The Heterogeneous Bank Lending Channel of Monetary Policy*

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Abstract

This paper develops a quantitative model to analyze the role of bank heterogeneity in the transmission of monetary policy through the bank lending channel. We calibrate the model to the euro area to capture two distinct forms of heterogeneity: ex-ante differences in loan pricing practices and ex-post variation in capital positions driven by idiosyncratic default risks. Consistent with empirical impulse responses, banks in fixed-rate economies experience severe net interest margin compression during monetary tightening as funding costs rise while income from legacy loans remains unchanged, leading to capital erosion and deeper lending contractions. The elasticity of new lending to monetary policy is approximately one-third larger in fixed-rate economies. Highly leveraged banks drive these differences: without default risk, banks would remain far from their regulatory limits. We discuss additional tradeoffs between monetary policy and financial stability, study the implications for gradual policy rate increases, and demonstrate fundamental limitations of representative-agent banking models.

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1. Introduction

This paper develops a quantitative model to analyze the role of bank heterogeneity in the transmission of monetary policy through the bank lending channel. Banks are widely recognized as key conduits for monetary policy transmission, serving as the primary counterparts of central banks. When monetary policy changes the relative attractiveness of assets and liabilities, banks adjust their leverage altering the scale of their lending activities. This leverage rebalancing transmits to the real economy as banks modify the overall supply of credit. Crucially, individual banks respond differently to monetary policy based on their risk exposures and risk-bearing capacities, and these heterogeneous responses generate reallocation of lending across institutions that shapes the aggregate supply of credit. The goal of our quantitative framework is to analyze the importance of heterogeneity in determining monetary policy transmission and to assess implications for the pace of policy adjustments and the interaction between monetary policy and bank regulation.

Despite the conceptual understanding of the lending channel (Bernanke and Gertler, 1995), the role of bank heterogeneity in determining transmission strength remains less clear. Portfolio rebalancing following changes in monetary policy may vary systematically across banks with different risk exposures and risk-bearing capacities. Early work by Kashyap and Stein (2000) documented how the strength of the bank lending channel depends on banks' characteristics. More recent work with improved identification has established that banks with low risk-bearing capacity—those with high leverage or low capital ratios—transmit changes in policy rates more strongly than well-capitalized banks (see, for instance, Jiménez et al., 2012; Dell'Ariccia et al., 2017; Altavilla et al., 2020).[1] Similarly, banks with greater interest-rate risk exposure—those with a higher share of fixed-rate loans—exhibit stronger monetary policy transmission (Altunok et al., 2023).

While this empirical literature identifies important differences in bank responses to monetary policy shocks, structural models are essential for two complementary reasons. First, quantitative models are needed to understand aggregate responses: cross-sectional estimates explain differences in lending responses across banks, but these heterogeneous effects do not translate to aggregate responses. Second, empirical

[1] Other references include Gambacorta and Mistrulli, 2004, Kishan and Opiela, 2000, and Holton and Rodriguez d'Acri, 2018.

estimates do not allow for meaningful counterfactual analysis. For instance, models are required to assess how monetary policy transmission would change if banks were homogeneous (identical replicas of each other) or how the role of heterogeneity would vary under alternative regulatory regimes. This paper presents such a model, calibrated to the euro area.

The euro area provides an ideal laboratory for studying these questions. Institutional factors related to local financial systems generate substantial differences in bank risk exposures and risk-bearing capacities, while changes in monetary policy are common to all banks within the monetary union. We motivate our model formulation by documenting the extent of heterogeneity in both risk-bearing capacity and risk exposure among euro area banks, distinguishing between two types of heterogeneity that guide our modeling approach.

We observe substantial heterogeneity in loan-pricing practices across countries, which determines banks' exposure to interest-rate risk. The euro area exhibits strong country-specific patterns: banks in France, Germany, Belgium, and the Netherlands price most loans with fixed rates, while those in Spain, Italy, Finland, and Portugal predominantly use variable rates. This creates systematically greater interest-rate risk exposure in the former country group. We interpret these institutional differences as ex-ante heterogeneity. We likewise observe heterogeneity in capital buffers, which indicates heterogeneous degrees of risk-bearing capacity before hitting regulatory constraints.[2] Because idiosyncratic default risks induce differences in capital buffers, we interpret these observed differences as ex-post heterogeneity.

The model. The observed ex-ante and ex-post heterogeneity measures guide our modeling decisions and calibration targets. To model differences in ex-ante heterogeneity in interest-rate risk exposure, we consider two versions of the model: one where banks price all loans at fixed rates and another where they price them at variable rates. Each version can be thought of as representing variable- and fixed-rate countries, respectively.

Within each country, there is a unit mass of atomistic banks. Each bank invests in central-bank reserves and loans. Banks are financed through a combination of deposits

[2] We define the capital buffer as a bank's core equity capital ratio minus the regulatory required ratio. We observe an average CET1 (Common Equity Tier 1) capital ratio of 15 percentage points during 2013-2020 and significant dispersion reflected in a standard deviation of 4.5 percentage points.

and retained earnings (internal equity). Banks face a risky maturity transformation problem since their deposit liabilities mature in one period, whereas loans are long-term and subject to default risk. The demand for loans and supply of deposits is determined in general equilibrium, but all the action is focused on banks.[3]

The loan portfolio comprises vintages of long-term loans. The issuance of new loans is subject to convex loan-origination costs. Once in the balance sheet, loan defaults are correlated according to the single risk factor model of Vasicek (2002). Upon a loan default, the bank loses the interest payments, recovers a fraction of the principal, and writes off principal loss. Reserves at the central bank are short-term (mature in one period) and pay an interest rate controlled by the central bank. Additionally, banks face i.i.d. deposit withdrawal shocks. Idiosyncratic risks induce ex-post heterogeneity.

