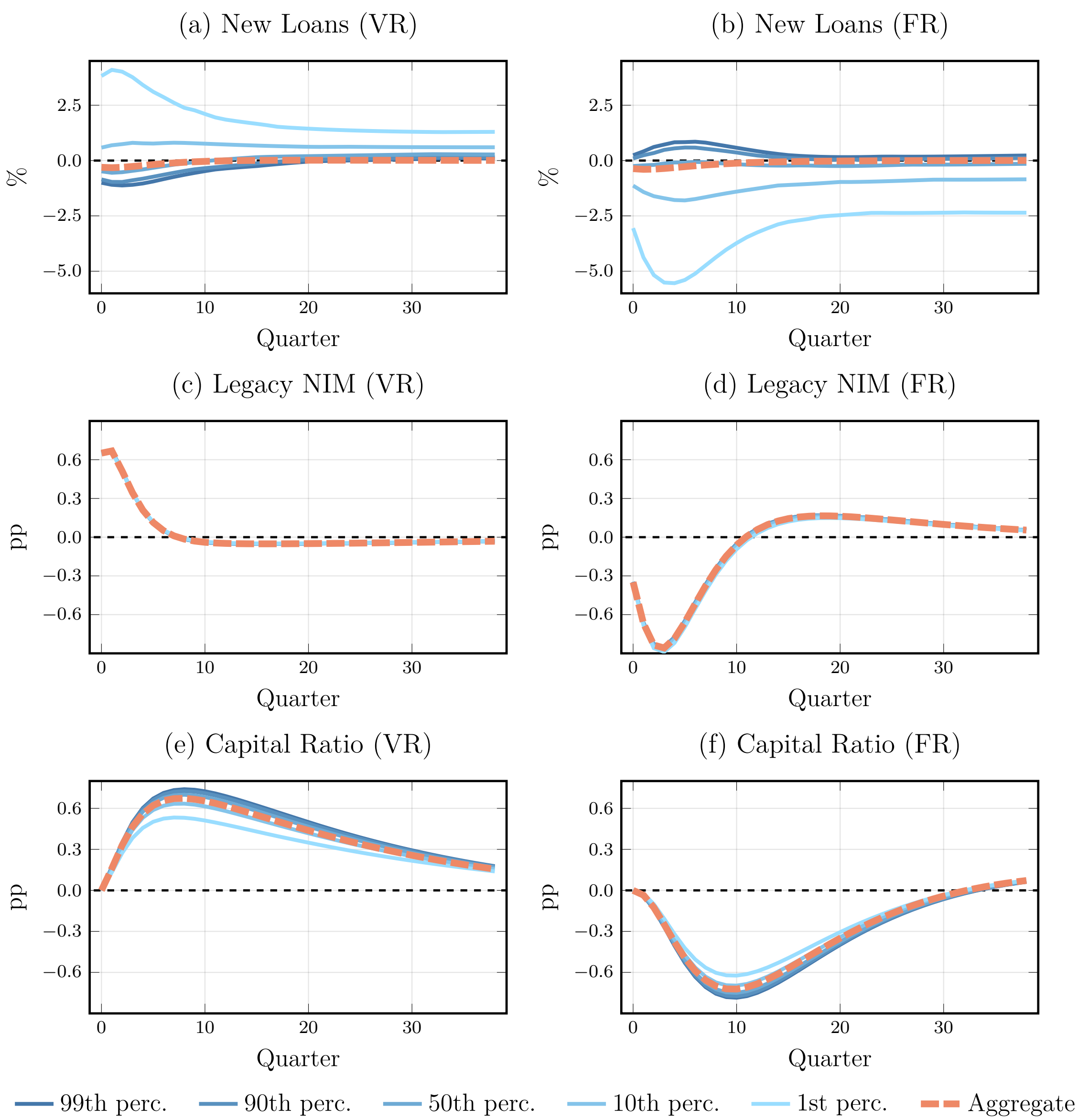


Note: The impulse responses denoted "Variable Rate" and "Fixed Rate" correspond to the baseline calibration. "Variable Rate (Lower Risk)" and "Fixed Rate (Lower Risk)" correspond to alternative parameterizations with $\rho = 0.1$ (versus $\rho = 0.51$ in the baseline), holding the mean loan-default probability p fixed and implying substantially lower dispersion in realized bank portfolio default rates.

Lower idiosyncratic default-rate dispersion compresses the dispersion in bank leverage, so neither heterogeneity channel operates materially. In the FR economy, legacy NIM compression no longer pushes a meaningful mass of banks toward the solvency threshold. In the VR economy, legacy NIM expansion has little effect on lending because solvency pressure is already negligible. This shows that endogenous bank fragility is the quantitatively dominant departure from Proposition 1, while the importance of the residual wedge between bank and borrower discount factors is quantitatively minor.

Cross-sectional responses. Which banks drive the aggregate differences? Figure 7 plots impulse responses for banks at selected percentiles of the steady-state capital-ratio distribution, with lighter shades corresponding to more highly leveraged banks. Within a regime, all banks face the same funding conditions and the same loan demand curve, so the new-loan rate moves identically across banks. Cross-sectional dispersion in lending instead arises because the same NIM dynamics have different consequences for banks at different leverage levels: the mapping from legacy profits to solvency risk and its impact on lending depends on each bank's distance to the regulatory threshold.

Figure 7: Individual impulse response functions



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

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

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

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

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

Robustness to credit-risk sensitivity. The baseline calibration keeps default risk policy invariant to isolate the bank-capital channel. Appendix D relaxes this assumption in a reduced-form exercise in which default probabilities in the VR economy increase with loan rates. The exercise is intentionally asymmetric. It captures the repricing of legacy VR loans, but it also applies rate-sensitive default risk to newly originated VR loans while leaving newly originated FR loans at the baseline default probability. Because higher contractual rates on new loans are not specific to VR contracts, this second margin would also operate in the FR economy in a symmetric cohort-level specification. The exercise therefore provides a conservative assessment rather than a clean comparison of the two regimes. Its main implication is that the equity dynamics behind the baseline mechanism are largely unchanged: the additional VR contraction comes from lower expected profitability of riskier new loans—a mechanism that should be present in the FR economy—and not from pushing more banks toward the solvency threshold.

Taking stock. In this model, legacy portfolio dynamics affect lending by changing banks' distance to the solvency threshold, which determines the strength of the discount-factor and precautionary channels. Funding costs and new-loan rates are common across banks within each regime; what differs is how legacy portfolio profits affect proximity to the solvency threshold. The core mechanism operates through reallocation of lending: In FR economies, NIM compression erodes equity, pushing low-capital banks to curtail lending and amplifying the aggregate contraction. In VR economies, NIM expansion rebuilds equity, encouraging low-capital banks to expand and dampening the aggregate contraction.

These findings align closely with recent cross-sectional evidence in Gomez et al. (2021), who study how banks' interest-rate risk exposures shape the transmission of monetary policy. They document that banks with larger interest-rate risk exposure experience NIM compression when rates rise, and that this compression reduces lending through its effect on bank equity. Crucially, the lending response is amplified for banks with lower capital ratios. Each of these patterns maps directly onto our model: NIM compression on legacy portfolios drives capital erosion (Figures 4 and 5), the effect operates only when the solvency threshold becomes relevant (Proposition 1), and low-capital banks are the key margin of transmission (Figure 7). The greater sensitivity of highly levered banks is also consistent with the broader literature on bank capital and lending (Jiménez et al., 2012; Dell'Ariccia et al., 2017; Altavilla et al., 2020).[41] Market-valuation evidence also corroborates the same mechanism: for the euro area, Ampudia and Van den Heuvel (2022) show that surprise policy-rate increases are associated with more negative bank stock price responses in fixed-rate countries, consistent with the asymmetric equity dynamics our model predicts across the two regimes.

6. Implications: monetary policy and financial stability

Section 5 focused on monetary transmission through lending. The same mechanism also has financial-stability implications. Figure 5 shows that bank failure probabilities rise in FR economies but fall in VR economies after the same monetary tightening (Panel f). This result follows from the mechanism documented above: legacy-loan NIMs drive profits, and hence equity, in opposite directions across regimes. This section studies the implications for two policy margins: the design and coordination of countercyclical capital buffers' release and the rationale for monetary policy gradualism.

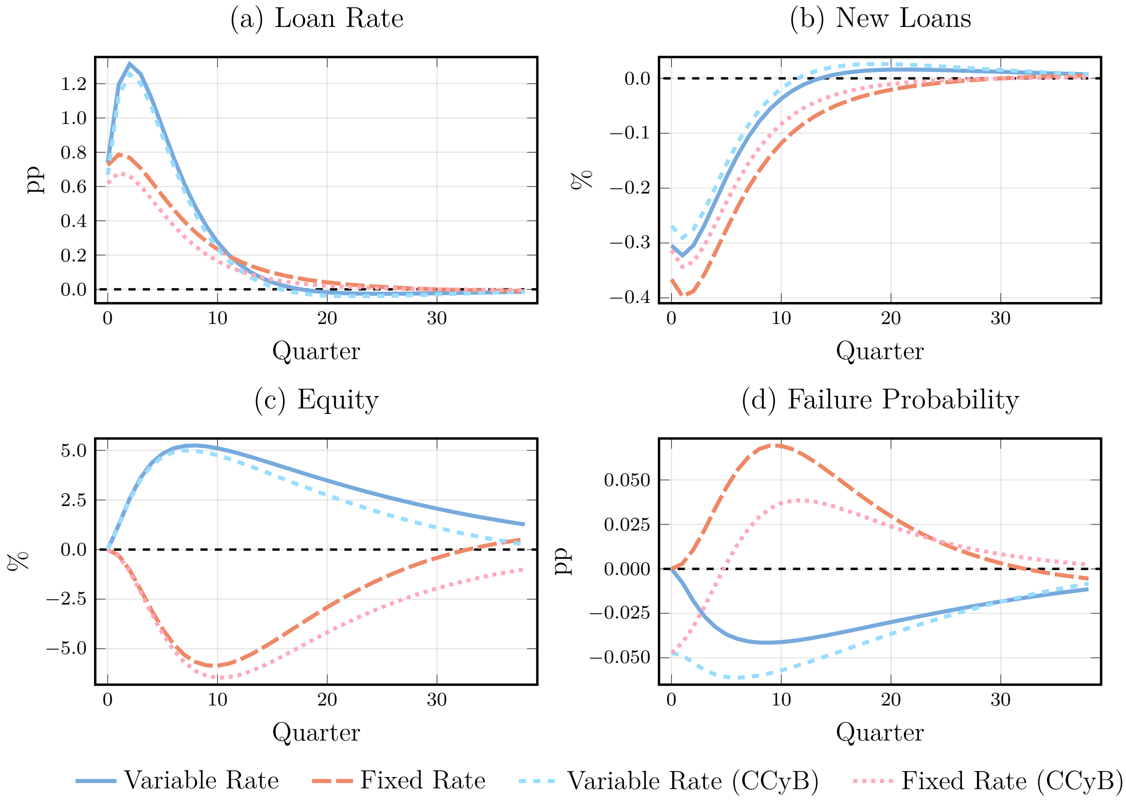
Countercyclical capital regulation. A prominent macroprudential tool is the countercyclical capital buffer (CCyB). The CCyB requires banks to build additional capital during credit expansions. The objective is to build resilience during booms and support credit supply during downturns, thereby dampening 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 and VR regimes.

