The Heterogeneous Bank Lending Channel of Monetary Policy*

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Abstract

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

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1. Introduction

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

While the bank lending channel is well understood, not all banks are created equal. In particular, banks may respond differently to monetary policy, depending on their interest-rate risk exposure, leading to heterogeneous effects across banks. For example, banks operating in specific geographic areas or specializing in specific industries predominantly offer fixed-rate loans, whereas others may 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 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.

We start by developing a theoretical benchmark. Regardless of loan origination costs and equity-financing frictions, an irrelevance result holds: monetary policy transmission is identical in fixed- and variable-rate banking systems so long as banks and borrowers discount loan repayments using the same discount factor. Differences in loan discounting arise only when banks risk violating their regulatory capital requirements.[1] This benchmark establishes that heterogeneity in interest-rate risk exposure matters only insofar as it affects the distribution of banks whose leverage is near regulatory limits.

[1] 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.

An implication of our irrelevance benchmark is that whether interest-rate risk exposure matters is ultimately a quantitative question: the answer depends on how likely banks are to approach their regulatory constraints. Answering this question requires a model calibrated to a specific institutional context, with a realistic formulation of regulatory constraints and a good fit to both the cross-sectional distribution of bank leverage and the aggregate dynamic responses of credit to policy changes.

We calibrate our model to the euro area, a natural setting for our quantitative analysis. Interest-rate risk exposure heterogeneity is particularly pronounced in this region: banks in France, Germany, Belgium, and the Netherlands predominantly price loans at fixed rates, while those in Spain, Italy, Finland, and Portugal use variable rates. This institutional variation creates systematic differences in interest-rate risk exposures across countries within the monetary union. Moreover, due to market frictions, interest rate risk hedging remains modest and varies over time and across institutions, leaving most banks exposed to it.[2] A pressing question for the European Central Bank (ECB) is therefore whether this ex-ante heterogeneity translates into different cross-country monetary-policy responses. Our calibration targets both aggregate moments and the dispersion in capital buffers across banks for 2013–2023, providing the discipline needed to address this question.

We find that heterogeneity is quantitatively significant, but only because a substantial number of euro area banks operate near their regulatory constraints. In our model, this arises from two forces: convex loan portfolio adjustment costs and idiosyncratic default shocks that prevent banks from fully controlling their leverage. The mechanism works as follows: when policy rates rise, fixed-rate banks experience capital erosion as funding costs increase while income from legacy loans remains unchanged; variable-rate banks face the opposite dynamic, with rising rates boosting interest margins and bolstering capital. Under these conditions, the elasticity of new lending to monetary policy is approximately one-third larger in fixed-rate systems. The divergence also extends to financial stability: rate hikes increase banks' failure probability in fixed-rate economies while reducing them in variable-rate systems. Confirming the logic of our

[2] Financing long-term loans with short-term deposits exposes banks to interest rate risk (English et al. (2018); Gomez et al. (2021); Ampudia and den Heuvel (2022)). Empirical evidence indicates that larger euro area banks make greater use of derivatives to hedge interest rate risk than their U.S. counterparts (Hoffmann et al., 2018; Begenau et al., 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.

theoretical benchmark, when we counterfactually reduce idiosyncratic default risk—thereby making banks more homogeneous—the differences between systems shrink dramatically, even when we allow for features other than capital regulation to drive differences in discount factors across banks and their borrowers.

These findings carry implications for two dimensions of policy design: the interaction between monetary and macroprudential tools, and the pace of monetary tightening. First, we show that countercyclical capital buffers can dampen or amplify the divergence between banking systems: releasing capital requirements during a tightening cycle pushes banks away from regulatory constraints, reducing the gap in credit responses between fixed- and variable-rate economies. Conversely, tightening macroprudential policy during a monetary contraction accentuates the divergence—a consideration especially relevant for monetary unions where a single policy rate interacts with heterogeneous national banking systems. Second, we provide a financial-stability rationale for gradualism in monetary policy. Comparing policy paths that deliver the same cumulative stance, we find that more gradual tightening substantially reduces failure rates in fixed-rate economies without materially increasing them in variable-rate systems. Gradualism avoids precisely the sharp equity losses that push fixed-rate banks toward binding constraints. Both results are natural corollaries of our theoretical benchmark: policy choices that keep banks away from regulatory limits diminish the relevance of interest-rate risk exposure.

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

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

This observation implies that banks with heterogeneous leverage positions or interest-rate risk exposure, which shape their access to non-deposit financing, will respond heterogeneously to monetary policy. An extensive empirical literature corroborates this hypothesis. Early work by Kashyap and Stein (2000) established that the strength of the bank lending channel depends on bank characteristics. Subsequent research with improved identification has focused on two key dimensions. First, banks with low risk-bearing capacity—high leverage or low capital ratios—transmit policy rate changes more strongly than well-capitalized banks (Jiménez et al., 2012; Dell'Ariccia et al., 2017; Altavilla et al., 2020).[3] Second, banks with greater interest-rate risk exposure—a higher share of fixed-rate loans—also exhibit stronger transmission (Altunok et al., 2023).

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

Our framework shares some similarities with the dynamic model of bank interest-rate risk developed by Van den Heuvel (2007), although embedded within a general equilibrium environment. A central result in that paper is that, when banks are unconstrained by capital regulation, current policy rates are a sufficient statistic for the supply of loans. Unlike in Kashyap and Stein (1995), equity financing in our models is not frictionless—banks cannot freely issue equity. Yet the result shows that the bank's capital position is irrelevant for determining the lending response to monetary policy unless regulation is (occasionally) binding. We establish a distinct but related irrel-

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

evance result: when banks are unconstrained, whether loans carry fixed or variable rates is also irrelevant for monetary policy transmission. Both results break down once capital constraints can bind—and the interaction between leverage heterogeneity and loan-pricing heterogeneity is what our analysis explores.

A recent literature develops quantitative banking models with heterogeneity to study monetary policy transmission, emphasizing different frictions. Some papers focus on the liability side: Leite (2025) study heterogeneity in deposit funding structures; Bianchi and Bigio (2022) investigate interbank market frictions and deposit withdrawals; Begenau et al. (2024) examine financial stability implications of uninsured deposit funding. Others emphasize capital and risk-taking: Coimbra and Rey (2023) analyze how monetary policy affects risk-taking; Corbae and D'Erasmo (2021) study regulation and bank risk-taking; Rios-Rull et al. (2023) examine capital requirements; Jamilov and Monacelli (2025) focus on shocks to bank return dispersion.[4] We contribute by examining how heterogeneity in loan pricing—fixed versus variable rates—interacts with leverage heterogeneity to shape the bank lending channel.

Closest to 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 maturity. Our framework abstracts from this margin of adjustment. Because maturity structure is slow-moving, for our purposes, we treat risk exposure as institutionally predetermined and ask when these ex-ante differences matter for transmission.

A related strand examines monetary transmission through the mortgage market. For example, Berger et al. (2021) and Eichenbaum et al. (2022) emphasize the path-dependency of policy rates in shaping household consumption. Greenwald (2018) highlights the role of loan-to-value and payment-to-income constraints, while Beraja et al. (2018) focus on the importance of home equity values.[5] Guren et al. (2021) and Elenev and Liu (2025) examine how mortgage contract design—fixed versus adjustable rates—shapes macroeconomic volatility, household default risk, and housing demand. A natural implication of this literature is that households' interest-rate risk exposure amplifies consumption volatility and default risk. As a result, fixed-rate contracts can

[4] Bellifemine et al. (2022) extend this framework with nominal frictions.

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

insulate households from interest-rate risk. However, aggregate risk does not vanish—it shifts to banks. Hence, relative to this literature, our paper provides the banking counterpart: we study how bank-side interest-rate risk exposure shapes monetary transmission and financial stability.

2. The model

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

The core of the model features a banking sector that intermediates funds from households to entrepreneurs, who undertake risky long-term projects requiring external financing. Entrepreneurs' entry decisions generates a microfounded, forward-looking demand for loans. The funding side is deliberately kept simple: the household block delivers a static deposit supply, yet remains flexible enough to match the observed dynamics of deposit rates following monetary policy shocks. This setup allows us to focus squarely on the bank lending channel.

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

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

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

2.1 Banks

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

Banks finance a portfolio of risky long-term loans and safe short-term assets using a combination of short-term insured deposits, wholesale debt, and equity accumulated via retained earnings.

Assets. Bank assets comprise risky long-term loans and safe short-term assets, which we refer to as reserves.[6] At the beginning of period t, bank j holds a portfolio of legacy loans, L_{jt}, originated in previous periods. It then chooses its origination of new loans, N_{jt}, and its holdings of central bank reserves, M_{jt}.

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

The loan portfolio consists of a continuum of long-term loans, each with a principal normalized to one. Following Leland and Toft (1996), each loan matures with an i.i.d. probability $\delta \in (0,1)$, implying an average loan maturity of $1/\delta$. Loans are subject to credit risk, which we model using the single-risk-factor framework of Vasicek (2002), described in Appendix A.1. The fraction of a bank's loan portfolio that defaults, ω_{jt+1}, is a random variable 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.[7]

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

[7] 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.

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.[8] 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, $r_t^D \leq r_t^B$). A bank's ability to issue deposits is constrained by the size of its legacy loan portfolio:

$$D_{jt} \leq \alpha L_{jt}, \tag{4}$$

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

We assume that retail deposits are fully insured by the government and that, while

[8] 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.

wholesale debt is not, its returns are also risk-free in equilibrium.[9]

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

$$E_{jt+1} = E_{jt} + (1-\tau)\Pi_{jt+1}, \tag{5}$$

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

$$\begin{aligned}\Pi_{jt+1} = (1-\omega_{jt+1})\left(r^L_{jt}L_{jt} + r^N_t N_{jt}\right) + r^M_t M_{jt} - r^D_t D_{jt} - r^B_t B_{jt} \\ - \lambda\omega_{jt+1}(L_{jt}+N_{jt}) - f\left(\frac{N_{jt}}{L_{jt}}\right)L_{jt} - \bar{\pi}E_{jt}.\end{aligned} \tag{6}$$

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:

$$L_{jt} + N_{jt} + M_{jt} = D_{jt} + B_{jt} + E_{jt}. \tag{7}$$

Regulation. The banking system is subject to both liquidity and capital regulation, akin to the Basel III framework. Liquidity regulation imposes a minimum amount of reserve holdings proportional to the bank's short-term liabilities:

$$M_{jt} \geq \theta(D_{jt} + B_{jt}). \tag{8}$$

Capital regulation imposes that a bank's equity must cover at least a fraction $\gamma \in (0,1)$ of its total loan portfolio:

$$E_{jt} \geq \gamma(L_{jt} + N_{jt}). \tag{9}$$

[9]To obtain this result, we need to assume that wholesale debt is either senior to deposits, or that it is collateralized with the bank's assets. This imposes some parametric restrictions on the relative size of each of these sources of funding and/or the recovery value of a bank's assets in case of default, such that wholesale debt returns are effectively risk free (see Appendix A.2 for a derivation of those restrictions).

Bank failure, entry and exit. A bank fails and is resolved by the regulator if, after the realization of portfolio defaults ω_{jt+1}, its equity falls below regulatory minimum: $E_{jt+1} < \gamma L_{jt+1}$. Upon failure, its equity is wiped out, and a deposit insurance agency seizes its assets, liquidates a fraction, and sells the remainder to new entrants. The agency allocates its proceeds to the bank's liability holders, in order of seniority, and repays all retail depositors in full.

Additionally, banks face an exogenous exit shock with probability $\chi \in (0,1)$ each period. Exiting banks repay liabilities and distribute remaining equity as dividends. To maintain a constant mass of banks, each exiting bank is replaced by a new entrant. New entrants start with an exogenous amount of equity $\bar{E}_t$ and a random amount of legacy loans that ensures that the leverage distribution of new banks is the same as that of surviving banks. These exit and entry dynamics ensure a stationary distribution of bank sizes. The fraction of loans in the legacy loan portfolio of exiting banks at $t+1$ that is not distributed among new banks, which we denote $\tilde{\chi}$, is liquidated.[10]

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:

$$V_t\left(L_{jt}, E_{jt}, x^L_{jt}\right) = \mathbf{1}_{\{E_{jt}\geq\gamma L_{jt}\}}\left[\max_{\{N_{jt},M_{jt},D_{jt},B_{jt}\}} \beta\mathbb{E}_t\left[(1-\chi)V_{t+1}\left(L_{jt+1}, E_{jt+1}, x^L_{jt+1}\right)\right.\right.$$
$$\left.\left. + \chi E_{jt+1}\right]\right], \tag{10}$$

with $x_{jt} = r^L_{jt}$ for FR banks and $x_{jt} = s^L_{jt}$ for VR banks. 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 constraint on retail deposits (4), the law of motion for equity (5), the balance-sheet constraint (7), and the regulatory constraints (8) and (9). The indicator function captures the failure condition. Lemma 1 below shows that the problem can be written more parsimoniously in terms of two state variables: the bank's leverage (L_j/E_j) and either the average legacy rate (r^L_j) for FR

[10] 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.

banks, or the average legacy spread (s_j^L) for VR banks.

2.2 Entrepreneurs: Loan demand microfoundation

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

An active project yields A units of the final good per period. At the end of period t, the project terminates if: (i) it reaches successful completion, which occurs with probability δ; (ii) it fails, which occurs with probability p; or (iii) its loan is liquidated as a result of the exit of its financing bank, which occurs with probability $\tilde{\chi}$. If the project is completed or the loan is liquidated, the principal is repaid in full. If the project fails, the bank recovers only $1-\lambda$ of the principal.

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

The value of a project depends on the interest rate regime. For a FR loan, the value at time t of a project with loan rate r_i^N is:

$$V_{it}^E(r_i^N) = \sum_{k=0}^{\infty} \beta^{k+1}(1-p)^{k+1}(1-\delta)^k(1-\tilde{\chi})^k \left[A - \left(r_i^N\right)\right], \tag{11}$$

The free-entry condition $V_{it}^E(r_t^N) = a(N_t)$ implies an aggregate demand for FR loans:

$$N_t = a^{-1}\left(\sum_{m=0}^{\infty} \Omega_m \left(A - r_t^N\right)\right), \tag{12}$$

where $\Omega_m \equiv \beta^{m+1}(1-p)^{m+1}(1-\delta)^m(1-\tilde{\chi})^m$ is the entrepreneurs' effective discount factor. Loan demand in the FR economy is not forward-looking with respect to future interest rates, as the bank bears all interest-rate risk.

For a VR loans, the aggregate demand is:

$$N_t = a^{-1}\left(\sum_{m=0}^{\infty} \Omega_m \left[A - \left(r_{t+m}^M + s_t^N\right)\right]\right). \tag{13}$$

In this case, loan demand is forward-looking, as entrepreneurs form expectations about future interest rates.

2.3 Households: Supply of bank funds

The household block determines the supply of funds available to banks. It plays a dual role. First, unlike partial equilibrium or ad-hoc formulations common in the literature, embedding household decisions in general equilibrium disciplines the analysis: it ensures that a consistent representation of funding supply exists and forces us to be explicit about how monetary policy is implemented. Second, the specific modeling choices ensure tractability: they deliver a static demand system—depending only on current rates—while government bond supply shocks, occurring contemporaneously with monetary policy shocks, allow both the deposit rate and the rate on reserves to follow their observed empirical trajectories. The loan rate, in contrast, responds endogenously. This flexibility to match the empirical path of funding costs while preserving endogenous loan pricing is key to accurately capturing banks' cost of funds, allowing us to squarely focus on the bank lending channel.

With that purpose in mind, households have quasi-linear preferences over two consumption goods—one entering with curvature, the other linearly—and derive additional utility from holding a bundle of monetary assets. The bundle combines highly liquid assets, D_t^H, with less liquid bonds, A_t^H, and the differing liquidity services of these assets generate an equilibrium spread between their returns. Highly liquid assets comprise bank deposits and short-term government paper; bonds comprise wholesale debt issued by banks, B_t^H, and longer-term government bonds, M_t^H. Within each category, the component assets are perfect substitutes from the household's perspective. Appendix A.3 details the full problem.