Banks face regulatory constraints designed to capture real-world prudential policy: In terms of liquidity regulation, banks must hold reserves above a fraction of their deposits at any point in time. In terms of capital regulation, banks must comply with a set of regulatory requirements to operate; failing to do so entails restrictions on dividend payouts and may subsequently lead to a bank failure. In particular, a *minimum capital requirement* constraint imposes that a bank must maintain enough after-dividend capital to satisfy that at least a fraction of its loans must be financed with the bank's capital.[4]

Despite the richness in the sources of risks, portfolio variables, and regulatory environment, banks' policies are size-independent: the only relevant individual state variables are the leverage and the average interest rate of their loan portfolio. This parsimonious state space is sufficient to capture various relevant forms of heterogeneity observed in the empirical analysis. This tractability makes the model-data contrast particularly transparent.

Quantitative Fit. We calibrate the model to euro area banking data for the period 2013-2023, employing a strategy that targets both cross-sectional and time-series moments. Crucially, we target euro-area-wide averages aggregated among variable and fixed interest-rate regimes, creating a demanding test for the model's ability to predict

[3] The model also features entrepreneurs, households, and the government. Entrepreneurs have access to long-term investment projects requiring bank funding. Households consume, own the banks, and save in deposits. The government includes the central bank operations, the management of the deposit insurance scheme, and tax receipts.

[4] A bank is declared *bankrupt* whenever its capital fails to satisfy the minimum capital requirement.

heterogeneous responses across these groups.

Our calibration approach directly sets parameters from regulatory frameworks and banking statistics with jointly calibrated parameters that discipline the model's key mechanisms. The key parameters of the model are those affecting the supply and demand for loans: a loan origination cost that induces adjustment costs on leverage and the loan-demand scale and interest-rate elasticity. These parameters are jointly identified to match the average capital ratios, the average level of lending rates and the peak response of new lending volumes to monetary policy shocks in the euro area. This dual targeting ensures that our model captures both steady-state credit market conditions and the dynamics of the bank-lending channel.

The calibrated model performs well along several untargeted cross-sectional dimensions that validate our framework. The model successfully replicates the consolidated balance sheet composition of euro area monetary financial institutions and generates a cross-sectional distribution of capital ratios that closely matches the left-tail of the empirical distribution observed in euro area banking data. Additionally, we reproduce the Pareto tail (power-law distribution) of the bank size distribution—modulated by one parameter and the distribution of equity returns. Furthermore, the model accurately reproduces the differential responses of new loan volumes, aggregate lending, interest rates on new loans, and net interest margins across fixed-rate and variable-rate banking systems following surprise monetary policy shocks.

The success in explaining untargeted moments that vary by fixed- and variable-rate economies is reassuring that our structural approach correctly identifies the key mechanisms underlying the mechanics of the bank-lending channel and that the model is a good laboratory to study the interaction between ex-ante and ex-post heterogeneity.

Role of heterogeneity. Our analysis reveals that bank heterogeneity plays a crucial role in monetary policy transmission, with both ex-ante and ex-post heterogeneity contributing substantially. We find that ex-ante heterogeneity in loan pricing creates quantitatively important differences in the bank lending channel: the elasticity of new lending to monetary policy shocks is approximately one-third larger in fixed-rate economies compared to variable-rate systems. This difference arises because fixed-rate banks experience severe net interest margin compression when policy rates rise, as their funding costs increase while income from legacy fixed-rate loans remains unchanged. In contrast, variable-rate banks benefit from rapid pass-through to both new and legacy loans, which improves their profitability and capital positions.

Beyond the differences in the strength of the bank-lending channel, the implications for financial stability move in opposite directions: monetary tightening increases bank failure probabilities in fixed-rate systems while reducing them in variable-rate economies.

Ex-post heterogeneity further amplifies these patterns through the interaction of bank leverage and regulatory constraints. Highly leveraged banks exhibit stronger lending responses to monetary policy in both systems; however, this heterogeneity becomes particularly pronounced in fixed-rate economies, where capital erosion forces the most leveraged institutions into more profound and more prolonged lending contractions.

Crucially, we demonstrate that ex-ante and ex-post heterogeneity interact in a fundamental way: when we reduce idiosyncratic risk in the model, the differences between fixed-rate and variable-rate systems largely disappear. The reason behind this result is quantitative: to rationalize the larger capital buffers observed in the data, loan origination costs must be substantial. Without ex-post loan-default risk, each bank would remain highly capitalized; otherwise, differences in capital losses are minimal.

This result reveals that ex-ante heterogeneity matters substantially for the transmission of monetary policy precisely because ex-post heterogeneity brings a large portion of banks close to their regulatory limits.

Implications of heterogeneity. These findings have important implications for monetary policy in the euro area and for macroeconomic modeling more broadly. As a monetary union, the euro area faces the challenge of implementing a single monetary policy across member countries with ex-ante different banking systems. Our results demonstrate that identical monetary policy shocks generate different effects across regions: fixed-rate banking systems experience deeper lending contractions and heightened financial stability risks. This heterogeneity creates tensions for monetary policymakers who must balance conflicting outcomes.

Furthermore, our analysis reveals a critical limitation of representative-agent banking models. Such models would fundamentally mischaracterize monetary policy transmission because they cannot account for the large portion of banks operating near their regulatory capital limits, where the interaction between leverage constraints and interest rate risk becomes the primary source of differences in the bank-lending channel. The substantial differences that emerge when we eliminate ex-post heterogeneity underscore that realistic modeling of the banking sector requires accounting for both sources of heterogeneity. This conclusion is quantitative; it depends on a successful calibration.