We model the CCyB release as a reduction in the capital requirement γ_t, which then evolves 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 returns to its steady-state value. Figure 8 displays the impulse response functions after a monetary policy tightening in the baseline economies and under a 1 percentage point CCyB release in both economies. Blue lines correspond to the VR economy, while red lines correspond to the FR economy, with dotted and dashed lines corresponding to the CCyB counterfactual in each economy, respectively.

The temporary relaxation of capital requirements dampens the differential effects of monetary policy across banking systems. A lower capital requirement increases regulatory headroom for a given equity

41. 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. (2024) 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: Impulse response functions — Monetary tightening and 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.

position, but this has an asymmetric effect across regimes. Because equity dynamics move in opposite directions in FR and VR economies (Panel c), the banks most exposed to failure risk differ across systems: FR banks lose equity and drift toward the threshold, while VR banks gain equity and move away from it. By shifting the threshold itself, the CCyB release relaxes the relevant margin for low-capital banks in the FR regime, narrowing the gap in credit responses across the two systems (Panel b). The result is consistent with Proposition 1: as banks move farther from the solvency threshold, heterogeneous interest-rate risk exposure has weaker effects on aggregate lending.[42]

The immediate effect of the release is a reduction in failure probability on impact in both banking systems, because the same equity position implies 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 solvency threshold.

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

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 a timely capital-buffer release can narrow the divergence between banking systems. A related question is whether the *path* of monetary policy itself can achieve a similar effect. We next compare policy rate paths that deliver the same cumulative stance—measured by the area under the policy rate impulse response—but differ in their speed of implementation. The motivation for holding the cumulative stance fixed is that, in the standard three-equation New Keynesian model, paths with the same cumulative real rate gap have equivalent effects on the current output gap.[43] 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 decomposed into 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, for a one-time innovation at $t = 0$, the area under the policy rate path equals

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

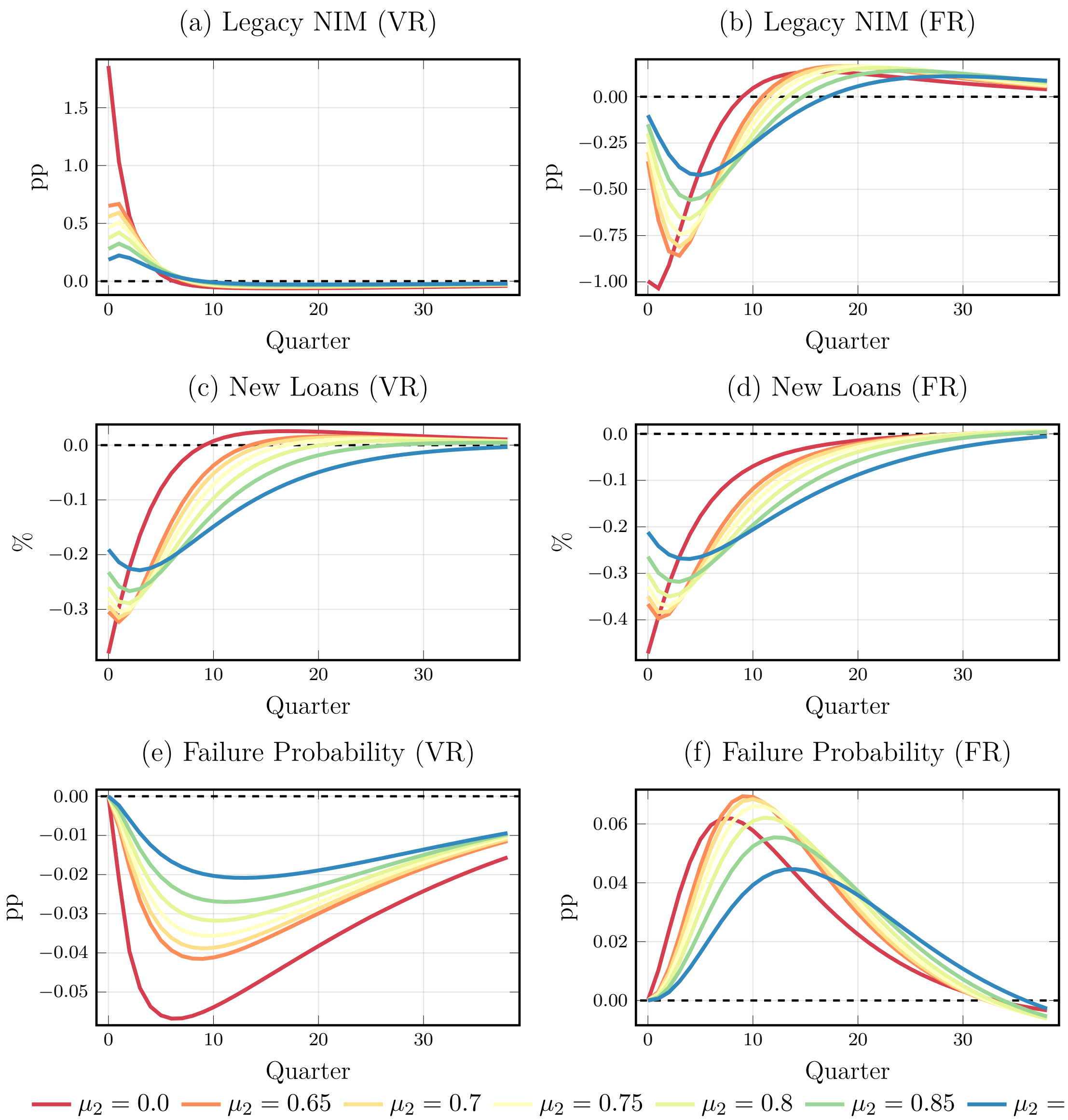
Fixing μ_1 at its baseline value, we generate more gradual policy paths with the same cumulative stance by increasing μ_2 while reducing σ proportionally, so that the area under the IRF remains unchanged.

Changing the speed of implementation affects new lending even before bank equity responds, because equilibrium loan pricing depends on the discounted value of shifted repayment paths. A second effect operates through bank capital accumulation.

To build intuition, consider first the direct pricing effect in isolation, abstracting from feedback effects coming from bank equity dynamics. In the FR economy, a more gradual rate path raises funding costs by less on impact and more later; equilibrium fixed rates on newly originated loans therefore rise by less on impact but remain elevated for longer. Since the area under the path is unchanged, new loan origination falls by less on impact but remains depressed for longer. In the VR economy, even though entrepreneurs

43. To see this, note that the three-equation New Keynesian model features an IS curve of the form $x_t = \mathbb{E}_t(x_{t+1}) - \varsigma(i_t - \mathbb{E}_t(\pi_{t+1}) - r_t^n)$, where x_t is the output gap, i_t is the nominal interest rate, π_t is the inflation rate, r_t^n is the natural rate of interest, and $\varsigma > 0$ is the intertemporal elasticity of substitution. Variables are expressed as log-linear deviations from the steady state. Iterating forward and defining the ex ante real rate gap as $\hat{r}_t \equiv i_t - \mathbb{E}_t(\pi_{t+1}) - r_t^n$, 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. We use this equivalence only as a benchmark for holding aggregate-demand pressure fixed; the quantitative exercise abstracts from inflation dynamics and focuses on the bank lending channel.

Figure 9: 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.

are forward-looking with respect to the variable rates they will pay, given their relative impatience, the present value of a back-loaded rate path is higher for them than that of a front-loaded one with the same cumulative area. New lending therefore also falls by less on impact under a more gradual path, even holding bank equity fixed.

When bank capital is allowed to respond, the pass-through to loan rates depends on equity dynamics, which differ across 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 lending (Panel d).

Gradualism gives banks more time to reduce leverag, because legacy loans mature before the full rate increase is in place. 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 increase banks' distance from the solvency threshold weaken the discount-factor and precautionary channels that make heterogeneous interest-rate risk exposure relevant for aggregate lending. 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. Buffer releases are envisaged only later, once the tightening begins to affect 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, in the model, push banks away from the solvency threshold precisely when interest-rate risk exposure generates the largest divergence across regimes. 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 only on backward-looking indicators such as the credit-to-GDP gap prescribed 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 producing a comparable increase 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. Crucially, such a strategy requires credibility: markets must believe that smaller initial moves will be followed by subsequent 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. Banks whose solvency deteriorates may face withdrawals of uninsured deposits, creating an additional feedback from equity losses to funding stress.[44]

7. Conclusion

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

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

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44. Drechsler, Savov, Schnabl, and Wang (forthcoming) formalize how rising interest rates simultaneously increase the value of the deposit franchise and the unrealized losses on long-duration assets. Their framework also prescribes gradualism. Begenau, Landvoigt, and Elenev (2026) 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 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 of the idiosyncratic loan-default-rate 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

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

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

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

where each balance-sheet item has been expressed in ratios to equity. In the quantitative implementation, this collateral condition is verified at each bank-state grid point under our baseline calibration.

A.2 Simplification of the bank's problem

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

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

with profits Π_{jt+1} defined as

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

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

$$r^L_{jt} = \frac{r^L_{jt-1}L_{jt-1} + r^N_{t-1}N_{jt-1}}{L_{jt-1}+N_{jt-1}},$$

for fixed-rate banks, and

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

for variable-rate banks with $r^L_{jt} = r^M_t + s^L_{jt}$.