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

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

and

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

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

The static demand system, which simplifies computation, follows directly from our assumptions. Quasi-linear preferences—standard in new-monetarist models (Lagos and Wright, 2005; Lagos et al., 2017) and also used in dynamic banking models (Bianchi and Bigio, 2022)—deliver demand functions that, unlike loan demand, depend only on current rates. The complementarity between liquid assets and bonds couples the two demands into a system, as in other quantitative models with competing monetary services (Drechsler et al., 2017; Di Tella and Kurlat, 2021), preventing a perfect pass-through from policy rates to deposit rates.

2.4 Consolidated government

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

These operations are consolidated in the following government budget constraint:

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

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

2.5 Equilibrium and characterization

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

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

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

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

4. *Markets for new loans, deposits, wholesale debt, reserves, and the consumption good clear.*

5. *The government budget constraint holds.*

Appendix A.4 provides more details on all equilibrium objects and market-clearing conditions.

Size independence. A key feature of our model is that banks' optimal policies exhibit size independence, substantially simplifying the analysis while preserving the relevant heterogeneity in leverage and portfolio composition. Because returns, costs, and regulatory constraints all scale proportionally with bank size, decision rules can be expressed independently of the current level of equity. Specifically, factoring out equity leaves leverage $l_{jt} \equiv L_{jt}/E_{jt}$ and the average legacy rate r^L_{jt} (for FR banks) or spread s^L_{jt} (for VR banks) as the sole relevant state variables for individual bank decisions.

Lemma 1 (Size independence). *The bank's value function $V_t\left(L_{jt}, E_{jt}, x^L_{jt}\right)$, which solves* (10)*, is linear in equity E_{jt}:*

$$V_t\left(L_{jt}, E_{jt}, x^L_{jt}\right) = v_t\left(l_{jt}, x^L_{jt}\right) E_{jt},$$

where

$$v_t\left(l_{jt}, x^L_{jt}\right) = \mathbf{1}_{\{l_{jt} \le 1/\gamma\}} \left[\max_{\{n_{jt}, m_{jt}, d_{jt}, b_{jt}\}} \beta \mathbb{E}_t \left[(1-\chi) v_{t+1}(l_{jt+1}, x^L_{jt+1}) g_{jt+1} + \chi g_{jt+1} \right] \right],$$

with $g_{jt+1} \equiv E_{jt+1}/E_{jt}$ denoting equity growth, and $\{n_{jt}, m_{jt}, d_{jt}, b_{jt}\}$ denoting, respectively, the ratio of $\{N_{jt}, M_{jt}, D_{jt}, B_{jt}\}$ to equity E_{jt}. The optimization is subject to the normalized counterparts of constraints (4)–(9).

Proof. See Appendix A.5.

This homogeneity arises because interest income, funding costs, and operating costs all scale linearly with the balance sheet, while regulatory constraints are proportional to loans and liabilities, respectively. Consequently, bank growth rates depend on leveraged returns and the realization of idiosyncratic shocks, not absolute scale. We characterize the economy by tracking the joint distribution of leverage the average loan rate (or spread). This simplification reduces the dimensionality of the problem considerably, while preserving the key interactions: highly leveraged banks are more likely to face binding capital constraints, and their distance from these constraints determines how loan-pricing conventions affect monetary transmission.

Irrelevance of interest-rate risk exposure. We now turn to a central question: under what conditions does the distinction between FR and VR loan pricing matter for monetary policy transmission? A central theme of this paper is that this distinction matters only through its interaction with capital regulation. We formalize this insight in the following proposition, which establishes conditions under which the transmission of monetary policy is identical in FR and VR economies.

Proposition 1 (Irrelevance of interest-rate risk exposure)**.** *Consider FR and VR economies facing the same exogenous sequences of policy rates $\{r_t^M\}_{t\geq 0}$ and deposit rates $\{r_t^D\}_{t\geq 0}$, and starting from the same aggregate legacy loan portfolio L_0. The equilibrium paths of aggregate new lending $\{N_t\}_{t\geq 0}$ and legacy loans $\{L_t\}_{t\geq 0}$ coincide in the two economies if:*

1. *Capital requirements are not binding for any bank at any date: constraint (9) holds with strict inequality for all j and t.*

2. *Banks and entrepreneurs share a common effective discount factor for cash flows at every horizon: for all $m \geq 0$, banks discount payments m periods ahead at the same rate as entrepreneurs.*

Under these conditions, the fixed loan rate r_t^N in the FR economy and the spread s_t^N in the VR economy are related by:

$$r_t^N = s_t^N + \bar{r}_t^M,$$

where $\bar{r}_t^M$ is the discounted average of expected future policy rates.

Proof. See Appendix A.6.

The logic underlying Proposition 1 mirrors that of the classical Modigliani-Miller theorem (Modigliani and Miller, 1958), which establishes that, when a firm and its financiers share a common discount factor, the division of cash flows between debt and equity does not affect firm value or investment. Our result offers an analogous irrelevance: when banks and entrepreneurs share a common discount factor, the allocation of interest rate risk between them—determined by whether loans carry fixed or variable rates—does not affect aggregate bank lending. In both cases, the structure of financial contracts is irrelevant for real allocations when discount factors are aligned.

The key insight is as follows. Consider a loan originated at date t. In the FR economy, the entrepreneur pays a fixed rate r_t^N each period until maturity. In the VR economy, the entrepreneur pays a variable rate $r_{t+m}^M + s_t^N$ in period $t+m$. When both parties discount future payments at the same rate, the net present value of these two payment streams is identical if r_t^N equals the discounted average of expected variable rates plus the spread. Under this condition, neither entrepreneurs nor banks prefer one contract structure over the other, and equilibrium lending is identical across economies. The distinction between FR and VR affects only the timing of when interest rate risk materializes in bank profits, not the present value of those profits.

Condition 1—that capital requirements remain non-binding—ensures that banks evaluate loans purely on net present value grounds, without shadow costs from regulatory constraints. When constraints do not bind, banks in both FR and VR economies value loans identically in present value terms, even though the timing of cash flows differs. A VR bank experiences immediate pass-through of policy rate changes to its legacy portfolio; a FR bank sees gradual adjustment as new loans replace maturing ones. These timing differences wash out when discounting is common and constraints are slack. However, when capital constraints bind, banks face a shadow cost of regulatory capital that differs systematically between FR and VR: under tightening, FR banks see their interest margins compressed, depleting capital and raising the shadow cost, while VR banks see margins expand. This asymmetric response is why Condition 1 is essential for irrelevance.

Condition 2—the alignment of discount factors—holds when banks and entrepreneurs face identical tax rates, exit probabilities, and access to risk-free investment opportunities. In our calibrated model, these features differ, introducing wedges between the discount factors of banks and entrepreneurs, formally violating Condition 2. We retain the differential tax treatment because it is quantitatively important for matching the empirical moments documented in Section 3, and we preclude entrepreneurs from investing in the risk-free asset to isolate the effects of interest rate changes on loan supply, while keeping demand fixed. Nonetheless, Condition 2 is not the primary driver of our results. As we show in Section 4, when idiosyncratic risk is reduced—so that Condition 1 is approximately satisfied—the quantitative differences between FR and VR economies become negligible, even though Condition 2 remains violated. This underscores that it is the binding of capital constraints (Condition 1), not the discount-factor wedge (Condition 2), that is essential for FR/VR differences.

Condition 1 has a natural interpretation in terms of the calibration of idiosyncratic risk. Recall that bank leverage heterogeneity arises from idiosyncratic loan default shocks, whose dispersion is governed by the parameter ρ (see Section 3). As $\rho \to 0$, idiosyncratic dispersion vanishes and all banks maintain identical leverage. If parameters are set so that this common leverage satisfies the capital requirement with slack, Condition 1 holds. The proposition thus delivers a sharp insight: differences in monetary policy transmission between FR and VR economies arise from the interaction of interest-rate risk exposure with binding capital constraints—not from interest-rate risk exposure per se. We verify this prediction quantitatively in Section 4 by showing that reducing ρ largely eliminates the differences between FR and VR economies.

2.6 Solution method

To solve the model, we use a value function iteration algorithm for the bank problem defined in Appendix A.5 and keep track of the bank distribution over log-equity $\log(E_{jt})$, leverage $l_{jt} = \frac{L_{jt}}{E_{jt}}$, and the loan rate/spread x_{jt} using the method of Young (2010). The steady state can then be found in an iterative procedure where, for a given guess of the loan rate r^N, we first solve for the policy functions using value function iteration and then compute the bank distribution using those policy functions. During this procedure, the guess for the loan rate is adjusted until an equilibrium in the loan market is found. The transitional dynamics after an MIT shock are computed similarly to Boppart et al. (2018). For a guess of a transition path for the loan rate $\{r_t^N\}_{t=0}^T$, we make a backward pass along the transition to compute the policy functions, followed by a forward pass to compute the distribution along the transition. Similar to our steady state algorithm, we adjust the transition path for the loan rate $\{r_t^N\}_{t=0}^T$ until the loan market clears in each period. Appendix C provides more details on the solution algorithm.

3. Calibration and model fit

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

3.1 Functional forms and parameter values

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

Pre-set parameters. The first block of Table 1 corresponds to the pre-set parameters. We follow Mendicino et al. (2020) and set the average loan default rate p to 2.65% (annualized) and the loan loss given default λ to 0.3. The average loan maturity δ is set to 0.05, implying an expected loan duration of 5 years, consistent with the average maturity of syndicated loans in developed economies reported by Cortina et al. (2018). The corporate tax rate τ is set to 20%, matching the average effective tax rate for European banks.[11]

Policy parameters are set based on Basel III regulatory levels. The capital requirement γ encompasses the minimum Common Equity Tier 1 (CET1) requirement of 4.5% plus the capital conservation buffer of 2.5%, both of which must be maintained with CET1 capital. The parameter α in equation (4), which determines the ratio of deposits to loans on a bank's balance sheet, is set to match the observed deposits-to-loans ratio of 0.78 in the consolidated balance sheet of euro area monetary financial institutions (MFIs). Similarly, the liquidity requirement θ is set to match the reserves-to-total-liabilities ratio of 0.118.[12] The steady-state policy rate r^M—the rate of remuneration on central bank reserves—is set to 1%, matching the average deposit facility rate in the

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

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

Table 1: Parameter values

Pre-set parameters

	Parameter	Value	Target/Source
p	Loan default rate, mean (%)	0.6625	Mendicino et al. (2020)
λ	Loan loss-given-default	0.30	Mendicino et al. (2020)
δ	Loan maturity	0.05	Cortina et al. (2018)
τ	Corporate tax rate	0.20	Damodaran database.
γ	Min. capital requirement (%)	7.0	Basel III CET1 + Buffer requirement.
α	Deposits-to-loans ratio	0.78	Consolidated EA banks balance sheet.
θ	Liquidity requirement (%)	11.8	Liquid asset to total deposit ratio.
r^M	Steady-state policy rate (%)	1.0	Avg. EA deposit facility rate, 1999-2019.
r^D	Steady-state deposit rate (%)	0.5	Avg. EA overnight deposit rate, 2003-2023.

Jointly calibrated parameters

	Parameter	Value	Target	Data	Model
β	Subjective discount factor	0.933	Banks' return on equity (%)	6.4	6.4
ρ	Loan default correlation	0.51	Bank failure probability (%)	0.66	0.66
η	Loan origination cost	0.22	Voluntary capital buffer (%)	5.1	4.8
ζ_1	Ent. entry cost (level)	5.78	Avg. lending rates (%)	3.0	3.0
ζ_2	Ent. entry cost (power)	0.50	Response of new lending (%)	-0.38	-0.37
$\bar{\pi}$	Fixed operating cost	0.012	Non-interest expenses to assets (%)	0.34	0.22
χ	Bank's exit rate (pp)	2.00	Slope of log-log asset distribution	-1.56	-1.56

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

euro area over 1999–2019. The steady-state deposit rate r^D is set to 0.5%, based on the average overnight deposit rate over 2003–2023.

Jointly calibrated parameters. The second block of Table 1 reports the parameters calibrated jointly to match a set of targeted moments. To model portfolio credit risk, we specify the cumulative distribution function (CDF) of loan default rates, ω_{jt+1}, using the Vasicek (2002) single risk-factor model:[13]

$$F_j(\omega) = \Phi\left(\frac{\sqrt{1-\rho}\Phi^{-1}(\omega) - \Phi^{-1}(p)}{\sqrt{\rho}}\right), \tag{17}$$

where $\Phi(\cdot)$ is the CDF of a standard normal, $\Phi^{-1}(\cdot)$ denotes its inverse, and $\rho \in [0,1]$ is the loan correlation parameter, which governs the volatility of a bank's portfolio default rate. To discipline the calibration of ρ, we target the average failure probability of 0.66% for European banks reported by Mendicino et al. (2020).

We assume that banks face a convex loan origination cost:

$$f(N_{jt}/L_{jt}) = \eta\left(\frac{N_{jt}}{L_{jt}}\right)^2, \tag{18}$$

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

$$a(N_t) = \zeta_1 N_t^{\zeta_2}, \tag{19}$$

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

The parameters ζ_1, ζ_2, and η are jointly calibrated to match (i) the historical average loan rate of 3%, (ii) the peak response of log new lending to a 100 basis-point monetary policy shock, equal to -0.38 (see Figure 3), and (iii) the average voluntary capital buffer of 5.1 percentage points, consistent with the mean CET1 buffer in 2021Q4 for banks supervised by the ECB.[14]

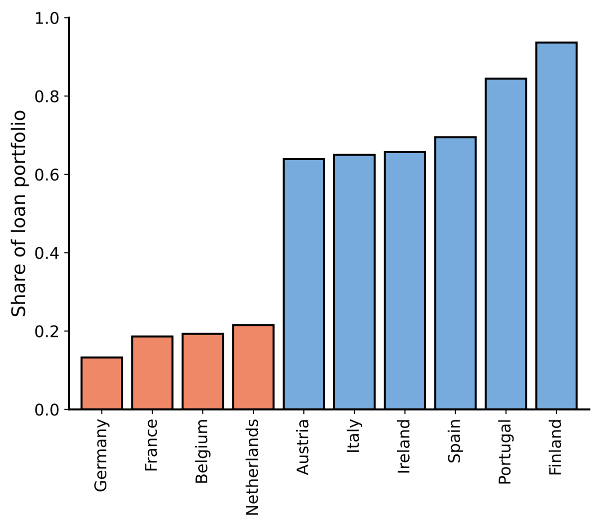
Finally, the discount factor β, the fixed operating cost parameter $\bar{\pi}$, and the exit rate χ are disciplined by jointly targeting banks' return on equity (ROE), the average ratio of non-interest expenses to assets, and the tail coefficient (slope) of the log-log asset-size distribution. As discussed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

[13] See Appendix A.1 for derivations. This distribution assumes that individual banks face limits to fully diversifying their loan portfolios and that loan defaults arise from common dependence on a single risk factor, as in the model underlying the internal ratings based (IRB) approach of Basel II. See Gordy (2003) and Repullo and Suarez (2004).

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

Ex-ante heterogeneity: FR and VR economies. As anticipated above, we study two versions of the model: one with FR loans and one with VR loans. This modeling choice is motivated by cross-country institutional variation within the euro area. Figure 1 presents the share of VR loan contracts in each country. VR loans are defined as those with original and remaining maturity over 1 year and interest rate reset within the next 12 months.[15] We observe that in a first group of countries—Germany, France, Belgium, and the Netherlands—approximately 80% of outstanding loans are fixed-rate contracts. In contrast, in a second group—Finland, Portugal, Spain, Ireland, Italy, and Austria—more than 60% of outstanding loans are variable-rate contracts.[16] We label the first and second groups as FR and VR countries, respectively, and use these definitions in Section 4, where we study the aggregate responses of bank balance-sheet variables to monetary shocks across country groups.

Figure 1: Share of variable-rate loans.



Note: Average share of total outstanding loans issued at variable rates, 2014–2020. Includes loans to non-financial corporations and to households (mortgage, consumer, and other loans). Orange bars correspond to our fixed-rate country classification; blue bars correspond to variable-rate countries. *Source*: ECB MFI Statistics.