Related Literature. Our work relates to the literature in macro-banking and monetary economics. Within macro-banking, we contribute to the expanding strand of heterogeneous banks' models by developing a model that combines ex-ante heterogeneity in loan rate fixation and ex-post heterogeneity in leverage. Our framework is well-suited to study the strength of monetary policy transmission along these two key dimensions of heterogeneity. Banks' heterogeneity along other dimensions has been the focus of related works. For example, Coimbra and Rey (2023) study the risk-taking channel of monetary policy. Corbae and D'Erasmo (2021) analyze the impact of regulatory policies on bank risk-taking. Rios-Rull et al. (2020) study the aggregate effects of capital requirements. Bianchi and Bigio (2022) examine the credit channel of monetary policy in a framework where interbank market frictions interact with deposit withdrawal shocks. Jamilov and Monacelli (2025) introduce ex-ante heterogeneity in banks' rates of return —alongside idiosyncratic return risk—within an intermediation framework à la Gertler and Kiyotaki (2010) to show how these features amplify real and financial fluctuations relative to a representative bank model, and Bellifemine et al. (2022) study monetary policy transmission based on a similar setup but with nominal frictions. Varraso (2025) study monetary transmission when intermediaries invest in both short and long-term assets. Relative to these papers, ours adds an extra degree of heterogeneity—namely, in loan rate fixation patterns—whose interaction with heterogeneity in leverage we identify as fundamentally shaping the transmission of monetary policy.

Our approach departs from the classical representative-bank macro literature through several key modeling assumptions. First, rather than assuming that banks directly hold productive assets—–as in Gertler and Karadi (2011), Gertler and Kiyotaki (2010), He and Krishnamurthy (2013), or Brunnermeier and Sannikov (2014), among others—–we explicitly model loan contracts between borrowers and banks. Second, our framework accounts for default risk in banks' loan portfolios, with defaults correlated within each bank according to Vasicek (2002) single risk factor model. This captures the asymmetric risk profile of defaultable loans, characterized by limited upside but unlimited downside risk (Nagel and Purnanandam (2020); Mendicino et al. (2024)). Third, we treat capital requirements as occasionally binding constraints, in contrast to previous models that assume always-binding capital constraints (see, e.g., Boyarchenko and Adrian (2015); Clerc et al. (2015); Mendicino et al. (2018, 2020)).

We contribute to the literature on the transmission of monetary policy to the real economy in heterogeneous-agent economies (Kaplan et al., 2018; Auclert, 2019; Garriga and Hedlund, 2020). These works develop models in which households face uninsurable income risk, transaction costs, and borrowing constraints while taking a simplified approach to the supply side of the credit market, abstracting from modeling lenders' heterogeneity. Related works also investigate the transmission of monetary policy through the mortgage market with heterogeneous households. For instance, Berger et al. (2021) and Eichenbaum et al. (2022) emphasize the path-dependency of policy rates in the transmission of to household consumption. Greenwald (2018) highlights the role of loan-to-valuation constraints and payment-to-income on monetary policy transmission, while Beraja et al. (2018) underscores the relevance of home equity in determining households' ability to respond to interest rate changes.

Finally, our paper also relates to recent research on how exposure to interest rate risk affects monetary policy transmission. 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. Elenev and Liu (2025) is closer to our credit supply analysis, as they explore how the type of mortgage contract influences financial intermediaries' equity positions in a representative bank framework, and provide insights into how financial stability interacts with monetary policy.

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, which includes a bank regulatory authority, a deposit insurance agency, a fiscal authority, and a monetary authority.

The core of the model features a banking sector that intermediates funds from households to entrepreneurs, who undertake risky long-term productive investment projects but require external financing. Banks engage in maturity transformation by funding risky long-term loans with short-term retail deposits, wholesale debt, and their own equity. This activity exposes them to credit risk and interest rate risk. The regulatory framework, which includes capital and liquidity requirements, as well as a deposit insurance scheme, shapes banks' decisions and their response to aggregate shocks. The interaction between banks' lending capacity and entrepreneurs' investment demand determines aggregate activity.

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. This allows us to study 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. They finance their asset portfolio, comprised of risky long-term loans and safe short-term assets, through a combination of short-term, insured deposits and wholesale debt, and with equity accumulated via retained earnings. Their operations are subject to capital and liquidity regulation. We first describe the composition and dynamics of a bank's asset portfolio, then its liability structure and equity dynamics, the regulatory framework it faces, and finally, its dynamic optimization problem.

Assets. A bank's assets consist of a portfolio of risky long-term loans and safe short-term assets, or central bank reserves.[5] 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}.

The loan portfolio comprises 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 $1/\delta$. These loans are subject to credit risk, which we model using the single-risk-factor framework of Vasicek (2002).

[5] In the remaining, we will refer to these safe short-term assets as central bank reserves, but they could also be thought of as safe short-term government bonds.

This implies that 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 loan's principal, where $\lambda \in [0,1]$ is the loss given default.

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

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

reflecting that the loan portfolio in period $t+1$ consists of the previous period's total loans, $L_{jt} + N_{jt}$, net of maturing and defaulted loans.

Originating new loans incurs a cost, specified as $f(N_{jt}/L_{jt})L_{jt}$, where $f(\cdot)$ is an increasing and convex function. This cost captures screening expenses or decreasing returns to finding profitable investment opportunities.

The contractual net interest rate of a bank's loans depends on the contracting environment. The interest rate on new loans originated at time t is denoted r_t^N.[6] In the *fixed-rate regime*, the net interest rate r_t^N is stipulated at origination and remains constant for the life of the loan. In the *variable-rate regime*, what is stipulated at origination is the spread s_t^N, which is added to the policy rate r_t^M set by the monetary authority (i.e., in this case, $r_t^N = r_t^M + s_t^N$). 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.

Given these assumptions about interest-rate fixation, the law of motion of the average interest rate on a bank's legacy loan portfolio, r_{jt}^L, can be obtained as

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

for banks operating in the fixed-rate environment (henceforth, fixed-rate banks), and $r_{jt}^L = r_t^M + s_{jt}^L$ for banks operating in the variable-rate environment (henceforth, variable-rate banks), where

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

denotes the average contractual spread in a bank's legacy loan portfolio.

[6]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.