The problem above implies a solvency threshold $\overline{\omega}_{jt+1} = \max\left(\min\left(\overline{\omega}^r_{jt+1}, 1\right), 0\right)$. If the realization of ω lies above the threshold $\overline{\omega}_{jt+1}$, a bank fails endogenously. We have that

$$\overline{\omega}^r_{jt+1} = \frac{E_{jt} + (1-\tau)\left[r^L_{jt}L_{jt} + r^N_t N_{jt} + r^M_t M_{jt} - r^D_t D_{jt} - r^B_t B_{jt} - f\left(\frac{N_{jt}}{L_{jt}}\right)L_{jt} - \bar{\pi}E_{jt}\right] - \gamma(1-\delta)(L_{jt}+N_{jt})}{(1-\tau)(r^L_{jt}L_{jt} + r^N_t N_{jt}) + \left[(1-\tau)\lambda - \gamma(1-\delta)\right](L_{jt}+N_{jt})}.$$

Reduction in state variables. Let lowercase variables denote ratios of stocks/flows to equity, e.g., $y_{jt} = \frac{Y_{jt}}{E_{jt}}$. Using the fact that the deposit constraint and the reserve requirement are binding in equilibrium, the problem of a bank can be written as

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

$$\text{s.t.} \quad b_{jt} = l_{jt} + n_{jt} + m_{jt} - d_{jt} - 1, \qquad \text{(Balance sheet identity)}$$

$$d_{jt} = \alpha l_{jt}, \qquad \text{(Deposits constraint)}$$

$$l_{jt+1} = (1-\omega_{jt+1})\frac{(1-\delta)(l_{jt}+n_{jt})}{g_{jt+1}}, \qquad \text{(Loans LOM)}$$

$$g_{jt+1} = 1 + (1-\tau)\pi_{jt+1}, \qquad \text{(Equity growth LOM)}$$

$$m_{jt} = \theta(d_{jt} + b_{jt}), \qquad \text{(Binding liq. requirement)}$$

with

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

$$\overline{\omega}^r_{jt+1} = \frac{1 + (1-\tau)\left[r^L_{jt}l_{jt} + r^N_t n_{jt} + r^M_t m_{jt} - r^D_t d_{jt} - r^B_t b_{jt} - f\left(\frac{n_{jt}}{l_{jt}}\right)l_{jt} - \bar{\pi}\right] - \gamma(1-\delta)(l_{jt}+n_{jt})}{(1-\tau)(r^L_{jt}l_{jt} + r^N_t n_{jt}) + \left[(1-\tau)\lambda - \gamma(1-\delta)\right](l_{jt}+n_{jt})},$$

and the failure threshold defined as before, $\overline{\omega}_{jt+1} = \max\left(\min\left(\overline{\omega}^r_{jt+1}, 1\right), 0\right)$.

A bank's decisions, therefore, depend only on its leverage l_{jt} and on the legacy-loan state x_{jt}: the average loan rate spread on legacy loans s^L_{jt} for variable-rate banks and the average loan rate on legacy loans r^L_{jt} for fixed-rate banks.

After substituting the binding constraints and the fact that $r^B_t = r^M_t$ for all t, the problem can be rewritten as

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

$$\text{s.t.} \quad l_{jt+1} = (1-\omega_{jt+1}) \frac{(1-\delta)(l_{jt} + n_{jt})}{g_{jt+1}}, \qquad \text{(Loans LOM)}$$

$$g_{jt+1} = 1 + (1-\tau)\pi_{jt+1}, \qquad \text{(Equity growth LOM)}$$

with

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

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

A.3 A microfoundation for aggregate deposit demand

This section provides a microfoundation for the deposit supply schedule used in the main text. The household problem generates demand functions for bank deposits and less liquid assets. Aggregating these demands delivers the deposit schedule faced by banks when the government supplies short-term public paper and reserves elastically at the target rates r^D_t and r^M_t.

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

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

subject to the budget constraint:

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

where X^B_t and X^E_t are dividend payouts transferred to the household by exiting banks and entrepreneurs, respectively.

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.

Household asset demand. Substituting the budget constraint into the objective function gives

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

Quasi-linearity implies that $V_t^H(A_{t-1}^H, D_{t-1}^H)$ is linear in its arguments. The first-order condition with respect to C_t yields

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

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

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

where $V_{A,t+1}^H(A,D) \equiv \frac{\partial V_{t+1}^H}{\partial A}$. The equality $r_t^M = r_t^B$ follows from perfect substitutability within the less liquid asset tier. Using the envelope theorem,

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

Substituting (A.1) evaluated at $t+1$, we have $U'\left(C_{t+1} + \ell(A_t^H, D_t^H)\right) = 1$. Thus:

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

Rearranging and using (A.1):

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

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

Proceeding analogously for deposits, we obtain:

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

where s_t^D denotes the corresponding spread for deposits.

Given (A.1), the partial derivatives are

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

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

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

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

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

Optimal quantities. The implied quantities follow by substituting the portfolio ratio back into the first-order conditions. From (A.3),

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

which can be rewritten as

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

From (A.7), we have:

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

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

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

Similarly, the demand for deposits satisfies:

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

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

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

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

Market clearing in the deposit market requires:

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

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

Market clearing in the reserve market requires:

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

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

The government and central bank choose supplies of short-term public paper and reserves, $\{D_t^S, M_t^S\}$, to implement the paths for r_t^D and r_t^M. Under this implementation, quantities adjust to clear markets at those rates. Banks therefore face a perfectly elastic deposit supply schedule at r_t^D.

A.4 Microfoundation for the asset structure

This appendix introduces explicit government bond markets and money market funds (MMFs) to provide microfoundations for the reduced-form asset structure in the main text. We suppress the time subscript in this subsection. The main text writes the household bond tier as $A^H = B^H + M^H$, where M^H is a reduced-form policy-rate government claim. In the richer structure below, this object is represented by household holdings of long-term government bonds, B^{hg}; households do not directly hold central bank reserves.

The richer structure has three components:

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 pledge or exchange long-term government bonds B^{bg} one-for-one for reserves M at the central bank.

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

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

Both M and B^{bg} earn the policy rate r^M. The position B^{bg} is the government-bond position that supports reserve creation through the central bank facility. This arbitrage condition ensures that banks are indifferent between holding reserves directly or holding government bonds that can be converted to reserves.[45]

Households. Households allocate wealth across two categories of assets: (i) highly liquid assets that earn r^D and provide liquidity services,

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

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

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

where B^H is bank wholesale debt and B^{hg} are long-term government bonds. Thus, B^{hg} is the extended-structure counterpart of the reduced-form policy-rate claim M^H in the main text.

The household problem yields static demand functions:

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

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

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

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

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 identity implies $S^g = D^S$.

Government. The government budget constraint is

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

Market-clearing conditions for bond markets Long-term bonds:

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

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

Short-term bonds:

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

held entirely by MMFs.

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

A.5 Derivation of the 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 at time t when the decision to issue new loans is taken.[46] 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 government budget constraint:

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

46. For simplicity, we omit the subscript j in the derivations in this section.

where

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

The expression for the mass of failing banks $\bar{\mathscr{F}}_{t-1}$ is derived in Appendix A.10.

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:

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

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:

$$
\begin{aligned}
\tau\Pi_t^B - \Theta_t &= \tau \int\int_0^{\bar{\omega}} \pi_t(l,x,\omega) E\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,E) \\
&\quad + \int\int_{\bar{\omega}}^{1} \left[g_t(l,x,\omega) + \tau\pi_t(l,x,\omega)\right] E\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,E) \\
&= \tau \int\int_0^{1} \pi_t(l,x,\omega) E\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,E) \\
&\quad + \int\int_{\bar{\omega}}^{1} g_t(l,x,\omega) E\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,E).
\end{aligned}
$$

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

$$
\begin{aligned}
E_t + X_t^B - \Xi_t &= (1-\chi)\int\int_0^{\bar{\omega}} g_t(l,x,\omega) E dF(\omega) dH_t(l,x,E) + \bar{\mathscr{F}}_{t-1}\bar{E}_t \\
&\quad + \chi \int\int_0^{\bar{\omega}} g_t(l,x,\omega) E\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,E) - \bar{\mathscr{F}}_{t-1}\bar{E}_t \\
&= \int\int_0^{\bar{\omega}} g_t(l,x,\omega) E\,\mathrm{d}F(\omega)\mathrm{d}H_{t-1}(l,x,E).
\end{aligned}
$$

Combining the last two expressions yields:

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

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

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

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:

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

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

Substituting this expression into the budget constraint yields

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

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

$$C_t + C_t^H + L_t + N_t = L_{t-1} + N_{t-1} + X_t^E - (1-\tau)\Pi_t^E + +Y_t - RC_t,$$

Aggregating the entrepreneurial wealth law of motion (10) while accounting for dividend payouts and failures yields

$$W_{t+1} = (1-\tilde{\chi})\left(\left[1 + (1-\tau) r_t^E\right] W_t + (1-\tau)\Pi_{t+1}^E\right),$$

with dividend payouts being

$$X_{t+1}^E = \tilde{\chi}\left(\left[1 + (1-\tau) r_t^E\right] W_t + (1-\tau)\Pi_{t+1}^E\right).$$

Using these expressions and $r_t^E = 0$, we can write

$$\begin{aligned}
X_t^E - (1-\tau)\Pi_t^E &= \tilde{\chi}\left(W_{t-1} + (1-\tau)\Pi_t^E\right) - (1-\tau)\Pi_t^E \\
&= \tilde{\chi} W_{t-1} - (1-\tilde{\chi})(1-\tau)\Pi_t^E \\
&= W_{t-1} - (1-\tilde{\chi}) W_{t-1} - (1-\tilde{\chi})(1-\tau)\Pi_t^E \\
&= W_{t-1} - W_t
\end{aligned}$$

Therefore, we can write the resource constraint as

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

and output is used for consumption, investment in entrepreneurs' projects, accumulation of entrepreneurial wealth, 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 is the amount of new loans made by banks net of projects that end through maturity, default, or liquidation following bank resolution or exit.

A.6 Derivation of the loan-liquidation probability

As in Appendix A.5, 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^{exit}_{t+1} is given by

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

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^s_{t+1}

$$l^s_{t+1} = \frac{\int\int_0^{\bar{\omega}}(1-\omega)(1-\delta)\frac{l+n_t(l,x)}{g_{t+1}(l,x)}\mathrm{d}F(\omega)\mathrm{d}H_t(l,x,E)}{\int F(\bar{\omega})\mathrm{d}H_t(l,x,E)}$$

and the mass of banks exiting or failing banks $\bar{\mathscr{F}}_t$ derived in Appendix A.10, we can write the aggregate loan portfolio of entering banks L^{entry}_{t+1} as

$$L^{entry}_{t+1} = \bar{\mathscr{F}}_t l^s_{t+1}\bar{E}_{t+1}$$

The aggregate law of motion of loans is then given by

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

where we implicitly defined the loan liquidation probability as

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

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) banks remain sufficiently well capitalized along the paths being compared that the insolvency threshold never affects continuation values; (iii) there is therefore no endogenous bank failure in either economy along those paths; and (iv) the FR and VR economies face the same exogenous sequences $\{r^M_t, r^D_t\}_{t\ge0}$.

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

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

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, and the equilibrium condition $r^M_t = r^B_t$ for all t, bank profits can be written compactly as

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

where

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

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. Dividing by $\Omega^B_{t,0}$ and using $\Psi_t = (1-p) r^N_t - \lambda p - r^M_t$ gives

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

where

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

and

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

The object Γ_t has no bank subscript in the benchmark because all banks face the same prices, deterministic default rate, funding costs, and adjustment-cost technology. With strictly convex origination costs, the bank first-order condition pins down a unique new-lending-to-legacy-loan ratio; in the definition of Γ_t, N_{t+m}/L_{t+m} denotes this common ratio. Thus the non-repayment components collected in Γ_t are common across banks and across contract regimes in the benchmark comparison, as shown below.