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

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

3.2 Cross-sectional validation

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

Bank balance sheet composition. begin by comparing the consolidated balance sheet of monetary financial institutions (MFIs) in the euro area to its model counterpart.[17] Table 2 shows that the model's steady-state consolidated balance sheet closely matches the composition of assets and liabilities observed in the data. While asset-side ratios are directly targeted in the calibration, the liability-side composition emerges as an untargeted prediction.[18]

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

Assets			**Liabilities**		
	Model	Data		Model	Data
Loans	88%	88%	Deposits	81%	78%
ST securities and reserves	12%	12%	Wholesale funding	9%	14%
			Equity capital	10%	8%

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

Asset-size distribution. The model generates a steady-state distribution of bank assets that closely mirrors the empirical distribution observed for euro area banks.[19] Figure 2 compares the right tails of the model and empirical asset distributions in log-log space, illustrating the substantial heterogeneity in bank sizes produced by the model.

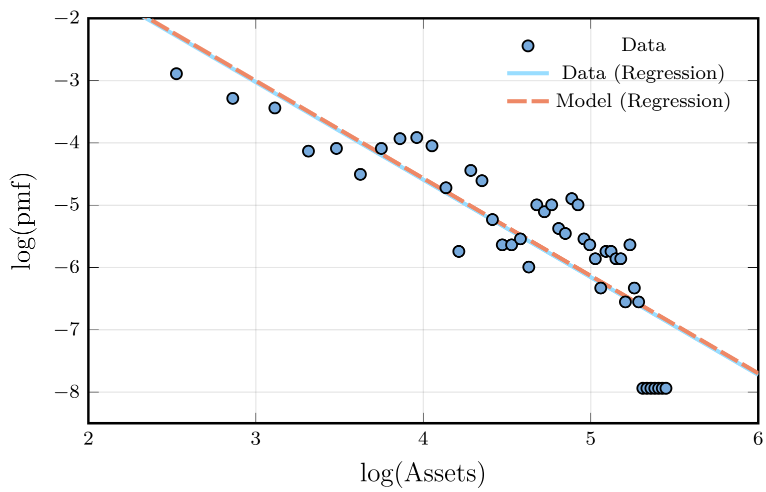
[17] Appendix B.1 details the composition of MFIs and the time series used.

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

[19] We characterize the distribution of bank assets using an unbalanced bank-level panel from S&P Global, a proprietary source. This quarterly dataset covers more than 70 euro area banks from 2013 to 2020 and includes information on CET1 capital levels, risk-weighted assets, and total assets. See Appendix B.3 for details.

The model reproduces the power-law behavior observed in the data, which emerges endogenously from the combination of size-independent growth rates and stochastic exit, consistent with Gabaix (2009).

Figure 2: Bank asset size distribution: Tail behavior.



Note: Blue dots represent equally spaced bins in the right tail of the empirical asset distribution. *Data (Regression)*: We fit a power-law distribution of the form $f(x) = \bar{A}x^{\psi}$, where ψ captures the tail behavior; it equals the slope of a log-log regression of the density on asset size. The light blue line shows the fitted relationship. *Model (Regression)*: The dashed red line is the model counterpart, based on the steady-state distribution. To ensure comparability, we scale asset values so that means match in the model and the data.

Capital ratio distribution. Table 3 reports the distribution of capital ratios in the data and in the model's steady state.[20] The model distribution captures its empirical counterpart well. The capital ratio at the first percentile is 9.7% in the model and 9.4 in the data, both slightly above the regulatory minimum of 7%. In both the model and the data, a substantial share of the mass lies close to the regulatory constraint, reflecting banks' incentive to operate with a buffer to avoid supervisory intervention. At the 40th percentile, the capital ratio is 12.7% in the model versus 13.5% in the data. For banks in the upper half of the distribution, the average capital ratio is 13.1% in the model and 18.7% in the data, indicating that the model underestimates the mass of banks with high capital ratios (i.e., low leverage).

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

Table 3: Capital-ratio distribution

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

Note: Capital ratios are defined as CET1 capital divided by risk-weighted assets. The sample covers more than 60 euro area banks from 2013 to 2020. Banks with assets exceeding €100 billion are classified as large; those with assets between €10 billion and €100 billion are classified as medium-sized. The "Large Banks" column includes banks with assets exceeding €10 billion. *Sources*: S&P Global and ESRB supervisory data on European banks' capital requirements.

To understand this discrepancy, we compare the model distribution with that of large banks, defined as those with assets exceeding €10 billion (second column of Table 3). For this subsample, the model's fit improves across the entire distribution. The average capital ratio for banks in the upper half, for instance, falls to 14.7% in the data (compared with 13.1% in the model). We attribute the remaining gap partly to additional regulatory constraints that our model does not capture. In particular, banks must satisfy a Minimum Requirement for Own Funds and Eligible Liabilities (MREL).[21] While larger banks typically issue contingent convertible liabilities to satisfy MREL, smaller banks often do so by holding additional CET1 capital, which may explain CET1 ratios well above 15% observed in the data

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

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

3.3 Time-series moment fit

Responses to a monetary tightening. Our primary interest is in how heterogeneous banks respond to monetary policy shocks. To evaluate the model's ability to capture the the transmission of monetary policy shocks to bank lending, we compare model-generated impulse response functions (IRFs) to their empirical counterparts. We estimate all empirical IRFs using a local projections approach (Jordà, 2005; Jordà et al., 2015).[22]

To compute the model's response of new loans to an unexpected increase in the policy rate r^M, we solve for the transitional dynamics following an unanticipated (MIT) shock, using an algorithm similar to Boppart et al. (2018).[23] Loan rates and quantities in the model are determined in equilibrium through market clearing. As explained in Section 2.4, the deposit side is calibrated to induce deposit-rate paths similar to those observed empirically. Thus, for new loans, quantities and prices are jointly determined by supply and demand; for deposits, rates are effectively exogenous, with quantities determined by banks' funding demand. The model takes as exogenous inputs the projected paths of both the policy rate and the deposit rate following a 100 basis-point increase in r^M, estimated from the data.

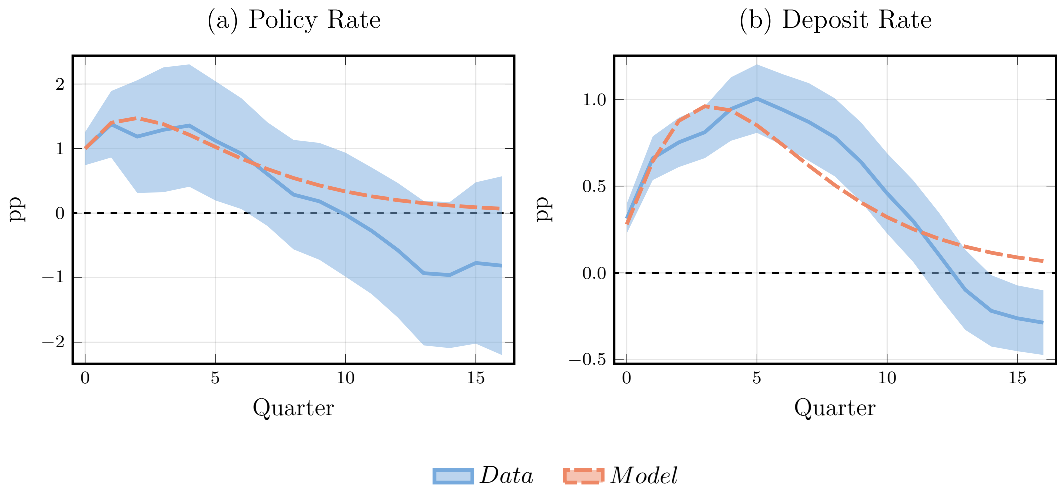
Figure 3 presents the IRFs of the exogenous rate processes. Panel (a) displays the estimated trajectory of the policy rate, and Panel (b) shows the corresponding path for the deposit rate. Solid blue lines and shaded bands correspond to point estimates and 95% confidence intervals from the empirical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

Figure 4 further analyzes the IRFs of variables that are not calibration targets, allowing us to assess the model's fit for additional bank balance-sheet variables. The left panels correspond to VR countries, while the right panels correspond to FR countries. The model fits the data well for both the rate charged on new loans and the volume of legacy loans. It captures the fact that pass-through to new loan rates is higher in VR

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

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

Figure 3: Targeted impulse responses



Note: Solid blue lines show the empirical impulse responses to a monetary policy shock; dashed red lines show the model counterparts. Light blue bands indicate 95% confidence intervals. Panels (a) and (b) report the responses of the policy rate and the deposit rate, respectively. See Appendix B.5 for details.

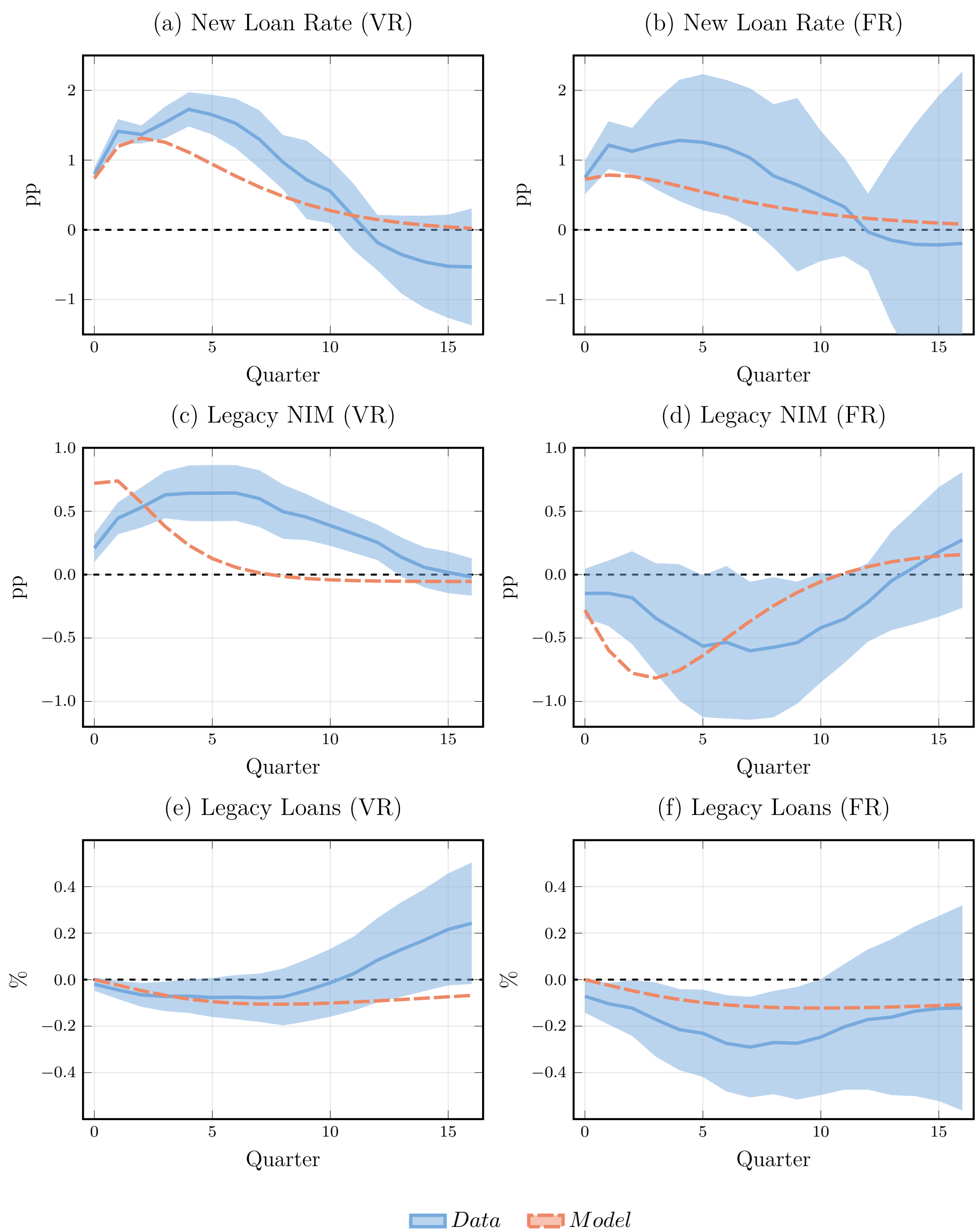
economies than in FR ones (panels a and b), as well as the larger and more persistent decline in legacy loan volumes in FR economies (panels e and f). Regarding the net interest margin (NIM; panels c and d), the response is positive for VR countries and negative for FR ones, both in the data and in the model—a pattern we explain in the next section. The model-generated NIM responses are of similar magnitude to those in the data but miss the persistence observed empirically.[24]

4. Inspecting the mechanism

In this section, we use the model to analyze how ex-ante and ex-post heterogeneity each affect the bank lending channel. We first consider the role of ex-ante heterogeneity by comparing aggregate IRFs in FR and VR economies following a one-percentage-point increase in the policy rate. We then evaluate the role of ex-post heterogeneity by examining how banks at different points in the capital-ratio distribution respond to the same shock. Finally, we contrast the baseline calibration with a version featuring lower idiosyncratic credit risk to provide a quantitative illustration of the results regard-

[24] 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.

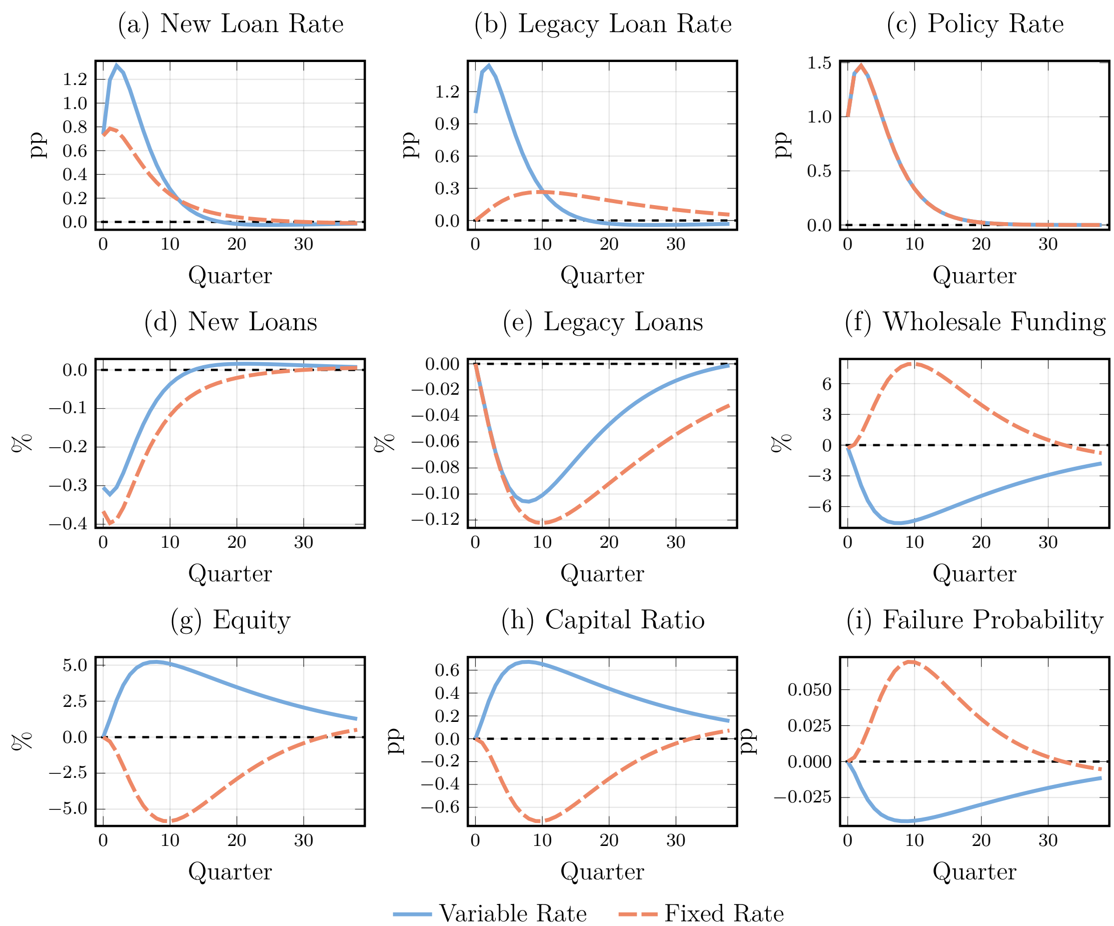
Figure 4: Untargeted impulse responses



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.5 for details.

ing the irrelevance of interest-rate risk exposure when capital constraints are relaxed highlighted in Proposition 1.