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

Liabilities. The bank's assets are funded with a mix of wholesale debt, (retail) deposits, and equity. Wholesale debt, denoted B_{jt}, is a one-period liability that pays a net interest rate r_t^B. Retail deposits, denoted D_{jt}, are also one-period debt liabilities and pay a net interest rate r_t^D and 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 $\alpha \geq 0$.[7] We assume that retail deposits are fully insured by the government and that, while wholesale debt is not, its returns are also risk-free in equilibrium.[8]

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

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

where $\tau \in (0,1)$ is the corporate tax rate and Π_{jt+1} denotes the bank's pre-tax profits realized between period t and $t+1$. These are given by

$$\begin{aligned}\Pi_{jt+1} = (1-\omega_{jt+1})\left(r_{jt}^L L_{jt} + r_t^N N_{jt}\right) + r_t^M M_{jt} - r_t^D D_{jt} - r_t^B B_{jt} \\ - \lambda\omega_{jt+1}(L_{jt}+N_{jt}) - f\left(\frac{N_{jt}}{L_{jt}}\right) L_{jt} - \bar{\pi} L_{jt}.\end{aligned} \tag{6}$$

Profits are determined by interest income on loans and reserves, net of interest expenses on deposits and wholesale debt, realized credit losses, loan origination costs, and operational costs, which are a constant factor $\bar{\pi} > 0$ over the legacy loan portfolio.

The balance sheet of the bank is:

[7] We think of this constraint as capturing, in reduced form, the complementarity between a bank's loan origination and deposit issuance businesses. In particular, one can think of this complementarity as stemming from the fact that, in order to expand its loan business, a bank may invest in offices across different geographies that are also required to provide deposit-related services (such as those related to access to cash provided by ATMs, etc.).

[8] 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 in terms of 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.3 for a derivation of those restrictions).

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

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:

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

Bank failure, entry and exit. If the bank cannot satisfy the minimum capital requirement, it fails and is resolved by the regulator. This is, a bank fails if, after the realization of portfolio defaults ω_{jt+1}, its equity falls below the minimum requirement relative to its legacy loan portfolio: $E_{jt+1} < \gamma L_{jt+1}$. Upon failure, the bank's equity is wiped out, and a deposit insurance agency seizes its assets, which are partly sold to new, entering banks, and partly liquidated (in proportions to be specified below). The agency allocates is proceedings to the bank's liability holders, in order on seniority, and repays all retail depositors in full.

Additionally, banks face an exogenous exit shock with probability $\chi \in (0,1)$ each period. An exiting bank repays all liabilities, and the remaining equity is distributed to its owners in the form of dividends.

To maintain a constant mass of banks, each exiting bank is replaced by a new entrant. New entrants start with a an exogenous amount of equity $\bar{E}_t$. Each individual new bank starts with 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.[9]

[9]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.

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 fixed rate banks, or the average spread s^L_{jt}. The bank's dynamic programming problem is represented by the following Bellman equation:

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

with $x_{jt} = \{r^L_{jt}, s^L_{jt}\}$ in the case of fixed- or variable-rate banks, respectively, and subject to the law of motion for loans (1); the law of motion for average interest rate (2) of the legacy loan portfolio in the case of fixed-rate banks, or the average spread (3) in the case of variable-rate 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. Appendix A.2 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 loan rate (r^L_j) of the legacy loan portfolio for fixed-rate banks, or the average spread for variable-rate banks (s^L_j).

2.2 Entrepreneurs: microfoundation for the loan demand

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

Once initiated, a project yields A units of the final good each period it remains active. At the end of each period t, an active project may terminate for one of three reasons: (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 bank exits, the loan principal is repaid in full. If the project fails, the bank recovers only $1-\lambda$ of the principal.

To initiate a project, an entrepreneur must exert an effort that entails 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. Free entry for entrepreneurs means 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 loan contract type. For a variable-rate loan, the value at time t of a project with spread s_i^N is:

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

Imposing the free-entry condition, $V_{it}^E(s_t^N) = a(N_t)$, yields the aggregate demand for variable-rate loans:

$$N_t = a^{-1}\left(\sum_{k=1}^{\infty} \beta^k (1-p)^k (1-\delta)^{k-1} (1-\tilde{\chi})^{k-1} \left[A - \left(r_{t+k-1}^M + s^N\right)\right]\right). \tag{12}$$

Loan demand is forward-looking, as entrepreneurs form expectations about future interest rates.

For a fixed-rate loan, the interest rate is constant for the life of the project. The value at time t of a project with interest rate r_i^N is:

$$V_{it}^E(r_i^N) = \sum_{k=1}^{\infty} \beta^k (1-p)^k (1-\delta)^{k-1} (1-\tilde{\chi})^{k-1} \left(A - r_i^N\right), \tag{13}$$

The corresponding aggregate loan demand is:

$$N_t = a^{-1}\left(\sum_{k=1}^{\infty} \beta^k (1-p)^k (1-\delta)^{k-1} (1-\tilde{\chi})^{k-1} \left(A - r_t^N\right)\right). \tag{14}$$

In this case, loan demand is not forward-looking with respect to future interest rates, as the bank bears all interest-rate risk. This distinction is central in the transmission mechanism in our analysis.

2.3 Households: microfoundation for the deposit supply

The household problem is presented in detail in Appendix A.1 and follows a similar approach as Bianchi and Bigio (2022). Households solve a consumption-savings problem in which they decide their holdings of bank retail deposits, wholesale debt and safe short-term assets (in this case, government bonds). The equilibrium return on government bonds is equalized to that of reserves, r_t^M. The demand schedule for retail deposits, wholesale debt and government bonds results from a joint asset-in-advance constraint and establishes the following relationship:

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

where $h(\cdot)$ is a convex and increasing function in each of its arguments.[10]

We assume an elastic supply of government bonds, which implies that the demand for deposits and wholesale debt by households are also fully elastic. Furthermore, on the one hand, since government bonds and wholesale debt are perfect substitutes from the household's perspective, their respective returns must be equal in equilibrium. On the other, we assume that households obtain liquidity services from their deposit holdings, so in equilibrium their required return is lower than that of the other short-term assets available (i.e., $r_t^D \leq r_t^M = r_t^B$).