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

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

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

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda_{t,m}^B r_{t+m}^M}{\sum_{m=0}^{\infty} \Lambda_{t,m}^B}. \tag{A.22}$$

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

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

$$\Omega_{t,m}^E = (1-\tau) \sum_{k=m}^{\infty} \beta^{k+1} (1-\tilde{\chi})^k \tilde{\chi} \left(\prod_{q=m+1}^{k} \Upsilon_{t+q}^E \right), \qquad \Upsilon_t^E \equiv 1 + (1-\tau) r_t^E, \tag{A.23}$$

and the corresponding effective discount factors 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

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Lambda_{t,m}^E r_{t+m}^M}{\sum_{m=0}^{\infty} \Lambda_{t,m}^E}. \tag{A.24}$$

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

$$\frac{\Lambda_{t,m}^E}{\Lambda_{t,0}^E} = \frac{\Lambda_{t,m}^B}{\Lambda_{t,0}^B} \qquad \text{for all } m \geq 0. \tag{A.25}$$

This is the ratio form of the main-text condition: there exists a scalar $c_t > 0$ such that $\Lambda_{t,m}^E = c_t \Lambda_{t,m}^B$ for all horizons m.

A primitive sufficient set of restrictions is: $\Upsilon_t^E = \Upsilon_t^B$ for all t and symmetric payout hazard rates for banks and entrepreneurs $\chi = \tilde{\chi}$.[47] 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 discount-factor sequences are proportional. Under $r_t^B = r_t^M$, primitive restriction $\Upsilon_t^E = \Upsilon_t^B$ implies

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

47. The equality $\chi = \tilde{\chi}$ is an auxiliary condition for aligning bank and entrepreneur valuation horizons in this benchmark. In the quantitative model, $\tilde{\chi}$ is the net loan-liquidation hazard implied by bank entry and exit: because entrants inherit part of the surviving loan portfolio of exiting or resolved banks, $\tilde{\chi}$ is generally below the bank exit hazard χ. Imposing $\chi = \tilde{\chi}$ while preserving positive inherited legacy loans would require an additional source of legacy loans for entrants, or an explicit replacement convention in which new entrepreneurs take over active projects from exiting entrepreneurs. The benchmark should therefore be read as an auxiliary environment for the irrelevance result rather than as imposing the full quantitative entry accounting.

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

□

A.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 $\phi^x_{j,t+i} = 1 - F(\bar{\omega}^x_{j,t+i})$ denote the probability that bank j fails in period $t+i$ in regime x, and define the cumulative survival probability

$$S^x_{j,t,k} \equiv \prod_{i=1}^{k} (1 - \phi^x_{j,t+i}).$$

For any horizon $k \geq 0$, let $\tilde{\mathbb{E}}^x_{j,t,k}[\cdot]$ denote expectations in regime $x \in \{FR, VR\}$ conditional on the date-t bank state and on endogenous survival through period $t+k+1$, that is, conditional on $\{\omega_{j,t+i} \leq \bar{\omega}^x_{j,t+i}\}_{i=1}^{k+1}$. Using this notation, the bank's value can be written as

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

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

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

where $\mathscr{R}^x_{j,t}$ collects the boundary terms generated by the dependence of future insolvency thresholds on current lending. We use the sign convention that a positive $\mathscr{R}^x_{j,t}$ raises the marginal cost of new lending. Under the maintained assumptions, additional lending raises future leverage and weakly lowers future solvency thresholds, so the boundary contribution is weakly positive when the threshold binds with positive density. The object

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

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

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

where $\tilde{\omega}^x_{j,t+1} \equiv \tilde{\mathbb{E}}^x_{j,t,0}[\omega_{j,t+1}]$ 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. Since wholesale debt and reserves earn the same rate, $r^B_t = r^M_t$, then $\mu_t = r^M_t$.

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

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

The product over $i = 1,\dots,m$ tracks the survival of the marginal loan from origination at t through horizon m, while the leading term $1-\omega_{j,t+m+1}$ is the performing share of the loan cash flow received at horizon m. If default risk is deterministic, $\omega_{j,t+i} = p$, then $\tilde{\varrho}^x_{j,t,m} = (1-p)^{m+1}(1-\delta)^m$, matching the benchmark effective repayment term. For $m = 0$, the same convention gives $\tilde{\varrho}^x_{j,t,0} = 1-\tilde{\omega}^x_{j,t+1}$. Let

$$\Phi_{t+m}(\omega) \equiv \alpha(r^B_{t+m} - r^D_{t+m}) - \lambda\omega - \mu_{t+m},$$

$$\mathscr{C}\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right) \equiv f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right).$$

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

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

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:

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

where

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

and

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

The object $\Xi^x_{j,t}$ is the idiosyncratic-risk counterpart to the benchmark term Γ_t. It is bank- and regime-specific because it inherits the bank's survival probabilities, expected credit losses, marginal funding costs, future nonprice payoff terms, and the boundary term $\mathscr{R}^x_{j,t}$.

The decomposition highlights the two channels emphasized in Section 3.3. 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 leverage and hence 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 Portfolio credit risk

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

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

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

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

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

For $0 < \rho < 1$, the law of large numbers implies that the loan-portfolio default rate ω_{jt+1}, defined as the fraction of loans in bank j's portfolio that default, coincides with the conditional default probability of a representative loan given the bank factor z_{jt+1}:

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

Solving this expression for the bank factor gives the inverse threshold

$$z(\omega) = \frac{\Phi^{-1}(p) - \sqrt{1-\rho}\Phi^{-1}(\omega)}{\sqrt{\rho}}.$$

Since $\omega(z)$ is decreasing in z, the CDF of the loan-portfolio default rate is

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

The displayed CDF is therefore the Vasicek distribution for $0 < \rho < 1$. The endpoints are understood as limits: as $\rho \downarrow 0$, idiosyncratic loan risk diversifies away and the portfolio default rate collapses to the constant p; as $\rho \uparrow 1$, the project-idiosyncratic factor vanishes and defaults are perfectly correlated within each bank.

A.10 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:

$\omega > \bar{\omega}$ and $\iota = 1$ → Exogenous Exit (Bank resolution mechanism),

$\omega \le \bar{\omega}$ and $\iota = 1$ → Exogenous Exit (Regular) ,

$\omega > \bar{\omega}$ and $\iota = 0$ → Endogenous Failure,

$\omega \le \bar{\omega}$ and $\iota = 0$ → Continues Operating.

A bank's equity at $t+1$ is a function of states (l_{jt}, x_{jt}, E_{jt}) at time t and shocks (ω, ι) at $t+1$.[48] We can write the law of motion of equity as

$$
\begin{aligned}
E_{jt+1}(l_{jt}, x_{jt}, E_{jt}, \omega, \iota) = {} & \mathbf{1}_{\{\omega \le \bar{\omega}, \iota = 0\}} g_{t+1}(l_{jt}, x_{jt}, \omega) E_{jt} \\
& + \mathbf{1}_{\{\omega > \bar{\omega}, \iota = 0\}} \bar{E}_{t+1} \\
& + \mathbf{1}_{\{\omega \le \bar{\omega}, \iota = 1\}} \bar{E}_{t+1} \\
& + \mathbf{1}_{\{\omega > \bar{\omega}, \iota = 1\}} \bar{E}_{t+1} \, .
\end{aligned}
$$

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

$$
\begin{aligned}
E_{jt+1}(l_{jt}, x_{jt}, E_{jt}, \omega, \iota) = {} & \mathbf{1}_{\{\omega \le \bar{\omega}\}} \mathbf{1}_{\{\iota = 0\}} g_{t+1}(l_{jt}, x_{jt}, \omega) E_{jt} \\
& + \left[\mathbf{1}_{\{\omega > \bar{\omega}\}} \mathbf{1}_{\{\iota = 0\}} + \mathbf{1}_{\{\omega \le \bar{\omega}\}} \mathbf{1}_{\{\iota = 1\}} + \mathbf{1}_{\{\omega > \bar{\omega}\}} \mathbf{1}_{\{\iota = 1\}} \right] \bar{E}_{t+1} \, ,
\end{aligned}
$$

where

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

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

Integrating over the Bernoulli distribution for ι yields

$$
\begin{aligned}
\int_0^1 E_{jt+1}(l_{jt}, x_{jt}, E_{jt}, \omega, \iota) dX(\iota) = {} & (1 - \chi) \mathbf{1}_{\{\omega \le \bar{\omega}\}} g_{t+1}(l_{jt}, x_{jt}, \omega) E_{jt} \\
& + \left[\mathbf{1}_{\{\omega > \bar{\omega}\}} + \chi \mathbf{1}_{\{\omega \le \bar{\omega}\}} \right] \bar{E}_{t+1} \, .
\end{aligned}
$$

Integrating over ω yields

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

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

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

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

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

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

$$G_t = \frac{1}{E_t}\int \bar{g}_{t+1}(l_{jt}, x_{jt}) E_{jt}\, dH_t(l_{jt}, x_{jt}, E_{jt}), \text{ and}$$

$$\bar{\mathscr{F}}_t = \int \left[1-(1-\chi)F(\bar{\omega})\right] dH_t(l_{jt}, x_{jt}, E_{jt}).$$

B. Empirical Appendix

B.1 CET1 capital ratios and buffers

Table B.1: Average CET1 ratios and buffers for euro area banks

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

Source: Regulatory requirements (G-SII, O-SII, SRB) are from the European Systemic Risk Board (ESRB). Pillar 2 CET1 requirements data are from ECB supervisory reports. Bank-level CET1 ratios and total risk-weighted assets are from S&P Global. *Note:* All numbers are in percentages. The first two columns correspond to the cross-sectional means of the centered distribution grouped over 2013–2020. *All banks* refers to all euro area banks in our sample, approximately 70 banks per quarter on average. *Large banks* refers to banks with total assets above EUR 100 billion. *Supervised banks* refers to significant institutions directly supervised by the ECB, 64 in our 2021.Q4 sample.

Table B.1 reports the cross-sectional average CET1 capital ratios and voluntary capital buffers for different groups of euro area banks.

The first two columns present averages from the pooled bank-quarter distribution for 2013–2020. Because CET1 ratios trend upward during the implementation of Basel III, we remove quarter fixed effects from each bank's CET1 ratio and buffer and recenter the pooled distribution using the 2019 cross-sectional mean. This centered distribution is the empirical object used in the calibration comparison. We construct the unbalanced bank-level panel using balance-sheet data from S&P Global, a proprietary source. The 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.