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.

Ex-ante heterogeneity. Figure 5 contrasts the aggregate-level IRFs to a one-percentage-point contractionary monetary policy shock in VR and FR economies. Both economies face the same policy-rate path (Panel c), and banks' funding costs rise accordingly as the interest rate on wholesale debt increases in tandem. In contrast, the pass-through to deposit rates remains gradual, by construction (recall the discussion of Figure 3).

This asymmetric response causes the marginal cost of funding—driven by wholesale debt rates—to rise sharply, while the average cost of funding increases more gradually.

The latter reflects the dominant share of deposits in banks' liability structure, whose rates adjust slowly.

The increase in funding costs depresses new-loan origination (Panel d). The resulting contraction in aggregate credit supply, in turn, raises the equilibrium rate on new loans as entrepreneurs face a lower available supply of credit.

For VR banks, the initial pressure on funding costs is offset by the rapid pass-through of the policy rate to both new and legacy loan rates (solid blue line, Panels a and b). This widens the NIM (as seen in Figure 4), raising profitability and, in turn, equity and capital ratios (Panels g and h).

In stark contrast, FR banks (dashed red line) experience a severe and prolonged compression of their NIM: funding costs rise while income from the fixed-rate legacy portfolio remains stagnant (Panel b). The higher interest rate on new loans raises the average rate on banks' portfolios only gradually, as new loans slowly replace maturing legacy ones. These dynamics erode FR banks' equity and capital ratios. The decline in equity is partially offset by increased reliance on wholesale funding (Panel f). The asymmetric response of equity—and its interaction with regulatory capital constraints—represents the main amplification channel explaining the diverging credit responses across the two banking systems.

Ultimately, the deterioration in bank capitalization under a FR regime leads to a significantly sharper decline in new-loan origination compared to the VR system (Panel d). As equity erodes, FR banks must reduce lending to prevent leverage from rising excessively and to maintain regulatory capital ratios. The result is a more prolonged contraction in the loan volume under fixed rates (Panel e), consistent with the empirical evidence presented in Figure 4.

The mechanism highlighted in our model aligns with the findings of Hoffmann et al. (2018), who document that cross-sectional variation in European banks' interest-rate risk exposures is primarily driven by cross-country differences on the asset side—arising from loan-rate fixation conventions—rather than by heterogeneity on the liability side. They show that net worth increases with interest rates for roughly half of the banks in their sample, precisely those operating in VR-dominated economies.

The monetary tightening has opposing effects on financial stability: the probability of bank failure increases markedly in the FR economy, owing to the fall in bank capitalization, whereas it declines in the VR economy (Panel i). Heterogeneity in loan-rate fixation patterns is therefore a critical determinant of both the amplification of monetary policy and its consequences for financial stability.

In sum, ex-ante heterogeneity produces a quantitatively significant difference in the bank lending channel: the elasticity of new lending is approximately one-third larger in fixed-rate economies. Beyond this quantitative difference, the implications for bank capital—critical for financial stability—are diametrically opposed: capital rises in VR economies and falls in FR economies. This finding is consistent with previous empirical work, such as that of Altunok et al. (2023), who document that U.S. banks with a higher share of adjustable-rate mortgages (ARMs) in their loan portfolios benefit from rate hikes. When monetary policy tightens, these banks earn higher interest income, exhibit stronger stock-price reactions, and expand credit supply, in contrast to banks with predominantly fixed-rate mortgage portfolios.[25]

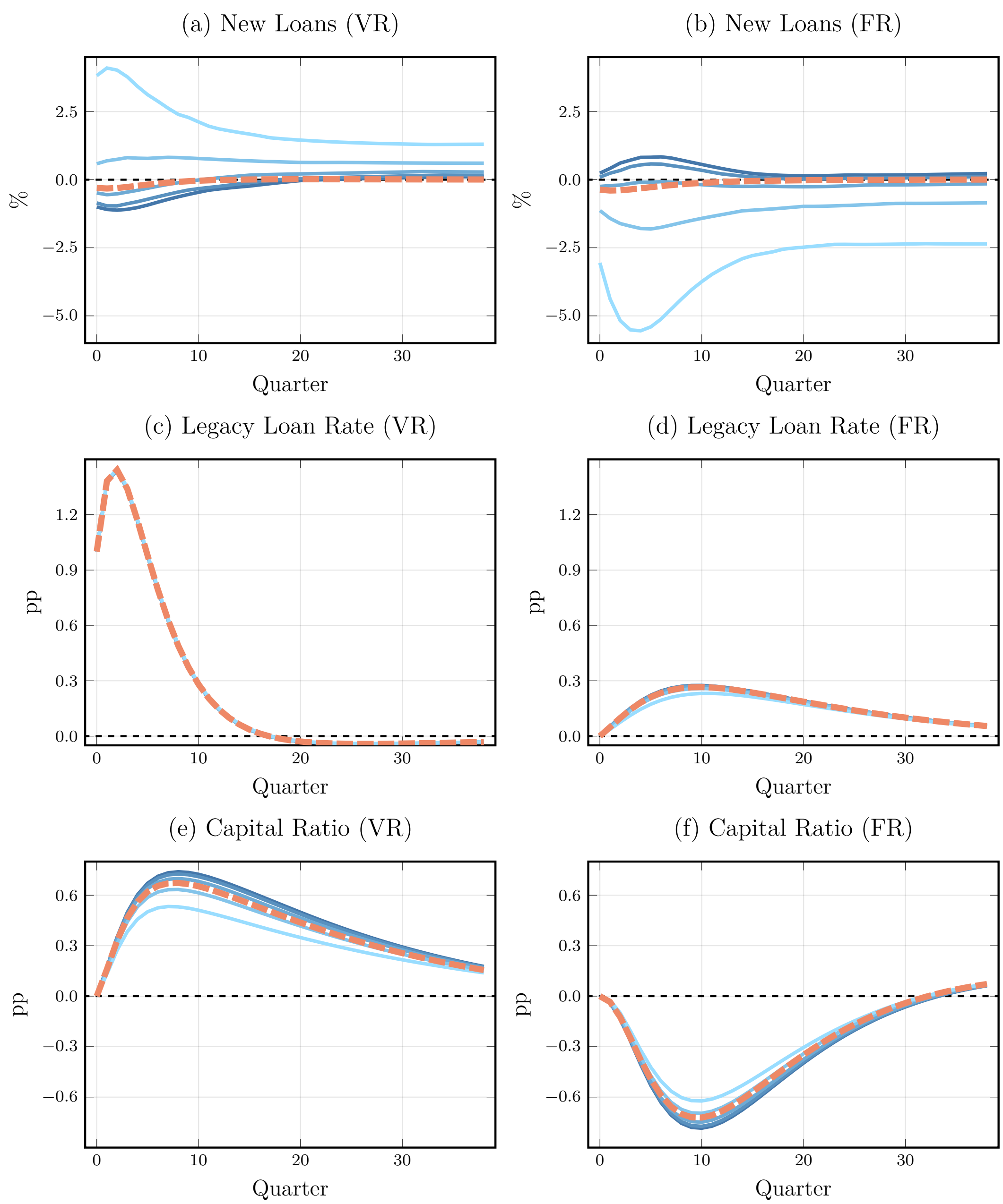
Ex-post heterogeneity. The aggregate responses mask substantial heterogeneity in the transmission of monetary policy to bank lending. To illustrate this, we disaggregate the responses and explore the role of ex-post heterogeneity—the dispersion in leverage arising from idiosyncratic default shocks. Figure 6 presents the impulse responses for banks at different percentiles of the steady-state capital-ratio distribution, with lighter shades representing more highly leveraged institutions (lower capital ratios).

Consistent with the empirical literature (e.g., Jiménez et al., 2012; Dell'Ariccia et al., 2017; Altavilla et al., 2020), high-leverage banks (shown in light blue) are a key margin of transmission. In both FR and VR systems, high-leverage banks exhibit the strongest lending response to the monetary policy shock, though in opposite directions: expanding lending in VR economies and contracting it in FR economies (Panels a and b).

To understand this result, note first that, as discussed above, a monetary contraction raises loan rates more in VR economies than in FR. The pass-through of rates to loan returns is identical across banks within a given economy because they operate in competitive loan markets (Panels c and d). Since deposit and policy rates are also common to all banks, the impact on profitability before lending decisions depends solely on leverage: more leveraged institutions experience proportionally larger gains or losses.

[25] Our model also provides a clear mechanism for the asymmetry in monetary policy transmission that these authors document. During rate hikes, banks with predominantly ARM portfolios expand credit supply much more strongly than fixed-rate mortgage banks because their net interest income and capital positions improve.

Figure 6: Individual impulse response functions



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

However, this effect is dominated by a second force: conditional on a given change in profitability, banks with lower capital ratios—those closer to the regulatory constraint—exhibit a much higher elasticity of new lending to changes in profits. This amplification explains why low-capital (high-leverage) banks increase lending most strongly in VR economies and contract it most sharply in FR economies (Panels a and b).

For low-capital banks in VR economies, the proportionally larger increase in new loans outpaces the increase in equity, so their capital ratios rise proportionally less than those of high-capital banks. Conversely, for high-capital banks, the increase in equity exceeds the increase in loans, so their capital ratios rise proportionally more than the aggregate. In FR systems, the dynamics are reversed: low-capital banks suffer the largest equity losses and must contract lending most sharply, widening the gap between high- and low-leverage institutions.

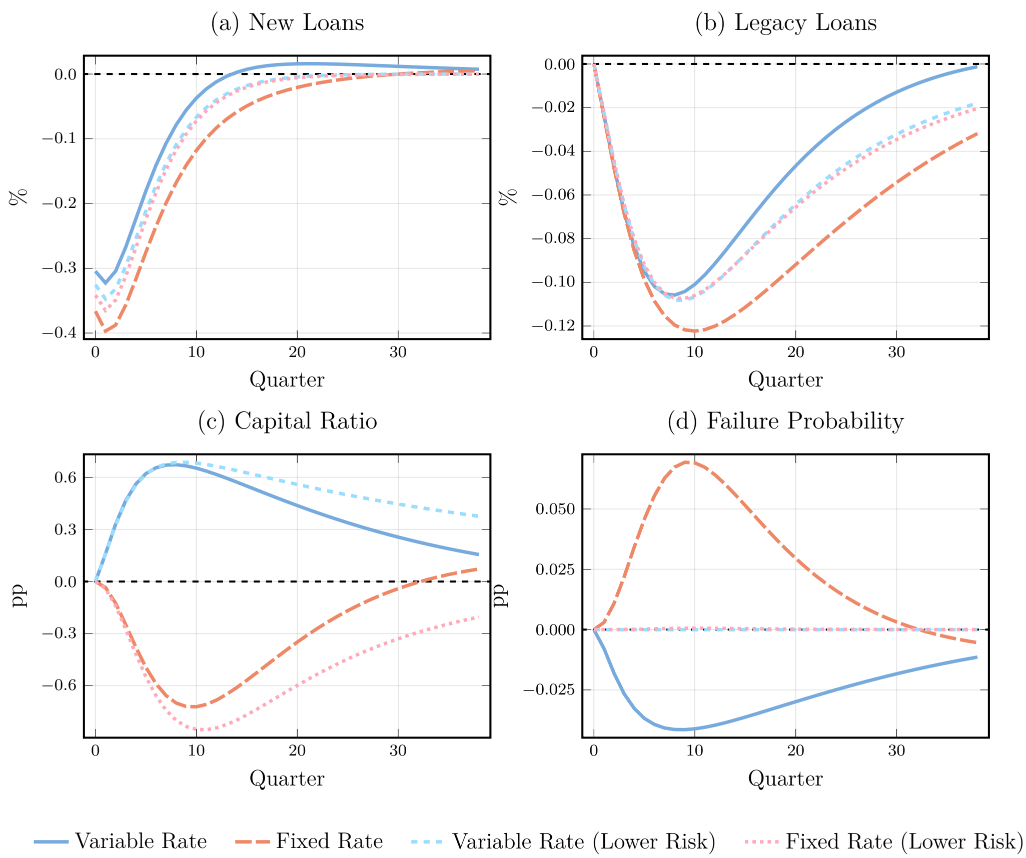
The bottom line is that a monetary policy contraction triggers a *credit redistribution* among banks. In VR economies, high-leverage banks increase their share of aggregate credit, whereas in FR systems, they reduce it.

Interactions between both types of heterogeneity. Figure 7 compares the responses of loan quantities and bank failure probabilities in both economies (FR and VR) against counterfactual cases where we substantially reduce idiosyncratic risk (shown as dotted light lines).

This experiment provides a quantitative benchmark for the theoretical results of Proposition 1. Recall that the irrelevance result requires two conditions: (1) that capital requirements are not binding for any bank at any time, and (2) that banks and entrepreneurs discount future cash flows at identical rates. In this experiment, Condition 1 is approximately satisfied: the low idiosyncratic risk renders banks homogeneous and reduces the share of institutions near the regulatory constraint. Condition 2, however, is not satisfied, as banks and entrepreneurs have different discount rates. Nonetheless, despite the violation of Condition 2, credit dynamics are nearly identical in FR and VR economies, as Panels a and b illustrate. This convergence occurs even though the policy rate shock moves capital ratios in opposite directions (Panel c). The failure probability remains at zero, reflecting the fact that no bank approaches the regulatory constraint. This finding highlights the primacy of Condition 1: capital constraints, not discount-factor differences, are the key driver of differential transmission.

This exercise quantitatively demonstrates one of the key results of this paper: het-

Figure 7: Impulse response functions — Lower idiosyncratic risk



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

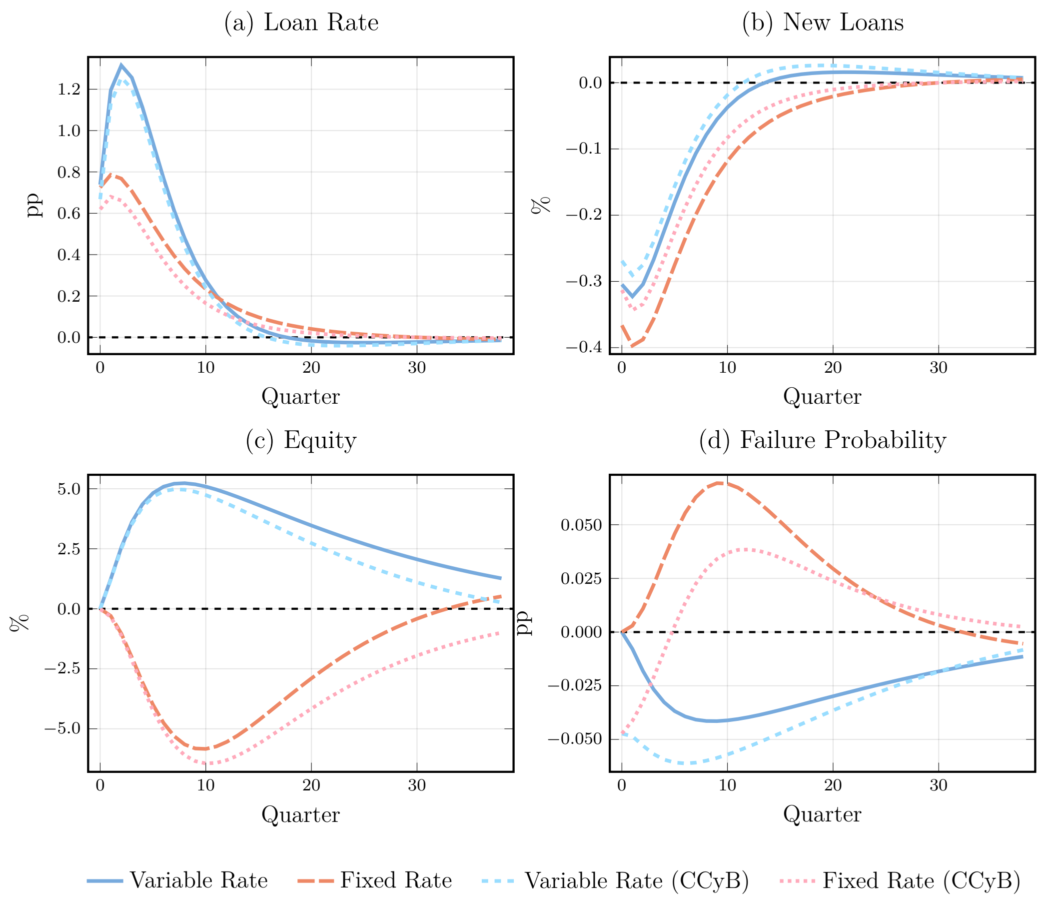
erogeneity in interest-rate risk exposure matters only insofar as idiosyncratic shocks generate ex-post leverage dispersion that pushes some banks toward binding capital constraints.