2.4 Consolidated government

The consolidated government includes of a central bank that sets the policy rate r_t^M (i.e., the rate of remuneration of reserves deposited by banks at the central bank) and a fiscal authority that raises taxes from banks and from households, and manages the deposit insurance scheme. All these operations are consolidated in the following government budget constraint:

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

where T_t are lump-sum taxes on households, Π_t are aggregate profits from banks, M_t is the aggregate supply of safe short-term assets, and Υ_t represents the net operating deficit of the deposit insurance scheme. Appendix A.2 presents the consolidated government in more detail.

[10] Similar to Bianchi and Bigio (2022), this formulation simplifies the computation of general equilibrium dynamics, while delivering allocations consistent with market clearing in the deposits and goods markets. The same assumptions are standard in new-monetarist models (Lagos and Wright, 2005; Lagos et al., 2017), which assume different goods can be purchased with different assets.

2.5 Equilibrium

An equilibrium is a set of functions such that:

1. Banks optimal choices $\{N_{jt}, M_{jt}, B_{jt}, D_{jt}\}$ solve the problem of an individual bank (10), taking prices $\{r_t^L, r_t^M, r_t^B, r_t^D\}$ as given.

2. Entrepreneurs aggregate demand of credit $\{N_t\}$ is consistent with the free entry condition, taking prices $\{r_t^N\}$ or $\{s_t^N\}$ as given.

3. Household optimal choices $\{C_t^D, C_t^B, C_t^M, D_t, B_t, M_t^H\}$ solve the household's problem in Appendix A.1, taking prices $\{r_t^D, r_t^B, r_t^M\}$ as given.

4. The credit market for new loans clears:
$$N_t = \int N_{jt} \mathrm{d}j.$$

5. The deposit market clears:
$$D_t = \int D_{jt} \mathrm{d}j.$$

6. The wholesale debt market clears:
$$B_t = \int B_{jt} \mathrm{d}j.$$

7. The safe short-term asset market clears:
$$M_t = M_t^H + \int M_{jt} \mathrm{d}j.$$

8. The consolidated government budget constraint in (16) is satisfied.

9. The consumption goods market clears (i.e., the aggregate resource constraint satisfies):
$$Y_t = C_t^D + C_t^B + C_t^M + (L_t + N_t - L_{t-1} - N_{t-1}) + RC_t, \tag{17}$$
where Y_t denotes total output, C_t^D, C_t^B and C_t^M denote the different components of households' consumption, and RC_t denotes resource cost due to bank resolution and loan issuance.

Appendix A.2 provides more details on all equilibrium objects.

Equilibrium properties. A key feature of our model is that banks' optimal policies exhibit size independence, which substantially simplifies the analysis while preserving the essential heterogeneity. Due to the quadratic structure of loan origination costs and the proportional nature of regulatory constraints, banks' decision rules can be expressed independently of their current equity level. Specifically, we can factor out current equity from all policy functions, leaving leverage—the ratio of loans to equity—as the sole relevant state variable for individual bank decisions.

This size independence property means that two banks with the same leverage ratio will make identical portfolio choices regardless of their absolute size, and consequently, bank growth becomes independent of size but depends on leveraged returns and idiosyncratic shocks. This allows us to characterize the entire cross-sectional distribution of bank behavior through the distribution of leverage alone. While this simplification reduces the dimensionality of the problem considerably, it preserves the crucial interactions between leverage, regulatory constraints, and loan pricing that drive the heterogeneous transmission of monetary policy. The model thus captures the essential economic forces while remaining tractable enough for quantitative analysis across different monetary and regulatory policy scenarios.

On the non-financial sector, we assume static loan demand and deposit supply functions that do not exhibit internal dynamics. To generate realistic deposit rate pass-through following monetary policy shocks—which empirically differs substantially from complete pass-through—we introduce preference shocks to the deposit supply function. This allows the model to match the observed gradual adjustment of deposit rates while maintaining the focus on the bank-lending channel.

2.6 Solution method

[TBC]

3. Calibration and model fit

We base the quantitative analysis on a calibration tailored to the euro area. Subsection 3.1 specifies functional forms adopted in the calibration, subsection 3.2 presents parameter values, and subsections 3.3 and 3.4 evaluate the model fit along the cross-sectional and time-series dimensions, respectively.

3.1 Functional forms

Loan-origination cost. The new-loan origination cost is quadratic:

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

with $\eta > 0$.

Default-rate distribution. The cumulative distribution function (cdf) of the default rates ω_{jt+1} follows the Vasicek (2002) single risk-factor model (see Appendix A.6):

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

The cdf formula for defaults is given by the cdf of a standard normal $\Phi(\cdot)$, with inverse $\Phi^{-1}(\cdot)$. The formula is such that the average default rate is p. In turn, $\rho \in [0,1]$ is a correlation parameter, which increases dispersion, and dictates how the underlying portfolio-level risk factor affects individual loan defaults. We opt for this specification as this distribution is used as a statistical foundation for the capital requirement formulas (IRB approach) of Basel II (Gordy, 2003).[11]

Entrepreneurs' entry cost. The entrepreneurs' cost of starting an investment project is assumed to be given by

$$a(N_t) = \zeta_1 N_t^{\zeta_2}, \tag{20}$$

with $\zeta_1 > 0$ and $\zeta_2 > 0$. These parameters govern the loan-demand elasticity. Importantly, $\zeta_1 > 0$ and $\zeta_2 > 0$ govern the scale of the loan demand and its interest-rate semi-elasticity, respectively.

3.2 Calibration

The notion of time period is one quarter. Parameter values are either set externally or set internally to deliver a target moment of the data. Table 1 reports all parameter values corresponding to both groups.

[11] See, e.g., Repullo and Suarez (2004) for details.