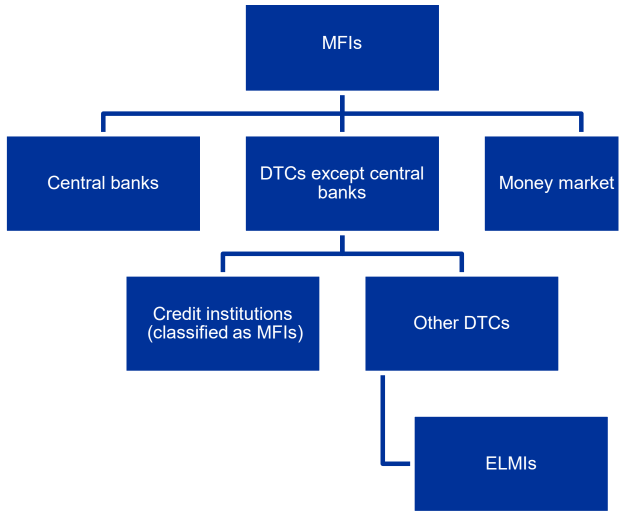
The third column presents CET1 ratios and capital buffer estimates for a sample of significant institutions directly supervised by the ECB as of 2021.Q4, as reported by the European Banking Authority (EBA). These estimates incorporate bank-specific Pillar 2 requirements for CET1 capital in addition to the combined buffer requirements. The average CET1 capital buffer is slightly lower once Pillar 2 requirements are included, but the overall distribution retains a similar shape and dispersion.

B.2 Euro area MFIs balance sheet

This section documents how we construct the empirical balance-sheet moments used in the calibration. We start from the ECB consolidated balance sheet of euro area monetary financial institutions (MFIs), excluding the Eurosystem,[49] and map its asset and liability categories into the model's balance-sheet objects: loans, liquid assets, deposits, wholesale funding, and equity. After excluding the Eurosystem, the relevant MFI sector consists of deposit-taking institutions and money market funds (MMFs).

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

Figure B.1: Components of the MFI sector



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

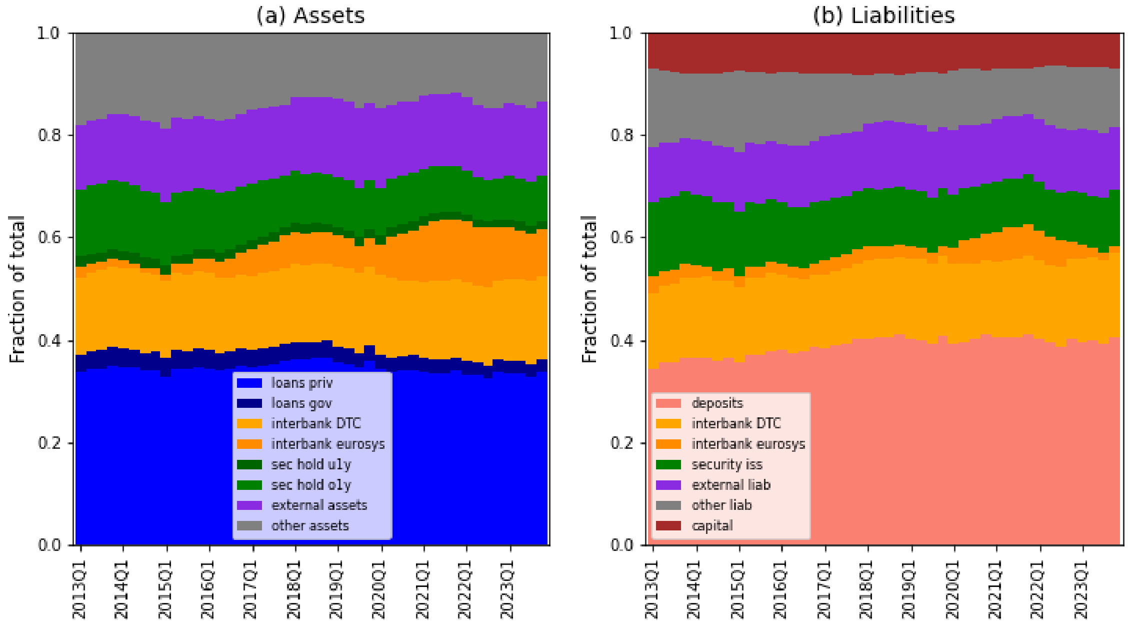
The balance-sheet data are from the ECB Balance Sheet Items (BSI) dataset, accessed through the ECB Data Portal.[50] We use monthly or quarterly BSI series, subject to availability, and transform all series to quarterly frequency. The period of analysis is 2013.Q1 to 2023.Q4.[51] Our sample begins in 2013 to ensure comparability across the publicly available ECB datasets and with our proprietary bank-level data from S&P Global, whose coverage also starts in 2013. The balance-sheet construction uses the following BSI series:

- Consolidated balance sheet of the MFIs, excluding the Eurosystem: https://data.ecb.europa.eu/publications/money-credit-and-banking/3031821
- MFI holdings of securities by maturity and instrument type: 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

50. See https://data.ecb.europa.eu/data/datasets/BSI/data-information.

51. We cannot distinguish MMFs from deposit-taking institutions for the entire time series. This does not materially affect the balance-sheet aggregates because MMFs are small relative to deposit-taking institutions. In 2024.Q2, for instance, MMF assets were EUR 1.8 trillion, less than 5% the size of deposit-taking institutions' assets.

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



Source: ECB Balance Sheet Items (BSI) dataset, accessed through the ECB Data Portal. Consolidated balance sheet of euro area monetary financial institutions (MFIs) excluding the Eurosystem. MFIs comprise deposit-taking corporations, money market funds, and central banks.

Figure B.2 shows that the asset composition of euro area MFIs is stable over the sample. On average, loans to households, firms, and the government account for 62% of assets. Interbank loans—which include repurchase agreements (repos), securities lending, and similar operations with other MFIs and national central banks—account for about 15% of assets. Security holdings, both short- and long-term, account for the remaining 23%.[52] On the liability side, deposits account for 63% of assets, interbank deposits for 15%, security issuance for 14%, and capital and reserves for 8%.[53] Table B.2 reports the underlying composition.

B.3 Loan pricing classification

We define variable-rate loans as contracts with a maturity of over one year and an interest rate that resets within the next 12 months.[54] Figure B.3 shows the share of variable-rate lending separately for credit to

52. 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 being identified separately.

53. This consolidated measure of capital and reserves does not coincide with the regulatory capital that is measured in Appendix B.1, namely Common Equity Tier 1 (CET1) capital expressed as a percentage of risk-weighted assets.

54. Approximating the share of variable-rate loans using loans with maturities of up to one year yields similar results and leaves the ten-country classification unchanged. The classification is also robust to reasonable changes in the 50% cutoff because none of the baseline countries is close to that threshold. The categorization in Figure B.3 is also consistent with the findings of Core et al. (2025), who use granular data on non-financial corporate loans in the euro area.

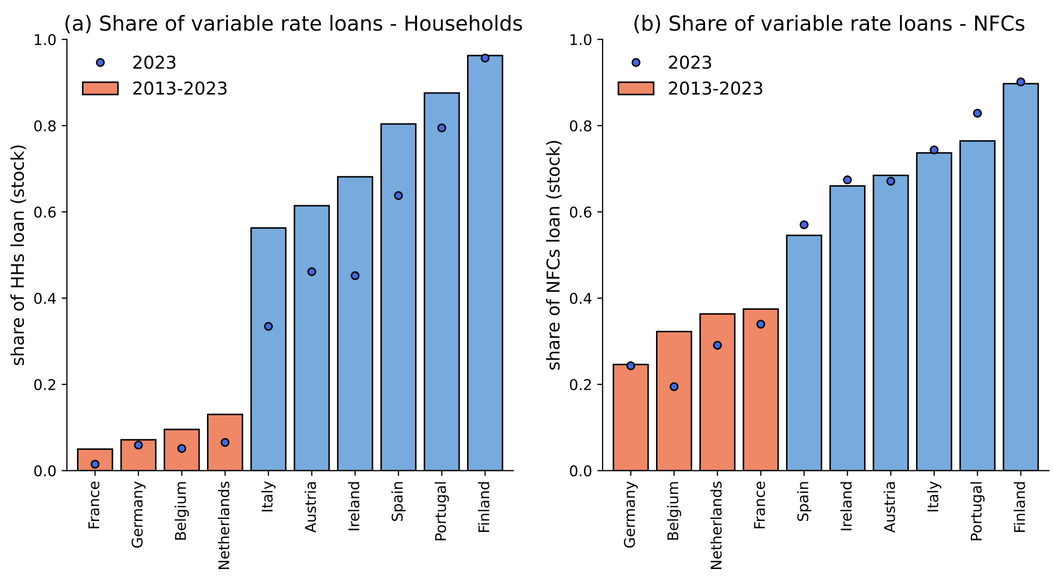
Table B.2: MFIs balance sheet composition (2013–2023)

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 Balance Sheet Items (BSI) dataset, accessed through the ECB Data Portal. Consolidated balance sheet of euro area MFIs, excluding the Eurosystem. *Note:* Time-series averages are computed over 2013–2023. *Loans* include loans to the private sector, loans to the general government, and 85% of external assets and other assets. *Interbank loans* include interbank loans with other deposit-taking corporations (DTCs). *Short-term security holdings* include securities with a maturity of less than one year and operations with national central banks (repos and securities lending). *Long-term security holdings* include securities with a maturity greater than one 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 operations with national central banks. *Capital* refers to a broad category of items treated as MFI equity, comprising equity issued to shareholders, profit or loss for the period, undistributed earnings, and provisions for anticipated future obligations.

households and non-financial corporations, using the ECB BSI dataset. The bars display averages for the reference period, 2013–2023. For most countries, these averages are close to the 2023 values shown by blue circles, indicating persistent cross-country differences in loan-pricing practices.

Figure B.3: Share of variable-rate lending by borrower sector



Source: ECB Balance Sheet Items (BSI) dataset, accessed through the ECB Data Portal. *Note:* The left panel presents the share of outstanding lending to households, including mortgage loans, consumer loans, and other loans, issued at variable rates. The right panel presents the share of outstanding lending to non-financial corporations (NFCs) issued at variable rates. Bars display averages for 2013–2023. Orange bars correspond to our fixed-rate country classification; blue bars correspond to variable-rate countries. Blue circles show the average for the year 2023.

B.4 Estimating local projections

We estimate local projections following 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, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal, and Spain), because this sample provides a balanced panel without data gaps. Variables include loan and deposit rates, net interest margin (NIM) rates, lending volumes, capital and equity ratios, and macroeconomic indicators, including inflation, GDP growth, and employment, among others, from 2003 to 2019.[55] Interest rates are from the ECB MIR dataset, and lending volumes are from the ECB BSI dataset. Macroeconomic controls are from ECB and Eurostat series. NIM is measured as the average rate on outstanding loans minus the average rate on outstanding deposits, matching the empirical counterpart used in Figure 4. All variables are consolidated at the country level and sampled quarterly.