5. Implications: monetary policy and financial stability

Our findings have important implications for the design and coordination of monetary and macroprudential policies. A prominent macroprudential tool is the countercyclical capital buffer (CCyB). The CCyB requires banks to accumulate additional capital during credit expansions and allows its release during contractions. 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.

As monetary policy also affects credit, a natural question is how these two policies interact. Figure 8 displays the impulse response functions following a monetary policy tightening in VR (solid blue line) and FR (dashed red line) economies. It also shows the responses when the macroprudential authority simultaneously releases the CCyB by 1 percentage point. The CCyB release is modeled as a reduction in the capital requirement γ_t, which then reverts according to $\gamma_t - \gamma = \rho_{\text{ccyb}}(\gamma_{t-1} - \gamma)$ with $\rho_{\text{ccyb}} = 0.95$. This implies that the capital requirement slowly reverts to its steady-state value.

Figure 8: Impulse response functions — Interest rate increase + CCyB release



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

A temporary relaxation of capital requirements can dampen the differential effects of monetary policy across banking systems. Looser requirements reduce the fraction of banks operating near the regulatory constraint. The immediate effect is a reduction in failure probability on impact, as banks enjoy greater regulatory headroom (Panel d).

Furthermore, a reduction in the capital requirement shifts the entire distribution of banks further from the regulatory constraint. This has an asymmetric effect: because equity dynamics move in opposite directions in FR and VR economies (Panel c), pushing banks away from binding constraints reduces the sensitivity of lending to equity fluctuations, making the credit response more similar across the two systems (Panel b). This is consistent with Proposition 1: the less binding capital constraints are, the less consequential is ex-ante heterogeneity.

The opposite result (not shown) also holds: if macroprudential policy tightens during a monetary contraction, the divergence in credit responses across banking systems is amplified. This dynamic complicates the trade-offs facing monetary policymakers in a monetary union, as macroprudential policy changes can amplify regional divergence in the response to a uniform policy stance.

Financial stability origins of monetary policy gradualism. Finally, we examine how different paths of monetary policy tightening that produce similar cumulative increases in interest rates may nonetheless have different financial stability implications for FR and VR banking systems.

To this end, we compare a range of policy rate paths that all yield the same area under the policy rate IRF. This approach is motivated by the standard 3-equation New Keynesian model: in that framework, two policy rate paths with the same cumulative stance—measured by the area under the ex-ante real rate IRF—have equivalent effects on the output gap.[26]

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

[26]To see this, note that the 3-equation New Keynesian model features an IS curve of the form

$$x_t = \mathbb{E}_t(x_{t+1}) - \varsigma(i_t - \mathbb{E}_t(\pi_{t+1}) - r_t^n),$$

where x_t is the output gap, i_t is the nominal interest rate, π_t is the inflation rate, r_t^n is the natural rate of interest, and $\varsigma > 0$ is the intertemporal elasticity of substitution. Variables are expressed as log-linear deviations from 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

$$x_t = -\varsigma \mathbb{E}_t \sum_{m=0}^{\infty} \hat{r}_{t+m}.$$

Thus, the output gap equals the (discounted) sum of expected real rate gaps. Two policy paths yielding the same cumulative real rate gap—i.e., $\mathbb{E}_t \sum_{m=0}^{\infty} \hat{r}_{1,t+m} = \mathbb{E}_t \sum_{m=0}^{\infty} \hat{r}_{2,t+m}$—produce the same output gap.

the 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 rewritten as two first-order processes:

$$\begin{aligned} \hat{r}\,t^M &= \mu_1 \hat{r}\,t-1^M + z_t, \\ z_t &= \mu_2 z t - 1 + \sigma \varepsilon_t, \end{aligned}$$

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

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

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

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

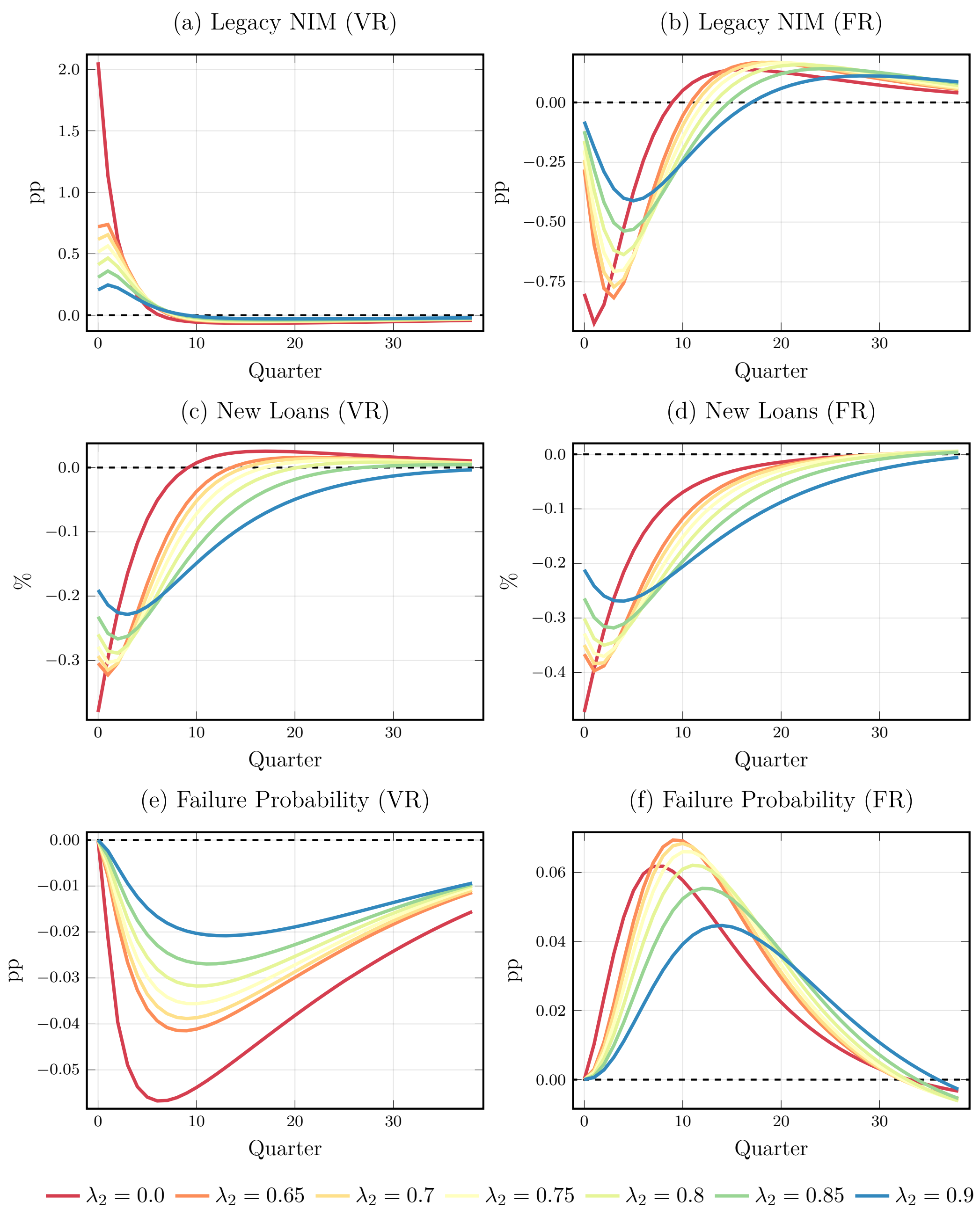
Consider the effect of a more gradual monetary policy tightening in an FR economy. As the rate path becomes more gradual, the initial rate hike is smaller, reducing the initial compression of the NIM (Panel b in Figure 9). This comes at the cost of a more prolonged period of depressed profitability, but the overall effect is to soften the decline in both equity and new loans (Panel d).

In the VR economy, the dynamics differ. The smaller initial rate hike reduces the positive effect on NIM (Panel a), which dampens the boost to bank equity and ultimately amplifies the decline in new loans (Panel c)—the opposite of the FR case. Moreover, because entrepreneurs in the VR economy are forward-looking with respect to interest rates, the prolonged period of elevated rates depresses loan demand more than a sharp but short-lived hike would.

Failure probabilities reflect these developments (Panels e and f): the sharp distinction between FR and VR economies progressively blurs as the tightening becomes more gradual.

Our analysis provides a theoretical foundation for gradualism in monetary policy. Rapid rate increases force abrupt deleveraging in FR banking systems, amplifying the contractionary effects on lending. In contrast, gradual policy adjustments allow banks to rebuild capital buffers and adjust their portfolios more smoothly, reducing the

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.

severity of the lending contraction while achieving the same cumulative policy stance.

The insights in this section suggest that effective macroeconomic stabilization requires careful coordination between monetary and prudential authorities. In particular, the timing and sequencing of policy interventions across these domains should account for differences in banking systems' interest-rate risk exposures.

6. Conclusion

This paper develops a quantitative framework to analyze how heterogeneity in banks' interest-rate risk exposure shapes the transmission of monetary policy through the bank lending channel. Our analysis is motivated by a simple observation: within the euro area, banks in some countries predominantly issue fixed-rate loans while those in others issue variable-rate loans, creating systematic differences in interest-rate risk exposure. We ask whether and when these differences matter for monetary policy transmission and financial stability.

Our main theoretical contribution is an irrelevance result: when banks are unconstrained by capital requirements and discount future cash flows at the same rate as borrowers, the structure of loan contracts—fixed versus variable rate—is immaterial for the aggregate response of credit to monetary policy. This benchmark, which resonates with the Modigliani-Miller theorem, clarifies that interest-rate risk exposure matters only through its interaction with regulatory capital constraints. Whether this interaction is quantitatively important, however, is ultimately an empirical question.

To address this question, we calibrate the model to the euro area, targeting both aggregate moments and the cross-sectional distribution of bank capital ratios. The calibrated model reveals that heterogeneity in loan pricing is quantitatively significant: the elasticity of new lending to a monetary policy shock is approximately one-third larger in fixed-rate economies than in variable-rate economies. The mechanism operates through bank profitability and equity dynamics. When policy rates rise, fixed-rate banks experience capital erosion as funding costs increase while income from legacy loans remains unchanged. Critically, banks near regulatory constraints—which are substantial in the calibrated distribution—are forced to adjust their lending aggressively to prevent violating regulatory constraints. Variable-rate banks, by contrast, see rising loan income that more than offsets higher funding costs, bolstering their equity positions.

The divergence extends to financial stability. Monetary tightening increases failure probabilities in fixed-rate economies while reducing them in variable-rate systems—a finding with direct relevance for central banks overseeing banking systems with heterogeneous loan-pricing conventions. Consistent with our theoretical benchmark, we show that counterfactually reducing idiosyncratic default risk, thereby making banks more homogeneous, dramatically shrinks the differences between fixed- and variable-rate economies.

These findings carry implications for policy design. First, macroprudential policy can modulate the heterogeneous effects of monetary policy: releasing countercyclical capital buffers during a tightening cycle pushes banks away from binding constraints, reducing the divergence in credit responses across banking systems. This interaction is particularly relevant for monetary unions like the euro area, where a common policy rate applies to heterogeneous national banking systems. Second, our analysis provides 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 bank failure probability in fixed-rate economies without materially worsening outcomes in variable-rate systems. Gradualism avoids the sharp equity losses that push fixed-rate banks toward binding constraints.

In sum, this paper shows that heterogeneity in banks' interest-rate risk exposure has quantitatively important implications for monetary policy transmission and financial stability, but only because a substantial share of banks operate near regulatory capital constraints. This finding underscores the importance of jointly considering monetary and macroprudential policies, particularly in currency unions where institutional differences in banking systems interact with a single policy stance.

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Appendices

A. Model derivations

A.1 Portfolio credit risk

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

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

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

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

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

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

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

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

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

A.2 Conditions for risk-free wholesale debt

The balance sheet of the bank, after substituting for the binding constraints (4) and (8), reads:

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

Solving for B_t:

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

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

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

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. We numerically confirm this condition to be satisfied across the state space for our calibration.

A.3 A microfundation for aggregate deposits demand

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

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

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

subject to the budget constraint:

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

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

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

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

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

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

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

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

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

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

where $V^H_{A,t+1}(A,D) \equiv \frac{\partial V^H_{t+1}}{\partial A}$. Using the envelope theorem and the fact that, in equilibrium, $r^M_t = r^B_t$ for all t:

$$V^H_{A,t+1}(A^H_t, D^H_t) = (1 + r^M_t) + U'\left(C_{t+1} + \ell(A^H_t, D^H_t)\right) \cdot \ell_A(A^H_t, D^H_t).$$

Substituting (A.2) evaluated at $t+1$, we have $U\left(C_{t+1} + \ell(A^H_t, D^H_t)\right) = 1$. Thus:

$$\beta\left[(1 + r^M_t) + \ell_A(A^H_t, D^H_t)\right] = 1.$$

Rearranging and using (A.2):

$$\ell_A(A^H_t, D^H_t) = \frac{1}{\beta} - (1 + r^M_t) := s^M_t, \tag{A.4}$$

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

Proceeding analogously for deposits, we obtain:

$$\ell_D(A^H_t, D^H_t) = \frac{1}{\beta} - (1 + r^D_t) := s^D_t, \tag{A.5}$$

where s^D_t denotes the corresponding spread for deposits.

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

$$\ell_A(A^H_t, D^H_t) = \frac{\nu\kappa\left[\left(A^H_t\right)^{\nu}\left(D^H_t\right)^{1-\nu}\right]^{1-\vartheta}}{A^H_t}, \tag{A.6}$$

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

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

$$\frac{\nu}{1-\nu}\frac{D^H_t}{A^H_t} = \frac{s^M_t}{s^D_t}. \tag{A.8}$$

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

Optimal quantities. To solve for the individual quantities, substitute the portfolio ratio back into the first-order conditions. From (A.4):

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

which can be rewritten as:

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

From (A.8), we have:

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

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

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

Similarly, the demand for deposits satisfies:

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

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

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

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

Market clearing in the deposit market requires:

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

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

Market clearing in the reserve market requires:

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

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

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

A.4 Derivation of Resource Constraint

Let $y_t(l,x)$ denote the policy for variable y_t of a bank with leverage l and average loan rate/spread x on legacy loans and let $H_t(l,x,e)$ denote the joint distribution of leverage, the loan rate/spread on legacy loans and equity.[27] 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

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

consolidated government budget constraint:

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

where

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

The expression for the mass of failing banks $\bar{\mathscr{F}}_{t-1}$ is derived in Appendix A.7.

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

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

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

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

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

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

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

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

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

Combining the last two expressions yields:

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

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

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

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

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

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

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

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

Substituting this expression into the budget constraint yields

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

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

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

or

$$Y_t = C^D_t+C^H_t+\Delta(L_t+N_t)+RC_t.$$

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

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

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

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

A.5 Bank problem

We start by summarizing the problem of a bank presented in Section 2.1. The problem of a bank is

$$V_t^B(L_{jt}, E_{jt}, x_{jt}^L) = \mathbf{1}_{\{E_{jt} \geq \gamma L_{jt}\}} \left[\max_{\{N_{jt}, M_{jt}, D_{jt}, B_{jt}\}} \beta \mathbb{E}_t [(1-\chi) V_{t+1}^B (L_{jt+1}, E_{jt+1}, x_{jt+1}^L) + \chi E_{jt+1}] \right]$$

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

with profits Π_{jt+1} defined as

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

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

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

for fixed-rate banks, and

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

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

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

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

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

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

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

with

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

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

A bank's decisions, therefore, only depends on its leverage l_t and on 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_t for fixed-rate banks, respectively.