Pre-set parameters. The first block of Table 1 correspond to the parameters set either following the calibration of other papers or set directly to their observed regulatory counterparts. 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 maturity of loans is set to 0.05, consistent with an average loan duration of 5 years reported by Cortina et al. (2018), which corresponds to the maturity observed for syndicated loans in developed economies from 1991 to 2014. The corporate tax rate τ is set at the average effective tax rate of 20% for European banks.[12]

Policy parameters are set based on Basel III regulatory levels: The capital requirement γ encompasses the minimum Common Equity Tier 1 (CET1) requirement, 4.5%, plus a capital conservation buffer, 2.5%, that must also be maintained with CET 1 capital. The liquidity requirement θ is such that the reserve-to-total-liabilities ratio is 11.8%, consistent with euro-area bank balance sheet data. The steady-state value of the policy rate r^M (i.e., the rate of remuneration on central bank reserves) is set to the historical average of the deposit facility rate in the euro area (1%).

Jointly calibrated parameters. The second block of Table 1 correspond to parameters calibrated jointly to deliver target moments. The parameter α, which determines the share of deposits in banks' balance sheet, is set to match the observed ratio of deposits to total assets of 0.78 in the consolidated balance sheet of euro area banks. The targets for banks' return on equity (ROE) of 6.4 percent and the bank failure probability of 0.66 percent are taken directly from Mendicino et al. (2020). These targets are key to identifying the bankers' discount factor β and the volatility of a bank's portfolio default rate ρ, respectively.

As explained above, the presence of loan-origination costs coupled with the actual loan demand induces an effective loan demand faced by individual banks. This effective loan demand governs the steady-state loan rate, given r^M, and the voluntary capital buffer. We jointly set the scale parameters η (of the loan-origination cost 18) and ζ_1 (of the loan demand 20) to target the historical average loan rates of 3% and the average voluntary capital buffer of 5.1 percent, a target consistent with the mean CET1 buffer for supervised banks reported by the European Banking Authority for 2021. The elasticity parameter ζ_2, is calibrated to induce a peak response of the logarithm of new lending, -0.38, to a monetary policy shock of 100 basis points, as explained below.

[12] See http://www.stern.nyu.edu/~adamodar/pc/datasets/taxrateEurope.xls

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
θ	Liquidity requirement (%)	11.8	Liquid asset to deposit ratio
r^M	Steady-state policy rate	1.0	Avg. EA deposit facility rate

Jointly calibrated parameters

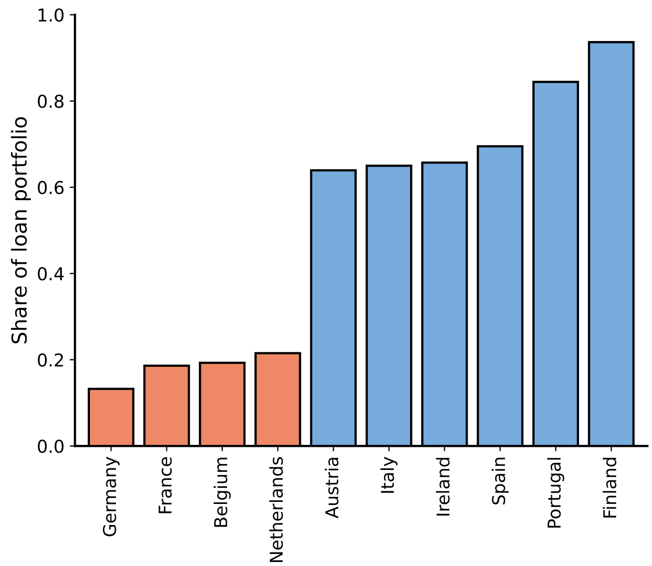
	Parameter	Value	Target	Data	Model
α	Deposits-to-loans ratio	0.97	Retail deposits to total assets	0.78	0.81
β	Subjective discount factor	0.933	Banks' return on equity (%)	6.4	6.4
ρ	Loan default correlation	0.46	Bank failure probability (%)	0.66	0.66
η	Loan origination cost	0.22	Voluntary capital buffer (%)	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.

The bank's fixed operating cost parameter $\bar{\pi}$ is informative about the average net non-interest expenses-to-assets ratio. Finally, the bank's exit rate χ is disciplined by targeting the slope of the log-log regression coefficient (tail coefficient) of the asset-size distribution. As discussed in Section 3.3, this single moment allows the model to replicate a power-law distribution of bank asset sizes, a salient feature of the data.

Fixed ex-ante heterogeneity. As anticipated above, we study two versions of the model, one with variable-rate (VR) and the other with fixed-rate (FR). This feature is motivated by cross-country institutional patterns in the observed countries of the euro area. Figure 1 presents the share of variable-rate loan contracts in each country.

Figure 1: Share of variable-rate loans.



Note: Average share of the aggregate total outstanding loans issued at variable rates from 2014 to 2020. Includes loans to non-financial corporations and loans to households– mortgage loans, consumer loans, and other loans. Orange bars corresponds to our classification of fixed-rate countries and Blue bars to variable-rate ones. *Source*: ECB MFI Statistics.

Variable-rate loans are defined as those with original and remaining maturity over 1 year and interest rate reset within the next 12 months.[13] We observe that in a first group of countries, Germany, France, Belgium, and the Netherlands, banks issue almost 80% of their contracts as FR contracts. In contrast, in a second group, Finland, Portugal, Spain, Ireland, Italy, and Austria, issue above 60% of their loans in VR contracts, which we label as variable-rate banking systems, are predominantly set with variable interest rates. We label the first and second groups as FR and VR banking systems, respectively. Appendix B.3 provides additional analysis of this categorization: In particular, we establish that these patterns have remained stable and extend across loan categories, affecting both household and corporate lending. We employ these definitions in Section 5, where we study the aggregate response of banks' balance sheet variables by groups to monetary shocks.