Countries are classified as variable-rate (VR) if their share of variable-rate lending exceeds 50% and as fixed-rate (FR) otherwise. In the ten-country baseline, the VR countries are Austria, Finland, Ireland, Italy, Portugal, and Spain; the FR countries are Belgium, France, Germany, and the Netherlands. Appendix B.5 presents robustness checks for the extended sample of 20 euro area countries and for a restricted sample that excludes a set of Southern European countries. The qualitative ranking of the IRFs is unchanged.

Interest rates. We estimate the following local projection specification:

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

where $r_{c,t+h}$ denotes the variable of interest (lending rates, deposit rates, NIM rates) for country c at time t and horizon h, with $h = 0, \ldots, 16$ quarters. The variable ε_t^{MP} denotes the change in the deposit facility rate (DFR) at time t, instrumented in a first stage with the *monetary policy component* of Jarociński and Karadi (2020), aggregated to quarterly frequency.[56] The dummy I_c^{FR} equals one for FR countries. IRFs are normalized to a 100-basis-point monetary tightening.

$X_{c,t}$ denotes the set of controls. We include the first lag of the dependent variable and the first lag of the DFR. We control for the zero-lower-bound periods by including a dummy variable for the relevant quarters. We also include contemporaneous and lagged inflation, the quarterly growth rate of industrial production, the first lag of the yield on a euro area BBB corporate bond index, and the first lag of the yield on the one-year German government bond.

55. For most euro area countries, interest-rate data are consistently available through the ECB MFI Interest Rate Statistics (MIR) dataset starting in 2003. See https://data.ecb.europa.eu/data/datasets/MIR/data-information.

56. Jarociński and Karadi (2020) decompose high-frequency monetary policy surprises around central bank announcement windows into two structural shocks: a monetary policy (MP) shock and a central bank information (CBI) shock. The decomposition is obtained from a structural VAR estimated on monthly data, identified by sign restrictions on the co-movement of interest rates and stock prices. The authors produce two estimates, imposing weak and strong sign restrictions. Under the *strong* sign restrictions, each month is classified as either an MP shock or a CBI shock. Under the *weak* sign restrictions, each month is a combination of the two shocks, with generally non-zero shares. We estimate the local projections under both identifications and find that the results are qualitatively unchanged; the main text reports the estimates based on the weak sign restrictions.

Quantities. For lending volumes, we estimate

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

For these specifications, ϵ_t^{MP} is the monetary policy component from Jarociński and Karadi (2020), aggregated to quarterly frequency and used directly rather than as an instrument for the DFR. This specification keeps the lending-volume responses tied to the high-frequency surprise series and avoids adding a policy rate regressor to the quantity equation; all reported responses are scaled to a 100-basis-point tightening. The control vector is the same as in the interest-rate specification, with real activity variables expressed in logarithms: the first lag of the dependent variable, contemporaneous and lagged HICP, the log of the industrial production index, the first lag of the yield on a euro area BBB corporate bond index, and the first lag of the yield on the one-year German government bond.

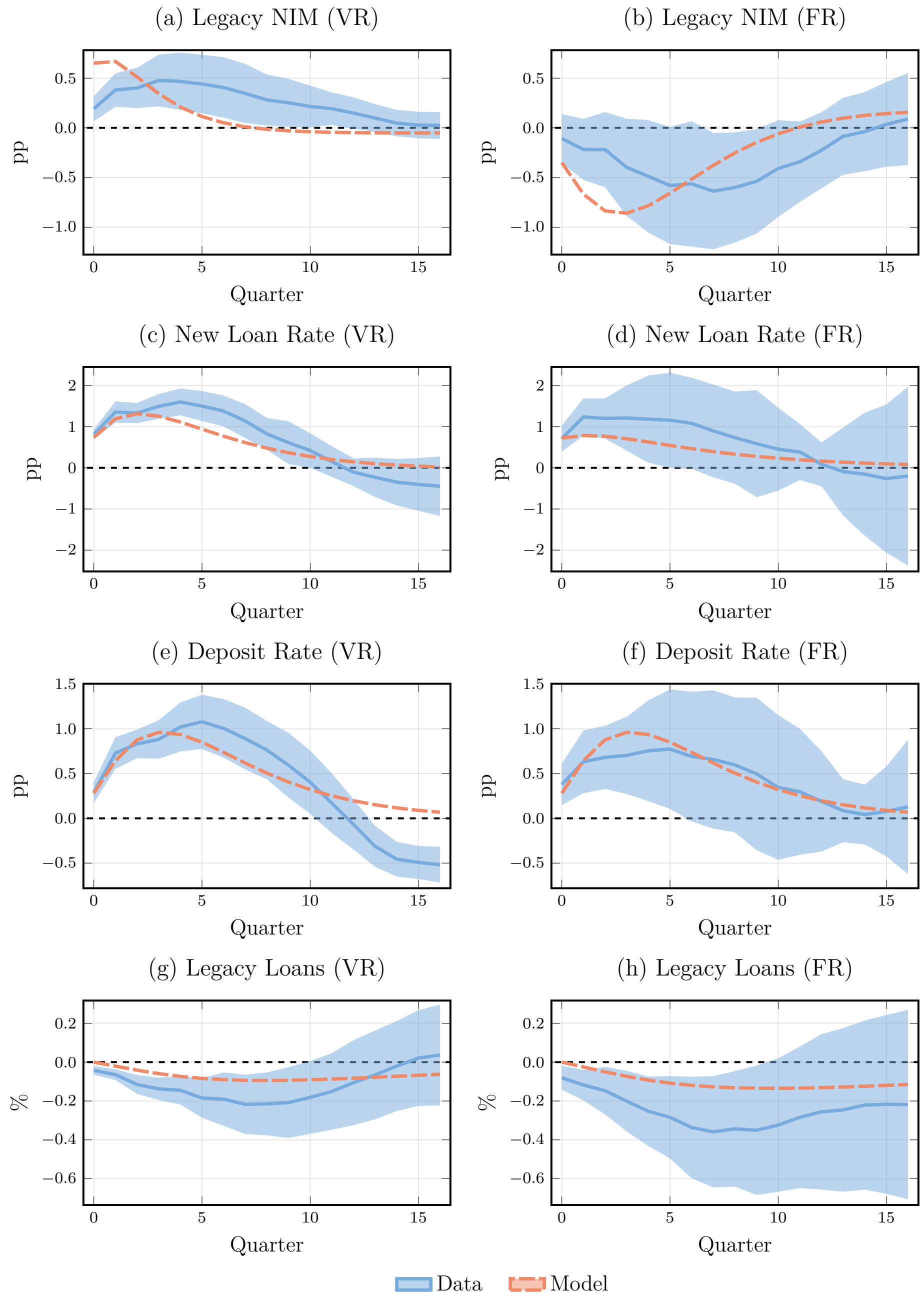
Figure 4 in the main text reports the estimated IRFs for interest rates, NIMs, and lending volumes. Because VR countries are the omitted group, the left panels plot $\{\beta_{1h}\}_{h=0}^{16}$, which shows the average response across VR countries. The right panels plot $\{\beta_{1h} + \beta_{2h}\}_{h=0}^{16}$, which shows the average response across FR countries. Solid blue lines report point estimates and light blue bands report 95% confidence intervals.

B.5 Robustness for local projections

Panel of 20 euro area countries. Figure B.4 presents robustness estimates for the extended sample including 20 euro area countries for the period 2003–2019. Belgium, France, Germany, the Netherlands, and Slovakia are classified as FR countries. Austria, Croatia, Cyprus, Estonia, Finland, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Portugal, Slovenia, and Spain are classified as VR countries. Figure B.5 presents the estimates for the extended period 2003–2023, for the same set of countries.

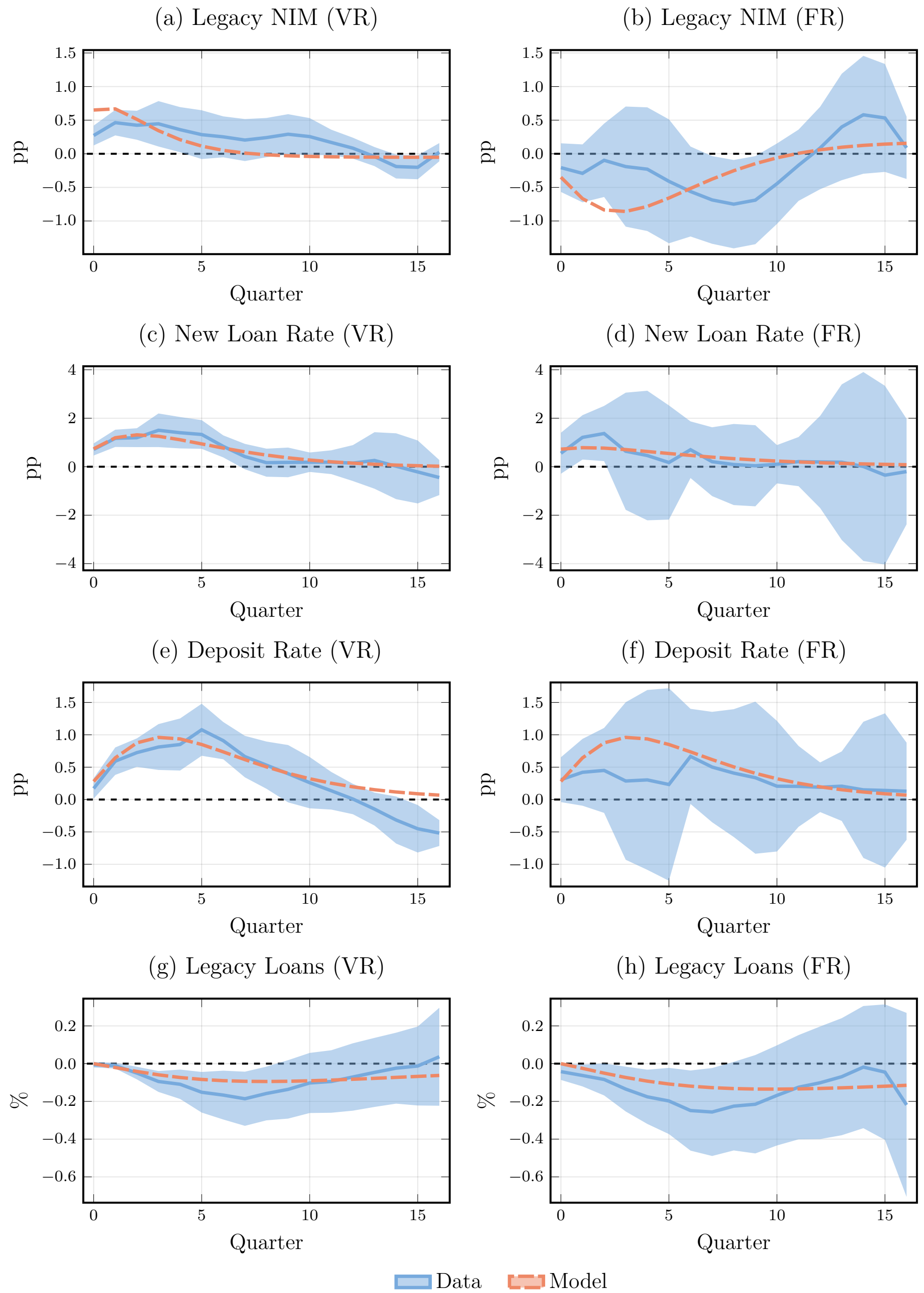
Panel of 20 euro area countries excluding periphery countries. Figure B.6 shows that the estimated empirical responses are not driven by a core-periphery classification. We present robustness estimates for 2003–2019 excluding a set of periphery countries: Italy, Ireland, Portugal, and Spain. This exclusion reduces the set of countries categorized as VR to Austria, Croatia, Cyprus, Estonia, Finland, Greece, Latvia, Lithuania, Luxembourg, Malta, and Slovenia. The set of FR countries is Belgium, France, Germany, the Netherlands, and Slovakia.