A.6 Proof of Proposition 1

We start with the problem of the FR bank. Assume, for now, that there is no idiosyncratic credit risk (i.e., $\omega_{jt} = p$ for all j and all t), implying that capital requirements never bind for any bank at any date, and there is zero failure probability. In this case, the problem of a bank j is:

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

subject to

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

In any equilibrium where $r^D_t < r^B_t$ (deposits are cheaper than wholesale funding) and $r^B_t \geq r^M_t$ (reserves earn less than or equal wholesale borrowing costs), the deposit constraint (4) and the liquidity requirement (8) hold with equality. We restrict attention to such equilibria, which our calibration confirms hold empirically. Under these binding constraints, D_{jt}, M_{jt}, and B_{jt} can be written as functions of N_{jt}, L_{jt}, and E_{jt}, leaving new lending N_{jt} as the sole choice variable. The bank's problem is reduced to:

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

subject to the laws of motion:

$$
\begin{aligned}
L_{j,t+1} &= (1-p)(1-\delta)(L_{j,t}+N_{j,t}),\\
E_{j,t+1} &= E_{j,t}+(1-\tau)\Pi_{j,t+1},\\
r^L_{j,t+1} &= \frac{r^L_{j,t}L_{j,t}+r^N_t N_{j,t}}{L_{j,t}+N_{j,t}},
\end{aligned}
$$

where bank profits, $\Pi_{j,t+1}$, are given by:

$$
\begin{aligned}
\Pi_{j,t+1} = (1-p)\left(r^L_{j,t}L_{j,t}+r^N_t N_{j,t}\right) &+ r^M_t\left[\frac{\theta}{1-\theta}(L_{j,t}+N_{j,t}-E_{j,t})\right]\\
&- r^D_t \alpha L_{j,t} - r^B_t\left[\frac{(1-\alpha(1-\theta))L_{j,t}+N_{j,t}-E_{j,t}}{1-\theta}\right]\\
&- \lambda p(L_{j,t}+N_{j,t}) - f\left(N_{j,t}/L_{j,t}\right)L_{j,t}.
\end{aligned}
$$

We can now iterate forward the laws of motion of the state variables:

Stock of loans $L_{j,t+k}$. To find the expression for $L_{j,t+k}$ as a function of $L_{j,t}$ and the sequence of new loans $\{N_{j,t+m}\}_{m=0}^{k-1}$, we can solve the law of motion for loans by forward iteration. The law of motion for $L_{j,t+k}$ is given by:

$$
L_{j,t+1} = (1-p)(1-\delta)(L_{j,t}+N_{j,t}).
$$

Let's define a constant $\varrho = (1-p)(1-\delta)$. The equation becomes $L_{j,t+1} = \varrho(L_{j,t}+N_{j,t})$. Then, for any time $t+k$:

$$
L_{j,t+k} = \varrho N_{j,t+k-1} + \varrho^2 N_{j,t+k-2} + \cdots + \varrho^{k-1}N_{j,t+1} + \varrho^k N_{j,t} + \varrho^k L_{j,t},
$$

which can be written more compactly as:

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

Average loan rate $r^L_{j,t+k}$. To find the expression for $r^L_{j,t+k}$, we start with its law of motion:

$$
r^L_{j,t+1} = \frac{r^L_{j,t}L_{j,t}+r^N_t N_{j,t}}{L_{j,t}+N_{j,t}}.
$$

We can define the bank j's total interest income from legacy loans in period t as $I_{j,t} = r^L_{j,t}L_{j,t}$. From the law of motion for $r^L_{j,t+1}$:

$$r^L_{j,t+1}(L_{j,t} + N_{j,t}) = r^L_{j,t}L_{j,t} + r^N_t N_{j,t}.$$

We know from the law of motion for loans that $L_{j,t+1} = \varrho(L_{j,t} + N_{j,t})$. Then $L_{j,t} + N_{j,t} = L_{j,t+1}/\varrho$. Substituting this into the rearranged equation gives:

$$r^L_{j,t+1}L_{j,t+1} = \varrho(r^L_{j,t}L_{j,t} + r^N_t N_{j,t}).$$

This gives us a law of motion for the total interest income, $I_{j,t+1} = \varrho(I_{j,t} + r^N_t N_{j,t})$. We can solve this by forward iteration, similar to how we solved for $L_{j,t}$:

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

To find the expression for $r^L_{j,t+k}$, we simply divide the total interest income, $r^L_{j,t+k}L_{j,t+k}$, by the total loan stock, $L_{j,t+k}$. Using the expression for $L_{j,t+k}$ from the previous step we get:

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

Equity $E_{j,t+k+1}$. The expression for bank equity $E_{j,t+k+1}$ in period $t+k+1$ is a function of the initial states $(E_{j,t}, L_{j,t}, r^L_{j,t})$, the history of the bank's choices for new loans $(\{N_{j,t+m}\}_{m=0}^{k-1})$, the path of exogenous interest rates $(\{r^M_{t+m}, r^B_{t+m}, r^D_{t+m}\}_{m=0}^{k-1})$, and the path of endogenous new loan rates $(\{r^N_{t+m}\}_{m=0}^{k-1})$.

The law of motion for bank equity is given by:

$$E_{j,t+1} = E_{j,t} + (1-\tau)\Pi_{j,t+1}.$$

The profit function $\Pi_{j,t+1}$ can be written compactly as:

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

where $\Phi_t \equiv \alpha(r^B_t - r^D_t) - \lambda p - \mu_t$ denotes the marginal return on legacy loans net of funding and credit costs, $\Psi_t \equiv (1-p)r^N_t - \lambda p - \mu_t$ the marginal return on new loans net of funding and credit costs, and $\mu_t \equiv \frac{r_t^B - \theta r_t^M}{1-\theta}$ the net cost of wholesale funding (accounting for liquidity requirements).

The law of motion of equity can now be rewritten as:

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

where $\Upsilon_t \equiv \left[1+(1-\tau)\mu_t\right]$. By iterating this relationship forward from t to $t+k+1$, we obtain the final expression:

$$\begin{aligned}E_{j,t+k+1} = &\left(\prod_{m=0}^{k}\Upsilon_{t+m}\right)E_{j,t} \\ &+ (1-\tau)\sum_{m=0}^{k}\left(\prod_{q=m+1}^{k}\Upsilon_{t+q}\right)\Big[(1-p)I_{j,t+m} + \Phi_{t+m}L_{j,t+m} \\ &\qquad + \Psi_{t+m}N_{j,t+m} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)L_{j,t+m}\Big],\end{aligned}$$

which holds with the convention that an empty product is equal to one ($\prod_{q=k+1}^{k}\Upsilon_{t+q} = 1$).

First-order condition for $N_{j,t}$. To obtain the first-order condition for the bank's optimal choice of new loans, we differentiate the objective function with respect to $N_{j,t}$. The objective function is:

$$V_{j,t} = \sum_{k=0}^{\infty}\beta^{k+1}(1-\chi)^k\chi E_{j,t+k+1}.$$

Using the expression for $E_{j,t+k+1}$ derived previously, we can isolate the terms depending on $N_{j,t}$. The choice of $N_{j,t}$ affects the equity path through two channels: the direct impact on profits in period t (where $m=0$), and the persistent impact on the stocks of loans and interest income in all future periods $t+m$ (where $m \geq 1$). We define the effective discount factor for a unit of equity realized in period $t+m+1$ as $\Lambda_{t,m}$:

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

This term represents the present value of the expected dividends generated by a marginal unit of after-tax profit in period $t+m$. Differentiating the objective function requires summing the impact of $N_{j,t}$ on the profit flow at each horizon m, weighted by $\Lambda_{t,m}$.
1. Immediate impact ($m = 0$): The choice of $N_{j,t}$ directly affects profits at t through the net return on new loans Ψ_t and the adjustment costs.

$$\frac{\partial \Pi_{j,t+1}}{\partial N_{j,t}} = \Psi_t - f'\left(\frac{N_{j,t}}{L_{j,t}}\right).$$

2. Future impact ($m \geq 1$): The choice of $N_{j,t}$ increases the stock of loans and interest income in future periods. From the laws of motion derived earlier, the marginal effect of $N_{j,t}$ on future states is:

$$\frac{\partial L_{j,t+m}}{\partial N_{j,t}} = \varrho^m,$$
$$\frac{\partial I_{j,t+m}}{\partial N_{j,t}} = r_t^N \varrho^m.$$

The impact on the profit flow at time $t+m$ is:

$$\begin{aligned}\frac{\partial \Pi_{j,t+m+1}}{\partial N_{j,t}} &= (1-p)\frac{\partial I_{j,t+m}}{\partial N_{j,t}} + \Phi_{t+m}\frac{\partial L_{j,t+m}}{\partial N_{j,t}} - \left[f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} - f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right]\frac{\partial L_{j,t+m}}{\partial N_{j,t}} \\ &= \varrho^m\left[(1-p)r_t^N + \Phi_{t+m} - f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} + f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right].\end{aligned}$$

Combining these terms, the expression for the derivative of the objective function with respect to $N_{j,t}$ is:

$$\begin{aligned}\frac{\partial V_{j,t}}{\partial N_{j,t}} = \Lambda_{t,0}&\left[\Psi_t - f'\left(\frac{N_{j,t}}{L_{j,t}}\right)\right] \\ &+ \sum_{m=1}^{\infty}\Lambda_{t,m}\varrho^m\left[(1-p)r_t^N + \Phi_{t+m} - f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} + f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right],\end{aligned}$$

which states that the optimal lending choice balances the immediate net return against the future value of maintaining a larger loan portfolio.

Variable-rate bank. We can proceed in a similar way to obtain the expression that characterizes the optimal choice of $N_{j,t}$ for the variable-rate bank:

$$\frac{\partial V_{j,t}}{\partial N_{j,t}} = \Lambda_{t,0}\left[\tilde{\Psi}_t - f'\left(\frac{N_{j,t}}{L_{j,t}}\right)\right] + \sum_{m=1}^{\infty}\Lambda_{t,m}\varrho^m\left[(1-p)s_t^N + \tilde{\Phi}_{t+m} - f'\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\frac{N_{j,t+m}}{L_{j,t+m}} + f\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)\right],$$

where the auxiliary variables are defined as:

$$\tilde{\Phi}_t \equiv \alpha(r_t^B - r_t^D) - \lambda p - \mu_t + (1-p)r_t^M,$$
$$\tilde{\Psi}_t \equiv (1-p)(s_t^N + r_t^M) - \lambda p - \mu_t.$$

Optimal new loans $N_{j,t}^{FR}$ (FR bank). Setting the derivative $\frac{\partial V_{j,t}}{\partial N_{j,t}} = 0$, substituting the functional form for origination costs, and solving for new loans $N_{j,t}^{FR}$ we obtain:

$$N_{j,t}^{FR} = \frac{L_{j,t}}{2\eta}\left[\Psi_t + \sum_{m=1}^{\infty}\frac{\Lambda_{t,m}}{\Lambda_{t,0}}\varrho^m\left((1-p)r_t^N + \Phi_{t+m} - \eta\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)^2\right)\right]. \tag{A.13}$$

Optimal new loans $N_{j,t}^{VR}$ (VR bank). Setting the derivative $\frac{\partial V_{j,t}}{\partial N_{j,t}} = 0$, substituting the functional form for origination costs, and solving for new loans $N_{j,t}^{VR}$ we obtain:

$$N_{j,t}^{VR} = \frac{L_{j,t}}{2\eta}\left[\tilde{\Psi}_t + \sum_{m=1}^{\infty}\frac{\Lambda_{t,m}}{\Lambda_{t,0}}\varrho^m\left((1-p)s_t^N + \tilde{\Phi}_{t+m} - \eta\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)^2\right)\right]. \tag{A.14}$$

Relationship between fixed rate r_t^N and spread s_t^N. Equating the optimal choices of new loans for the fixed- and variable-rate banks implies that the fixed rate r_t^N must equal the fixed spread s_t^N plus a weighted average of the current and future policy rates $\{r_{t+m}^M\}_{m=0}^{\infty}$. Defining the weighting factor for horizon m as $w_{t,m} \equiv \frac{\Lambda_{t,m}}{\Lambda_{t,0}}\varrho^m$ (with $w_{t,0} = 1$), the relationship is:

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

This condition states that for the bank to be indifferent between the two pricing structures, the fixed rate must "price in" the expected future path of the market rates that the bank gives up by locking in a fixed rate at origination. The weights depend on the loan survival rate (ϱ) and the bank's effective discount factor (Λ).

Relationship between r_t^N and s_t^N from loan demand. We seek the relationship between the fixed rate r_t^N and the variable spread s_t^N that ensures the quantity of new loans demanded, N_t, is identical in both economies. We equate the demand functions (12) and (13) and let Ω_m be the effective discount factor for the entrepreneur's payoffs m periods after the loan origination (specifically, the interest payment at $t+m+1$):

$$\Omega_m \equiv \beta^{m+1}(1-p)^{m+1}(1-\delta)^m(1-\tilde{\chi})^m.$$

The demand equality condition is:

$$\sum_{m=0}^{\infty} \Omega_m (A - r_t^N) = \sum_{m=0}^{\infty} \Omega_m \left[A - (r_{t+m}^M + s_t^N)\right].$$

Since A, r_t^N, and s_t^N are known at time t and do not depend on m, we can separate the terms:

$$A\sum_{m=0}^{\infty} \Omega_m - r_t^N \sum_{m=0}^{\infty} \Omega_m = A\sum_{m=0}^{\infty} \Omega_m - \sum_{m=0}^{\infty} \Omega_m r_{t+m}^M - s_t^N \sum_{m=0}^{\infty} \Omega_m.$$

The terms involving the parameter A cancel out. We can rearrange the remaining terms to isolate r_t^N:

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty} \Omega_m r_{t+m}^M}{\sum_{m=0}^{\infty} \Omega_m}. \tag{A.16}$$

This result mirrors the supply-side condition: for the entrepreneur to be indifferent between fixed and variable rate loans, the fixed rate must equal the fixed spread plus a weighted average of the expected future path of market rates.

Combining (A.15) and (A.16) we obtain that, for the irrelevance result to hold, we need:

$$\frac{\sum_{m=0}^{\infty} w_{t,m} r_{t+m}^M}{\sum_{m=0}^{\infty} w_{t,m}} = \frac{\sum_{m=0}^{\infty} \Omega_m r_{t+m}^M}{\sum_{m=0}^{\infty} \Omega_m}.$$

Verification of Condition 2. For both conditions (A.15) and (A.16) to be satisfied simultaneously for *any* path of policy rates $\{r_{t+m}^M\}_{m\geq 0}$, the weighted averages must coincide. This requires that the discount factor sequences $\{w_{t,m}\}$ and $\{\Omega_m\}$ be proportional:

$$\frac{w_{t,m}}{w_{t,0}} = \frac{\Omega_m}{\Omega_0} \quad \text{for all } m \geq 0. \tag{A.17}$$

Since $w_{t,0} = 1$ by definition and $\Omega_0 = \beta(1-p)$, condition (A.17) becomes:

$$w_{t,m} = \frac{\Omega_m}{\beta(1-p)} = \beta^m(1-p)^m(1-\delta)^m(1-\tilde{\chi})^m \quad \text{for all } m \geq 1. \tag{A.18}$$

We now derive $w_{t,m}$ in terms of primitives. Assuming interest rates are constant over time (or, equivalently, focusing on steady state), we have $\Upsilon_{t+q} = \Upsilon$ for all q, where $\Upsilon \equiv 1 + (1-\tau)\mu$ and $\mu \equiv \frac{r^B - \theta r^M}{1-\theta}$. Under this assumption:

$$\begin{aligned}
\Lambda_{t,m} &= (1-\tau)\sum_{k=m}^{\infty} \beta^{k+1}(1-\chi)^k \chi \Upsilon^{k-m} \\
&= (1-\tau)\chi\beta^{m+1}(1-\chi)^m \sum_{j=0}^{\infty} \left[\beta(1-\chi)\Upsilon\right]^j \\
&= \frac{(1-\tau)\chi\beta^{m+1}(1-\chi)^m}{1-\beta(1-\chi)\Upsilon},
\end{aligned}$$

provided $\beta(1-\chi)\Upsilon < 1$ (a standard transversality condition). Hence:

$$\frac{\Lambda_{t,m}}{\Lambda_{t,0}} = \left[\beta(1-\chi)\right]^m.$$

Recalling that $w_{t,m} \equiv \frac{\Lambda_{t,m}}{\Lambda_{t,0}}\varrho^m$ with $\varrho = (1-p)(1-\delta)$, we obtain:

$$w_{t,m} = \left[\beta(1-\chi)(1-p)(1-\delta)\right]^m.$$

Condition (A.18) therefore requires:

$$\left[\beta(1-\chi)(1-p)(1-\delta)\right]^m = \left[\beta(1-p)(1-\delta)(1-\tilde{\chi})\right]^m \quad \text{for all } m \geq 1.$$

This holds if and only if:

$$\chi = \tilde{\chi}.$$

Condition 2 (as stated in Proposition 1) is therefore equivalent to requiring that the bank exit rate χ equal the loan liquidation rate upon bank exit $\tilde{\chi}$, together with the assumption that the effective discount factor Υ is constant over time. When interest rates vary, this condition generalizes to requiring that banks and entrepreneurs discount cash flows at every horizon identically, which in turn requires aligning tax rates, exit probabilities, and access to safe asset investments.