[13]An approximation is necessary, as the time-series for loans are not exclusively classified by type of interest rate fixation but rather by the maturity. The ECB data is available starting in 2014.

3.3 Cross-sectional moment fit

Bank balance sheet composition. We begin by comparing the consolidated balance sheet of monetary financial institutions (MFIs) operating in the euro area to our model's counterpart.[14] Table 2 shows that the model's steady-state consolidated balance sheet closely aligns with the composition of assets and liabilities in the data.

Table 2: Consolidated bank balance sheet composition: euro area 2013–2023 vs. model

Assets		**Liabilities**	
Loans	0.88 (0.89)	Deposits	0.78 (0.81)
ST securities and reserves	0.12 (0.11)	Wholesale funding	0.14 (0.09)
		Equity capital	0.08 (0.10)

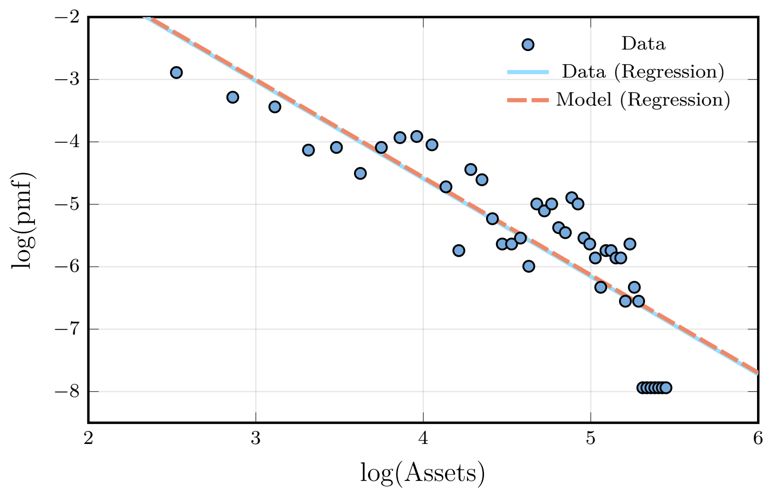
Note: The composition is expressed in terms of ratios of variables to total assets. Model counterparts are shown in parentheses. The data corresponds to the consolidated balance sheet of euro area Monetary Financial Institutions (MFIs), excluding the Eurosystem, reported by the European Central Bank. *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 and other liabilities. *Wholesale funding* corresponds to debt securities issued. *Equity capital* comprises capital and reserves.

Asset-size distribution. The model generates a steady-state distribution of bank assets that closely mirrors the asset distribution observed for euro area banks with only the exit parameter.[15] Figure 2 compares the model's and the empirical right tails of the asset distribution in the log-log space, illustrating the substantial heterogeneity in bank sizes produced by the model. As explained in Gabaix (2009), growth independence and an exit rate coefficient, both features of the model, yield power laws. This empirical regularity is observed in many datasets, and the bank-size distribution is not an exception. While we target the exit rate to match the corresponding Pareto tail, the fact that we can fit the data well indicates that the model effectively captures the statistical properties of bank-level risks.

[14]MFIs includes deposit-taking institutions (banks) and money market funds (MMFs). We cannot distinguish MMF from the deposit-taking institutions for the entire time series, but the presence of MMFs is immaterial given their size. For example, in 2024Q2, MMFs totaled €1.8 trillion—less than 5% of deposit-taking institutions (€38 trillion). Appendix B details on the composition of MFIs and the time series used.

[15]We construct an unbalanced bank-level dataset using balance-sheet data from S&P Global, a proprietary source. The quarterly dataset covers the period from 2013 to 2020 and includes information on common equity tier 1 (CET1) capital levels, risk-weighted assets, and total assets. We fit a power law distribution of the form $f(x) = \bar{A}x^{\psi}$, where ψ denotes the slope of the fitted curve and captures the tail behavior of the asset distribution.

Figure 2: Banks' asset size — Tail distribution (steady state)



Capital-ratio distribution. Panel (a) in Figure 3 reports the distribution of capital ratios in the data.[16] Panel (b) reports the calibrated model's steady-state counterpart. The distribution in the model captures the empirical counterpart predominantly in its left tail: both in the model and in the data, a substantial part of the mass is close to the constraint imposed by capital regulation, which truncates its left tails. Notice that the capital distribution is affected by the regulatory constraint: banks try to operate above the constraint to avoid being liquidated.

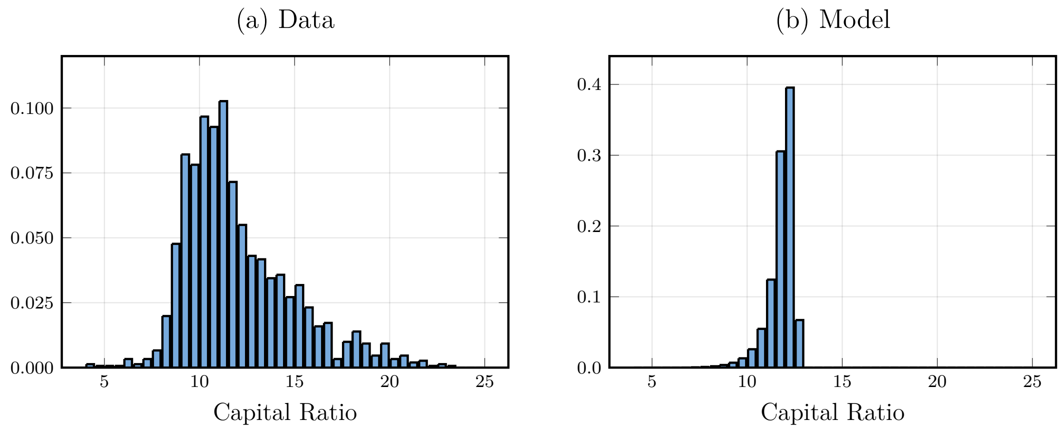
The model, however, fails to account for the right tail in the data. Most of the mass above 12% in the data gets concentrated in a spike. We attribute this failure, among other things, to additional regulatory constraints that our model is not able to capture.[17] In any case, the failure to replicate the right tail is mainly inconsequential for our results. As we show below, the behavior of banks far away from the constraint is pretty much homogeneous. Therefore aggregate dynamics are affected by the left tail and not by the

[16] Since the gradual implementation of Basel III in 2013, capital ratios for euro area banks have increased steadily. This adds additional dispersion to the histogram distribution. To adjust the empirical distribution for time trends, we normalize each period by subtracting its mean and then re-centering the data using the long-term mean.