Figure B.4: Untargeted impulse responses. Panel of 20 euro area countries, period 2003–2019.



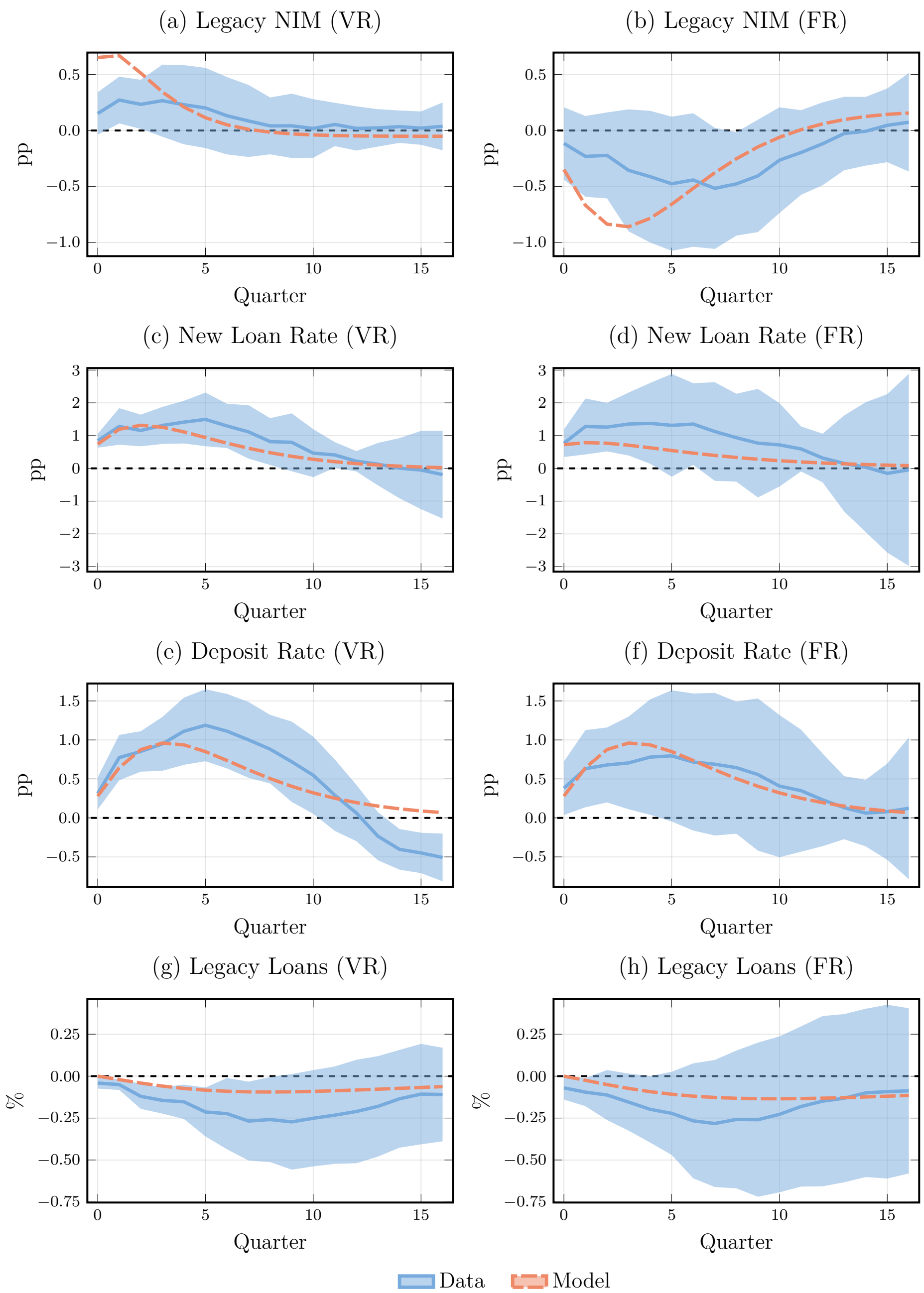
Note: Solid blue lines show the empirical impulse responses to a monetary policy shock; dashed red lines show the model counterparts. Light blue bands show the 95% confidence intervals. Left panels report responses for VR countries; right panels report responses for FR countries in the data and in the model. See Appendix B.4 for estimation details.

Figure B.5: Untargeted impulse responses. Panel of 20 euro area countries, period 2003–2023



Note: Solid blue lines show the empirical impulse responses to a monetary policy shock; dashed red lines show the model counterparts. Light blue bands show the 95% confidence intervals. Left panels report responses for VR countries; right panels report responses for FR countries in the data and in the model. See Appendix B.4 for estimation details.

Figure B.6: Untargeted impulse responses. Panel excluding periphery euro area countries, period 2003–2019.

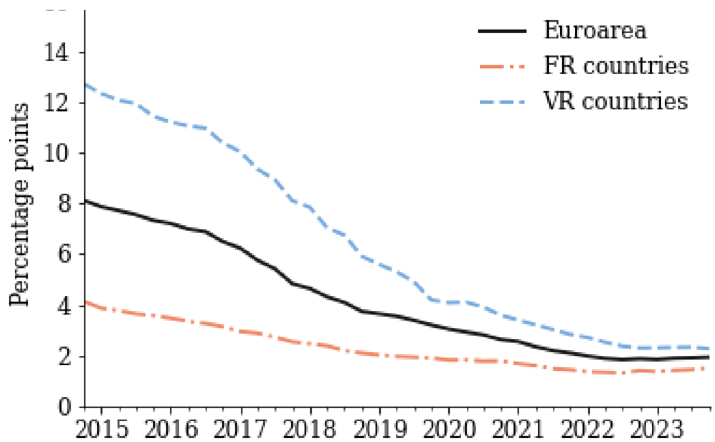


Note: Solid blue lines show the empirical impulse responses to a monetary policy shock; dashed red lines show the model counterparts. Light blue bands show the 95% confidence intervals. Left panels report the response for VR countries; right panels report the response for FR countries in the data and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

B.6 Credit risk in the euro area

This section examines credit-risk dynamics across euro area countries using time-series data on non-performing loans (NPLs) from the ECB's Consolidated Banking Data (CBD2) dataset. The descriptive series covers 2014.Q4–2023.Q4.[57] As before, we focus on the ten largest euro area economies, grouped by their share of variable-rate lending. The FR countries include Belgium, France, Germany, and the Netherlands; the VR countries include Austria, Finland, Ireland, Italy, Portugal, and Spain.

Figure B.7: Average non-performing loans (NPLs).



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

Figure B.7 shows average NPL ratios across FR countries, VR countries, and the euro area. VR countries have higher NPL ratios early in the sample, but their NPL ratios decline over the decade and converge toward the levels observed in FR countries. Using granular credit registry data, Core et al. (2025) document higher default probabilities on variable-rate non-financial corporate loans than on fixed-rate loans in the euro area. Bandoni, Fourne, and Jarmulska (2025) document a similar decline in mortgage default rates in a sample of securitized mortgages in Ireland, Italy, Portugal, and Spain.[58]

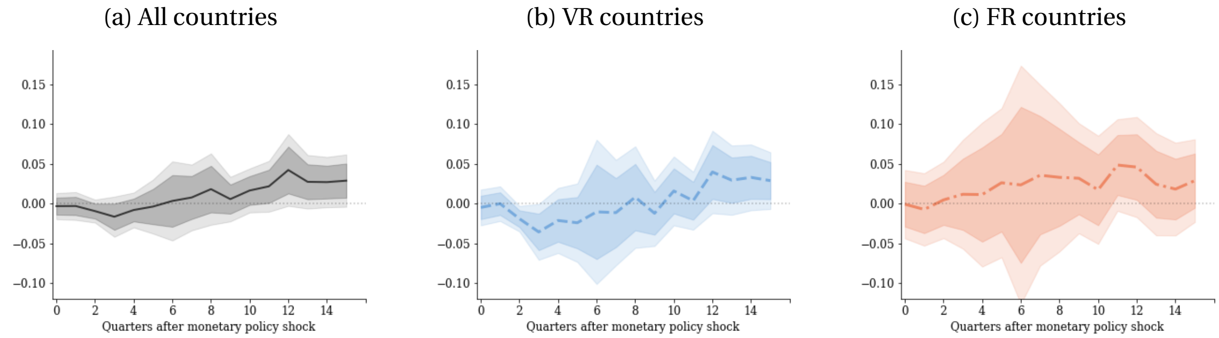
Figure B.8 shows local-projection responses of NPL ratios to a monetary shock, estimated with the same country classification and control set as in Appendix B.4. The shock is the monetary policy component from Jarociński and Karadi (2020), normalized to a 100-basis-point tightening. Panels (a), (b), and (c) show responses for VR countries, FR countries, and all countries, respectively. The responses do not differ significantly across country groups.[59]

57. The country-level NPL ratio is available in CBD2 starting in 2014.Q4.

58. Core et al. (2025) use AnaCredit loan-level data for December 2021 and find that the one-year probability of default on fixed-rate loans averaged 6.26%, with a standard deviation of 19.64%, compared with 9.52%, with a standard deviation of 25.05%, for variable-rate loans. Using loan-level data on securitized mortgages for 2014–2019, Bandoni et al. (2025) estimate an average mortgage default rate of 0.9% across countries.