Sufficiency: Equilibrium equivalence under Conditions 1 and 2. We now show that, under Conditions 1 and 2, the equilibrium paths of aggregate lending coincide in the FR and VR economies.

Step 1: Loan supply equivalence. Consider the optimal lending policy for bank j in the FR and in the VR economy, given by equations (A.13) and (A.14), respectively. Using the definitions of $\tilde{\Psi}_t$ and $\tilde{\Phi}_{t+m}$, we can rewrite:

$$N_{j,t}^{VR} = \frac{L_{j,t}}{2\eta}\Bigg[\Psi_t + (1-p)\left(s_t^N + r_t^M - r_t^N\right) \\ + \sum_{m=1}^{\infty} w_{t,m}\left((1-p)s_t^N + (1-p)r_{t+m}^M + \Phi_{t+m} - \eta\left(\frac{N_{j,t+m}}{L_{j,t+m}}\right)^2\right)\Bigg].$$

Comparing with $N_{j,t}^{FR}$, we see that $N_{j,t}^{FR} = N_{j,t}^{VR}$ if and only if:

$$(1-p)r_t^N + \sum_{m=1}^{\infty} w_{t,m}(1-p)r_t^N = (1-p)\left(s_t^N + r_t^M\right) + \sum_{m=1}^{\infty} w_{t,m}(1-p)\left(s_t^N + r_{t+m}^M\right).$$

Factoring out $(1-p)$ and rearranging:

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

which is equivalent to the supply-side equivalence condition (A.15).

Step 2: Loan demand equivalence. The demand-side analysis in equations (12) and (13) implies that entrepreneurs are indifferent between FR and VR loans when:

$$r_t^N = s_t^N + \frac{\sum_{m=0}^{\infty}\Omega_m r_{t+m}^M}{\sum_{m=0}^{\infty}\Omega_m}.$$

Step 3: Equilibrium. Under Condition 2, the discount factors $\{w_{t,m}\}$ and $\{\Omega_m\}$ are proportional (equation A.17). Therefore, both supply and demand conditions reduce to the *same* relationship between r_t^N and s_t^N:

$$r_t^N = s_t^N + \bar{r}_t^M, \tag{A.19}$$

where $\bar{r}_t^M \equiv \frac{\sum_{m=0}^{\infty} w_{t,m} r_{t+m}^M}{\sum_{m=0}^{\infty} w_{t,m}}$ is the discounted average of expected future policy rates.

In the FR economy, the equilibrium is characterized by loan demand $N_t = a^{-1}(\cdot)$ depending on r_t^N, and loan supply satisfying the bank FOC. In the VR economy, the equilibrium is characterized by loan demand depending on s_t^N (and the path $\{r_{t+m}^M\}$), and loan supply satisfying the VR bank FOC.

Under the price relationship (A.19), loan demand is identical (i.e., the NPV of interest payments from the entrepreneur's perspective is the same), and loan supply (bank FOCs) delivers identical quantities, as shown in Step 1. Therefore, the equilibrium quantity of new lending N_t is the same in both economies. Since the law of motion for aggregate loans,

$$L_{t+1} = (1-p)(1-\delta)(L_t + N_t),$$

is identical in both economies, and initial conditions coincide by assumption, the paths $\{L_t\}_{t\geq 0}$ and $\{N_t\}_{t\geq 0}$ are identical.

Verification of Condition 1. It remains to verify that the capital constraint $E_{jt} \geq \gamma(L_{jt} + N_{jt})$ is non-binding for all banks at all times.

In the presence of idiosyncratic risk, bank leverage $l_{jt} = L_{jt}/E_{jt}$ varies across banks due to heterogeneous realizations of ω_{jt}. Some banks may experience sufficiently adverse shocks that their leverage approaches or exceeds the regulatory limit $1/\gamma$.

Consider the limiting case $\rho \to 0$, where idiosyncratic dispersion in default rates vanishes. In this limit, all banks experience the same default rate $\omega_{jt} = p$ (the unconditional mean). Consequently, all banks follow identical paths and leverage is equalized across banks.

Let l^* denote the common steady-state leverage. The capital constraint is non-binding if and only if $l^* < 1/\gamma$. This condition imposes a restriction on parameters: the expected return on lending net of funding costs must be sufficiently high that banks accumulate equity faster than they expand lending, maintaining leverage below the regulatory threshold.

To verify formally, note that, in steady state, $l^* = \varrho(l^* + n^*)/g^*$, where $n^* = N/E$ is steady-state new lending per unit of equity and $g^* = 1 + (1-\tau)\pi^*$ is the steady-state gross equity growth rate. The capital constraint is slack if $l^* + n^* < 1/\gamma$.

We verify numerically that, for the calibration in Section 3, this condition is satisfied when ρ is sufficiently small. As documented in Section 4, reducing ρ causes differences between FR and VR economies to vanish, confirming the logic of the irrelevance result. □

A.7 Law of motion of a bank's equity

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

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

A bank's equity at $t+1$ is a function of states $(l_{jt}, x^L_{jt}, e_{jt})$ at time t and shocks (ω, ι) at $t+1$.[28] We can write the law of motion of equity as

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

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

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

where

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

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

Integrating over the Bernoulli distribution for ι yields

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

[28] 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.

Integrating over ω yields

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

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

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

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

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

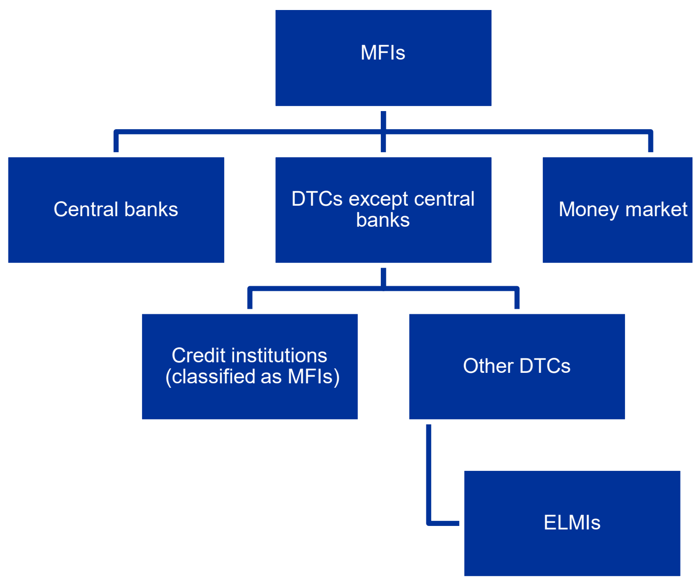
$$
\begin{aligned}
G_t &= \frac{1}{E_t} \int \bar{g}_{t+1}(l_{jt}, x_{jt}^L) e_{jt} dH_t(l_{jt}, x_{jt}^L, e_{jt}), \text{ and} \\
\bar{\mathscr{F}}_t &= \int \left[1 - (1-\chi) F(\bar{\omega})\right] dH_t(l_{jt}, x_{jt}^L, e_{jt}).
\end{aligned}
$$

B. Empirical Appendix

B.1 Consolidated banks balance sheet: Data sources

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

Figure B.1: Components of the MFIs sector



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

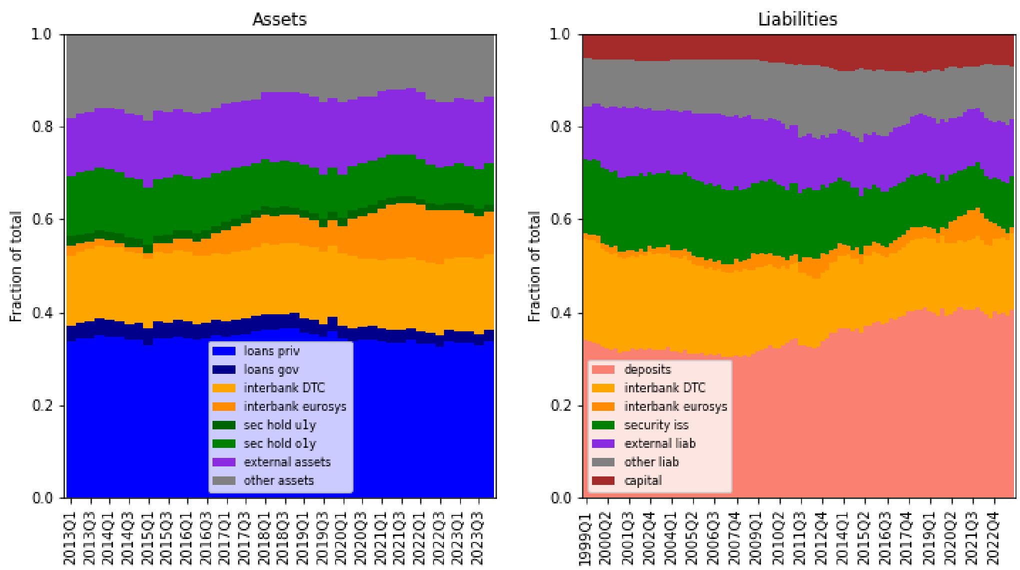
The main source is the Statistical Data Warehouse (SDW) of the ECB. We use monthly or quarterly data subject to availability and transform the series to quarterly frequency. The period of analysis starts corresponds to 01/1999 - 01/2024. Datasets:

- Consolidated balance sheet of the MFIs (excluding the Eurosystem). https://data.ecb.europa.eu/publications/money-credit-and-banking/3031821
- MFI holdings of securities breakdown by maturity and types: Debt securities, equity, and non-MMF investment fund shares. https://data.ecb.europa.eu/publications/money-credit-and-banking/3031889
- Sectoral breakdown of MFI loans vis-à-vis the private sector. https://data.ecb.europa.eu/publications/money-credit-and-banking/3031822

B.2 Euro Area MFIs Balance Sheet

This section summarizes the salient features of the aggregated balance sheet of monetary financial institutions (MFIs) operating in the euro area, excluding the Eurosystem.[29] These MFIs include deposit-taking institutions (banks), and money market funds (MMFs).

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



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

An inspection of the asset side of Monetary and Financial Institutions (MFIs) in the euro area from 1999 to 2023, in Figure B.2, shows that their asset composition has been remarkably stable. On average, the lending portfolio to households, firms, and the government accounts for 62% of assets. Interbank loans—which include repurchase agreements (repos), securities lending, and similar operations with other MFIs and national central banks—account for about 15% of assets. Security holdings, both short and long-term, account for the remaining 23%.[30] On the liabilities side, most liabilities

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

[30]We assign external assets and other assets proportionally to the loans and short-term security holdings

(60%) are deposits and interbank deposits (17%). The remaining liabilities are securities (16 %) and capital (7%).[31] See the breakdown below in the Table B.1.

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

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

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

B.3 CET 1 Capital Ratios and Buffers

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

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

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

categories. External assets are holdings of cash in currencies other than the euro, holdings of securities issued by non-residents of the euro area, and loans to non-residents of the euro area (including banks). For statistical purposes, these items are included indistinguishably in MFIs' external assets without identifying them separately.

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

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

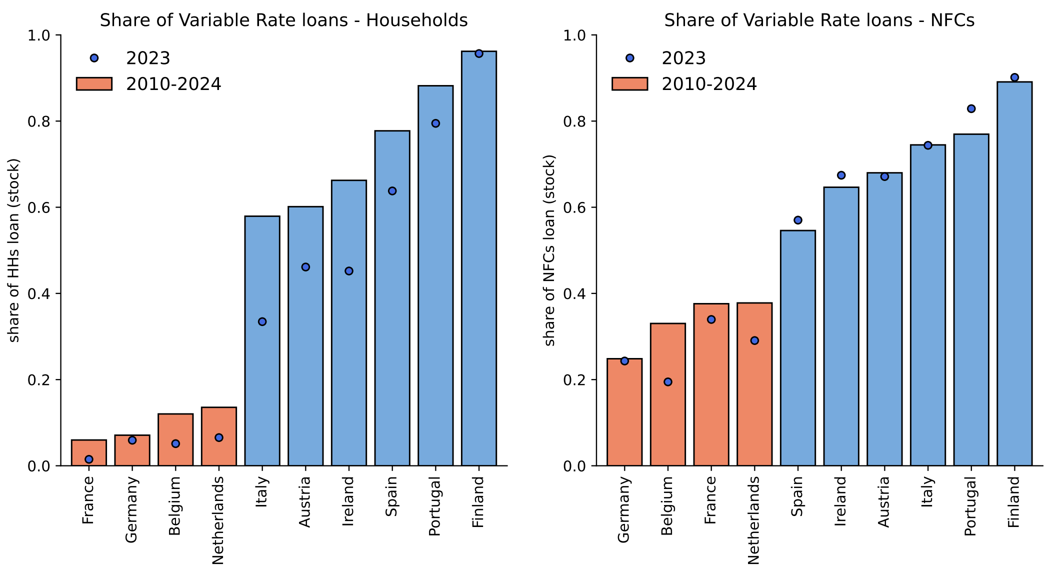
The first two columns present the cross-sectional averages of the grouped distribution for a sample of euro area banks from 2013 to 2020. We construct an unbalanced bank-level panel using balance-sheet data from S&P Global, a proprietary source. Our quarterly dataset includes information on common equity tier 1 (CET1) capital levels, risk-weighted assets, and total assets. For each bank in the sample, we calculate the capital buffer as the difference between its CET1 ratio and the applicable Combined Buffer Requirement (CBR) in each quarter. The CBR is defined as the sum of the Capital Conservation Buffer (CCoB), the Countercyclical Capital Buffer (CCyB), and the maximum of the following institution-specific components: the Systemic Risk Buffer (SRB), the Global Systemically Important Institution (G-SII) buffer, and the Other Systemically Important Institution (O-SII) buffer.

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

B.4 Loan Rate Pricing

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

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



Data sources: ECB Statistical Data Warehouse. The left panel presents the share of the stock of aggregate lending to households (including mortgage loans, consumer loans, and other loans) issued at variable rates. The right panel presents the share of stock of aggregate lending to non-financial corporations issued at variable rates. The bars display the average for 2010Q1-2024Q1. Orange bars corresponds to our classification of fixed-rate countries and blue bars to variable-rates. Blue circles depict the average for the year 2023.

B.5 Estimating Local Projections

We estimate Local Projections a là Jordà (2005) and Jordà et al. (2015). We use as a monetary policy shock the first differences in the deposit facility rate (DFR) instrumented with a measure of monetary surprises.

We built a balanced panel for the twenty euro are countries. In our baseline estimations, presented in the paper, we restrict to the ten largest countries (Austria, Belgium, Germany, Finland, France, Italy, Ireland, Netherlands, Portugal, and Spain) because this allows to construct a balanced panel without data gaps. Variables include lending, deposit rates, and net interest margin (NIM) rates, lending volumes, capital/equity ratios, and macroeconomic indicators (inflation rates, GDP growth, employment, among others) from 2000 to 2023. All variables in the panel are consolidated at the country level, the data frequency is quarterly.

Countries are categorized as variable-raters (VR) if their share of variable-rate lending is above 50% or fixed-raters (FR) otherwise. VR countries are Spain, Portugal, Italy, Finland, Ireland, and Austria. FR countries are Germany, France, Belgium, and the Netherlands. In Appendix B.6 we present robustness checks for the extended sample with all 20 euro area countries, and for a restricted sample where we exclude a set of southern european countries. All IRFs remain qualitatively unchanged.

Interest rates. We estimate the following local projection specification:

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

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

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

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

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

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

Figure 4 (in the main text) shows the estimated IRFs for interest rates, and lending volumes. The sample period is 2003 to 2019.[32] In each Figure, the left Panel depicts the sequence of estimated dynamic coefficients $\{\beta_{1h}\}_{h=0}^{h=16}$ of the monetary policy shock as a solid blue line together with 95% confidence bands. This represents the average effect across VR countries. The right Panel depicts the sequence of estimated dynamic coefficients $\{\beta_{1h}+\beta_{2h}\}_{h=0}^{h=16}$ of the monetary policy shock as a solid blue line together with 95% confidence bands. This represents the average effect across FR countries.

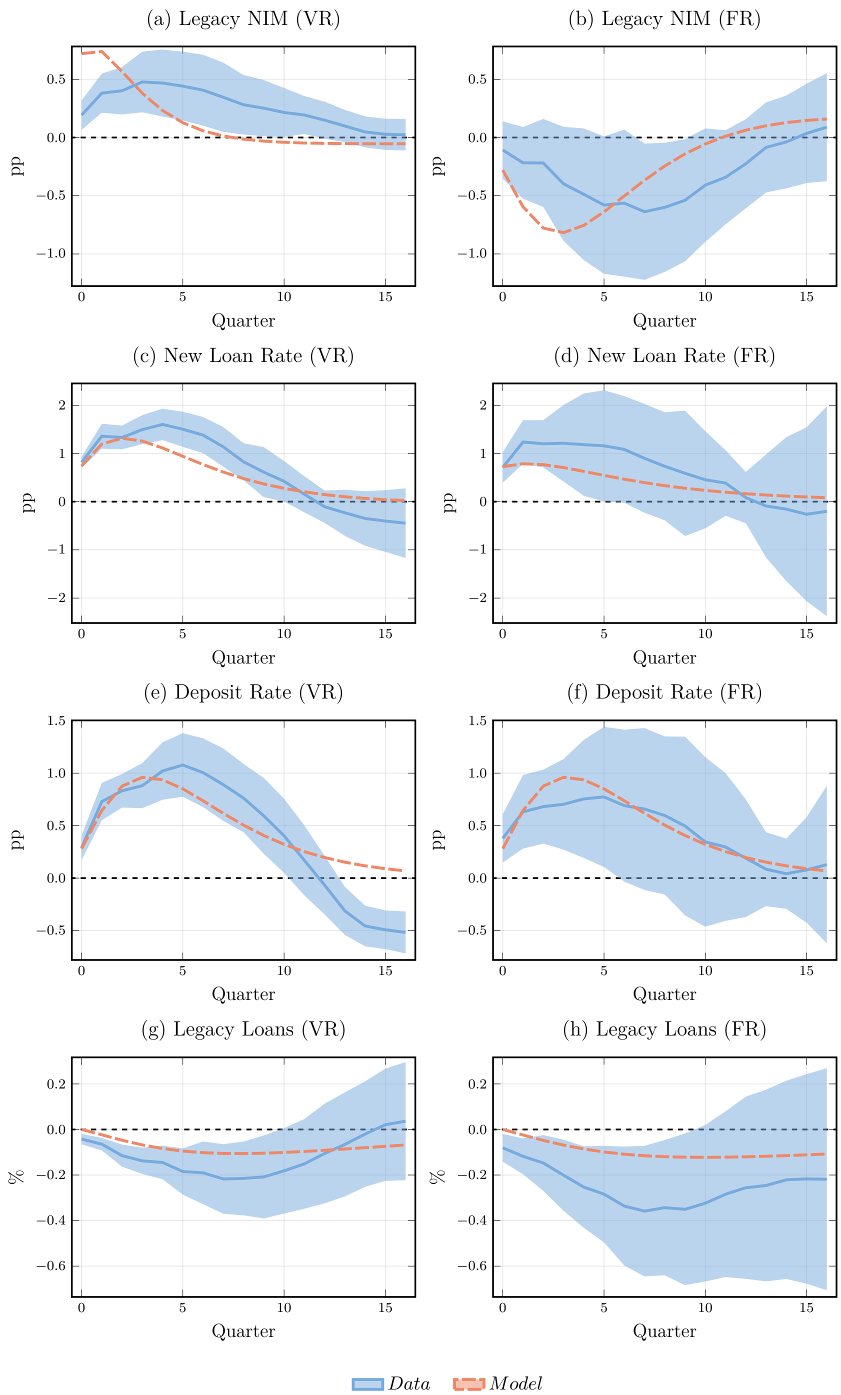
B.6 Robustness for Local Projections

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

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

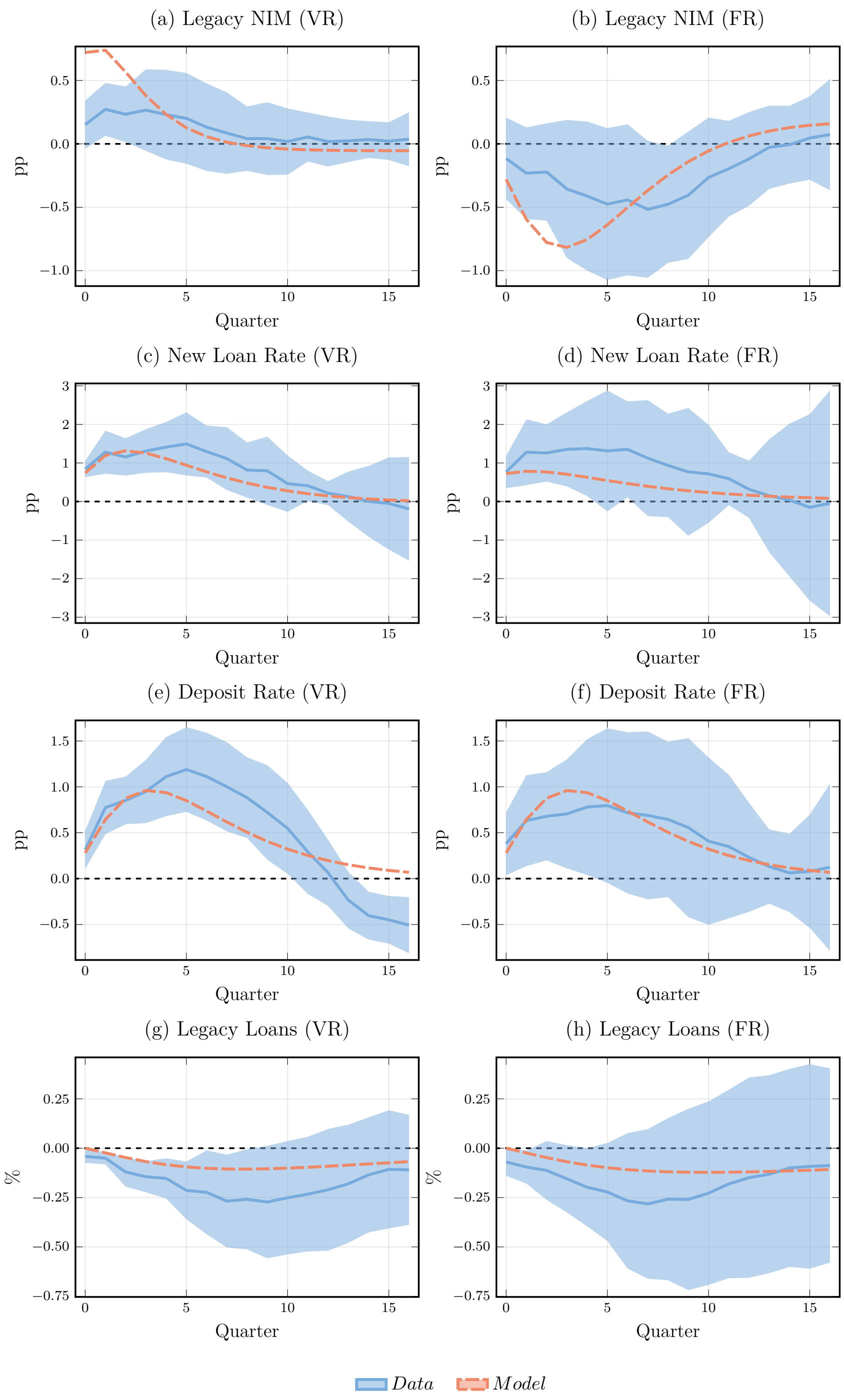
[32] The estimates for the sample period 2003 to 2023 are qualitatively similar.

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



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

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

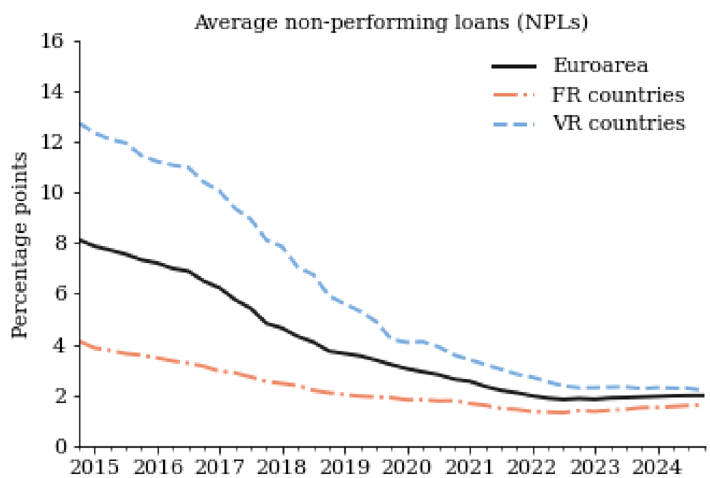


Note: Solid blue lines show the empirical impulse responses to a monetary policy shock and dashed red lines compute the model counterparts. Light blue bands show the 95% confidence intervals. Panels on the left report the response across VR countries, while right Panels report the response across FR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

B.7 Credit risk in the euro area

This section examines credit risk dynamics across euro area countries using time-series data on non-performing loans (NPLs) from the ECB's Consolidated Banking Data (CBD2) dataset. The dataset covers the period from 2014 Q1 to 2024 Q1. As before, we focus on the ten largest euro area economies, grouped by their share of variable-rate lending. FR countries: Belgium, France, Germany, and the Netherlands, and VR countries: Austria, Finland, Ireland, Italy, Portugal, and Spain.

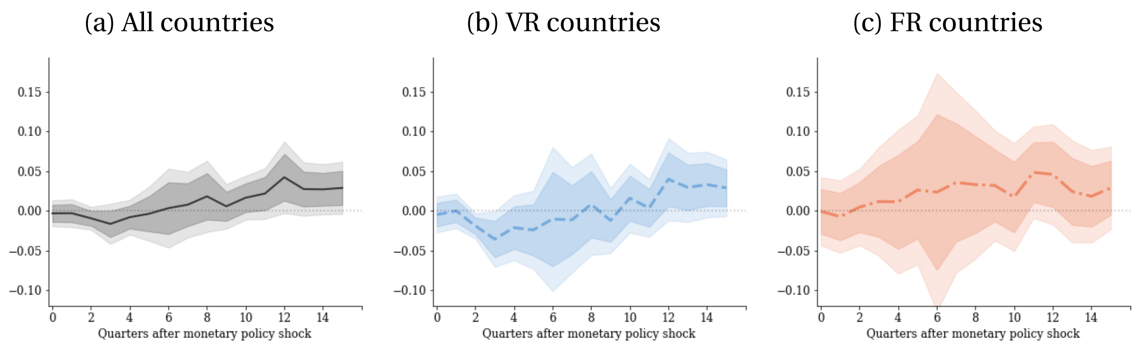
Figure B.6: Average non-performing loans (NPLs).



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

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

Figure B.7: Local Projections on NPLs



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

declining pattern for mortgage default rates computed from a sample of securitized mortgages in Spain, Portugal, Ireland, and Italy.[33]

Figure B.7 shows the responses of NPLs to a monetary surprise estimated by Local Projections. We estimate the same specification used for interest rates, see Appendix B.5. Panel (a) shows the average response across all countries. Panels (b) and (c) show the responses for VR and FR countries, respectively. Responses do not differ significantly across country group types.[34]

[33] Core et al. (2025) use Anacredit loan level data in December 2021, they find that the 1-year probability of default (PD) on fixed-rate loans averaged 6.26% with a 19.64% standard deviation, and 9.52% with a standard deviation of 25.05% for variable-rate loans. Bandoni et al. (2025) use loan-level data on securitised mortgages from the European DataWarehouse (EDW). For the period 2014 to 2019, they estimate an average mortgage default rate of 0.9% across countries.

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

C. Solution algorithm

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

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

which captures how slack the capital constraint is. Note that given this definition, the capital constraint simplifies to $k_t^{gap} \geq 0$. 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 $k_t^{gap}, n_t, d_t, b_t, m_t \geq 0$. Note that the constraint on d_t is always satisfied since $l_t \geq 0$ and $d_t = \alpha l_t$. If, additionally, $b_t \geq 0$ then the constraint on m_t is also satisfied since $m_t = \theta(b_t + d_t)$. Therefore, we only need to ensure

$$\begin{aligned} n_t &= \frac{1 - \gamma l_t - k_t^{gap}}{\gamma} \geq 0, \\ b_t & \frac{l_t + n_t + m_t + (\theta - 1)d_t - 1}{} \geq 0, \end{aligned}$$

which implies two upper bounds on k_t^{gap}

$$\begin{aligned} 1 - \gamma l_t &\geq k_t^{gap}, \\ 1 - \gamma(1 + (1-\theta)\alpha l_t) &\geq k_t^{gap}. \end{aligned}$$

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

$$k_t^{gap,max} = \min\{1 - \gamma l_t, 1 - \gamma(1 + (1-\theta)\alpha l_t)\},$$

In the implementation of Algorithm 1, it is ensured that these constraints are not violated.

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

We discretize the state space for $l_t \in [0, 1/\gamma]$, $x_t^L \in [x^L - \sigma, x^L + \sigma]$, where σ is the size of the MIT shock, and $\log(E_t) \in [\log(0.13), \log(3000)$ using equally spaced grids.[35] Algorithm 1 describes the value function iteration algorithm used to solve the problem of an individual bank which, due to size-independence, only depends on (l_t, x_t^L). Algorithm 2 describes the algorithm to compute the bank distribution. Finally, Algorithm 3 describes the complete algorithm used to solve for the steady state.

Algorithm 1 (Individual Problem)**.**

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

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

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

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

Algorithm 2 (Bank Distribution)**.**

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

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

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

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

Algorithm 3 (Steady State)**.**

1. *Make an initial guess for the loan rate r^N.*
2. *Solve the individual bank problem as described in Algorithm 1.*
3. *Solve for the bank distribution as described in Algorithm 2.*
4. *Check whether r^N clears the loan market. If the loan market does not clear, update the guess for r^N and go to step 2.*

Transition. We use an algorithm similar to the one described in Boppart et al. (2018) to solve for the transitional dynamics after an MIT shock. The approach is similar in spirit to the steady-state algorithm presented above. However, in this case, we are not trying to find a single value for the loan rate r^L to clear the loan market but a path $\{r_t^N\}_{t=0}^T$ 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 $\{r_t^N\}_{t=0}^T$.*
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.*[36]
4. *Update the paths for the distribution $\{\mathscr{H}_t(l, x^L, \log(E))\}_{t=0}^T$ by iterating forwards from $t = 1,\ldots,T$ 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 $\{r_t^N\}_{t=0}^T$ and its guess. Stop the algorithm if the maximum difference is less than a given degree of precision.*

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

7. *Update the guess* $\{r_t^N\}_{t=0}^T$ *by taking a weighted average of the old guess and the implied paths. Go to step 3.*