59. These estimates capture responses of a stock measure of credit risk. Measuring responses of flow default concepts, such as 60- or 90-day defaults, would require granular credit registry data because no country-consolidated flow series are available.

Figure B.8: Local projections on NPL ratios



Source: ECB Consolidated Banking Data (CBD2), *Note:* The country sample covers the ten largest euro area economies, grouped by their share of variable-rate lending. FR countries include Belgium, France, Germany, and the Netherlands; VR countries include Austria, Finland, Ireland, Italy, Portugal, and Spain.

C. Solution algorithm

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

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

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

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

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

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

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

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

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

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

Steady State. Solving for the model's steady state comprises two main steps: First, solving for the individual bank policy functions using value function iteration. Second, computing the steady-state bank distribution over equity E_t, leverage l_t, and the average loan rate/spread x_t^L using the method of Young

(2010). These steps must then be executed iteratively to find the equilibrium loan rate r^L which clears the loan market.

We discretize the state space for $l_t \in [0, 1/\gamma]$, $x_t \in [x-\sigma, x+\sigma]$, where σ is the size of the MIT shock, and $\log(E_t) \in [\log(0.13), 20)$ using equally spaced grids.[60][61] 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). Algorithm 2 describes the algorithm to compute 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 $k_0^{gap}(l,x)$ and the value function $V_0(l,x)$.*

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

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

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

Algorithm 2 (Bank Distribution)**.**

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

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.*

60. Note that, technically, there is no need for the x grid in the steady state, since it stays constant for all banks. However, computing the steady-state policies for $x_t \neq x$ 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 has not yet converged back to the steady state.

61. Since E_t follows a power-law distribution, its moments can be sensitive to large values in the right tail. We therefore choose a sufficiently high upper bound for the $\log(E_t)$ grid so that the results are insensitive to further increases in this bound.

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.*[62]
4. *Update the paths for the distribution $\{\mathscr{H}_t(l, x, \log(E))\}_{t=1}^{T-1}$ 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.*

62. This part of the algorithm proceeds analogously to solving for the steady state.

D. Additional results

This appendix assesses whether the baseline comparison between FR and VR economies is sensitive to allowing monetary policy to affect borrower default risk. The baseline model keeps loan default risk policy invariant. This restriction shuts down borrower-side credit-risk feedbacks and isolates the bank-capital channel: monetary policy affects lending through funding costs, legacy NIM dynamics, and banks' distance to the solvency threshold. We therefore report a reduced-form robustness exercise that relaxes this restriction for VR loans and explains how the exercise should be interpreted.

Specification. We let the mean default probability applied to VR loan portfolios vary with the new-loan rate according to

$$p_t - p = \beta_p (r_t^N - r^N), \tag{D.1}$$

where r^N is the steady-state new-loan rate and β_p is the slope of the default-probability response to the lending rate. We apply equation (D.1) to both new and legacy loan portfolios in the VR economy. Default probabilities in the FR economy remain fixed at p. All other objects, including the steady states from which the economies are perturbed, are unchanged.

This specification is intentionally reduced form. It does not model borrowers' strategic default, endogenous screening by banks, or aggregate-demand feedbacks. It also treats the VR loan portfolio uniformly, even though legacy borrowers and new borrowers face different economic margins. The uniform rule is useful as a stress test because it loads borrower-side credit-risk feedbacks onto the VR economy. It is not a symmetric counterfactual comparison of FR and VR systems.

Legacy loans versus new loans. The asymmetry is appropriate for legacy loans. In the VR economy, each legacy cohort pays the current policy rate plus its origination spread, summarized in the bank state by the average legacy spread $s_{j,t}^L$. A monetary tightening therefore raises legacy borrowers' debt-service burden and can raise default risk. In the FR economy, legacy borrowers continue paying the fixed rate set at origination, so the same repricing channel is absent. Holding default risk fixed for legacy FR loans is therefore consistent with the logic of the exercise.

The same argument does not apply to new loans. New FR loans are originated after the shock at the prevailing fixed rate r_t^N, and new VR loans are originated at the contemporaneous policy rate plus the new spread. If higher contractual rates make new borrowers riskier, the default probability of newly originated loans should rise in both economies. The current exercise instead raises default probabilities for new VR loans while leaving new FR loans at the baseline default probability. This assigns to the VR economy a generic new-loan credit-risk effect that is not specific to variable-rate contracts.

This distinction matters for interpretation. A higher default probability on new loans lowers the expected value of new lending even if banks' equity positions remained almost unchanged (or even if the conditions in Proposition 1 were to hold). This is different to the baseline mechanism, which operates through legacy NIM dynamics moving banks toward or away from the solvency threshold.

A fully symmetric implementation, though, would require default probabilities to depend on each loan's contractual rate. For new loans, this would mean applying the same rate-sensitive default mapping in both economies at origination. For legacy loans, it would mean keeping FR cohorts tied to their origination rates while allowing VR cohorts to reprice with the current policy rate and their cohort-specific spreads.

That specification breaks the two-state representation used in the quantitative model. In the baseline, a bank's state is summarized by leverage and one legacy-pricing state: the average legacy loan rate in the FR economy, or the average legacy spread in the VR economy. This aggregation is valid because the default distribution does not depend on the contractual rate of each surviving cohort. If default probabilities depend on contractual rates, the average legacy rate or spread is no longer sufficient. The bank's expected credit losses, surviving loan law of motion, and continuation value depend on the full distribution of surviving cohorts and their contractual rates.

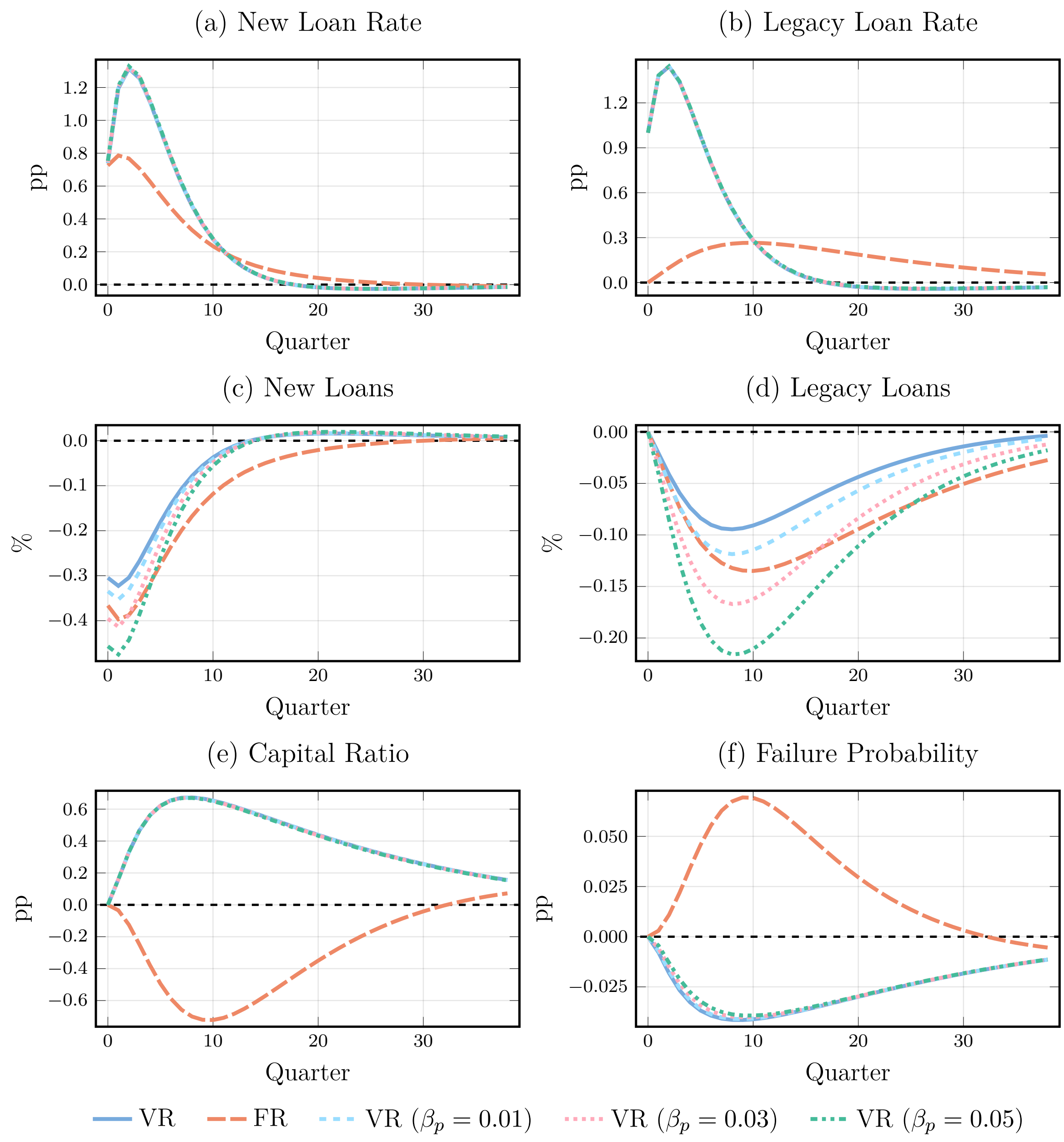
Because loans mature geometrically, every period contains surviving loans from all previous origination dates. Exact cohort tracking would therefore require an infinite-dimensional portfolio state, or a high-dimensional finite approximation that would remove the tractability gained from the current reduction of the bank problem to leverage and one legacy-pricing state. For this reason, equation (D.1) should be read as a reduced-form stress test rather than as the model's symmetric treatment of borrower default risk.

Results. Figure D.1 reports results for $\beta_p \in \{0.01, 0.03, 0.05\}$. We interpret $\beta_p = 0.01$ as the preferred benchmark based on available empirical evidence for the euro area.[63] For $\beta_p = 0.01$, FR economies continue to exhibit larger lending contractions than VR economies (panel c). For $\beta_p = 0.03$, the lending responses are close to equal, whereas for $\beta_p = 0.05$, lending contracts more in the VR economy.

Importantly, these responses do not imply that the baseline bank-capital mechanism is overturned. In this exercise, the equity dynamics that drive the baseline mechanism remain close to those in the baseline economy (panel e). The additional contraction in VR lending therefore comes mainly from the lower expected profitability of newly originated loans when their default probability rises, not from a deterioration in bank equity that pushes more banks toward the solvency threshold. Since the new-loan credit-risk margin would also operate for new FR loans under a symmetric cohort-level specification, the exercise is conservative with respect to the baseline result. If anything, it reinforces the view that abstracting from borrower-side credit-risk feedbacks should not alter the main mechanisms driving our results.

63. Although limited, this evidence suggests that the effect of interest-rate changes on borrower defaults is generally small, nonlinear, 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 implied slope of default probabilities with respect to lending rates is at most about 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.

Figure D.1: 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.