[17] In particular, banks should satisfy a Minimum Requirement for Own Funds and Eligible Liabilities (MREL). This is a regulatory framework that requires financial institutions to hold a sufficient amount of own funds and eligible liabilities to absorb losses and potentially recapitalize in case of failure. While medium and large banks typically issue contingent liabilities to satisfy this requirement, small local banks typically satisfy this constraint by issuing additional CET1 capital, which may explain the CET1 levels well above 15%.

right one.

Figure 3: Capital-ratio distribution



Sources: S&P Global and ESRB supervisory data on European banks' capital requirements. Capital ratios are defined as CET1 capital over risk-weighted assets. The sample corresponds to 60 large and medium-sized European banks from 2013 to 2020.

Marginal propensity to lend. We define the marginal propensity to lend (MPL) as a statistic that summarizes a bank's increase in lending out of a marginal increase in equity capital, a concept we adopt from Jamilov and Monacelli (2025). Figure 4 shows the model's distribution of MPLs, ranging from 0.4 to 1.2. We obtain that banks with a higher leverage (i.e., those closer to the regulatory constraint) feature a higher MPL.[18] Although, to the best of our knowledge, there are no empirical estimations of a bank's MPL—of new lending— in the literature, these values are broadly consistent with Gambacorta and Shin (2018)'s bank-level elasticity of total assets to equity ratio (0.66).

3.4 Time-series moment fit

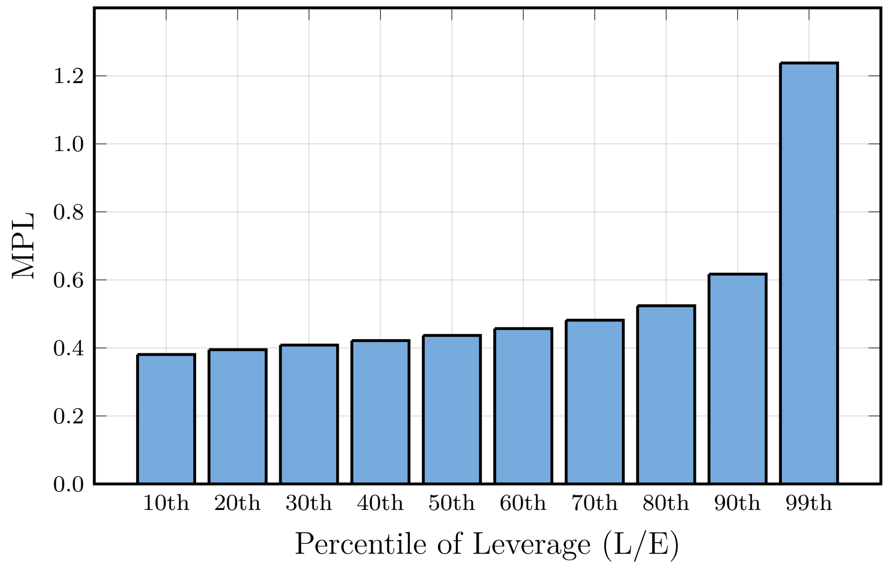
Responses to a monetary tightening. The main focus of interest is on how heterogeneous banks respond to monetary policy shocks, along various dimensions. To evaluate

[18]The steady-state policy function for new loans of a bank with leverage $l = L/E$ and equity E can be written as $N(l, E) = n(l)E$. The marginal propensity to lend (MPL) is then defined as

$$\frac{dN(l,E)}{dE} = \frac{dn(l)}{dl}\frac{dl}{dE}E + n(l) = -l\frac{dn(l)}{dl} + n(l)$$

Thus, the marginal propensity to lend only depends on the leverage of a bank.

Figure 4: Distribution of marginal propensity to lend (MPL)



the model's ability to account for the bank lending channel, we compare the model-generated impulse response functions (IRFs) with their empirical counterparts. All the empirical IRFs are estimated using a local projections approach (Jordà, 2005; Jordà et al., 2015) (Appendix B.4 presents the estimation details).

To obtain the model's response of new loans to an unexpected increase in the policy rate r^M, we compute the transitional dynamics after an unanticipated (MIT) shock following an algorithm similar to Boppart et al. (2018). This is equivalent to solving a model with aggregate risk by a first-order perturbation method.The loan rates and quantities in the model are determined through equilibrium via market-clearing. We also introduce preference shocks on the deposit side to induce similar deposit-rate paths as observed in the empirical IRF. Thus, for new loans, quantities and prices are jointly determined by demand and supply. For deposits, rates are de facto exogenous with quantities determined by the demand for funding by banks. All in all, the model takes as exogenous inputs the projected paths for both the policy rate and the deposit rate after a 1 percentage point increase in the policy rate, r^M, estimated from the data.

The upper row of panels in Figure 5 presents the empirical IRFs to the policy rate for the exogenous rate targets; the surprise is equivalent in magnitude to the change in the ECB's deposit facility rate (DFR). Panel (a) displays the estimated trajectory of the

Figure 5: Targeted IRFs

monetary instrument, and Panel (b) shows the corresponding path for the deposit rate. The solid blue line and the blue shaded areas correspond to the point estimates and confidence bands of the IRFs. The dashed lines in those top panels are the exogenous rate paths induced into the model.

The bottom rows in Figure 5 report the response of the quantities of new loans for variable- and fixed-rate countries, both in the model and the data. It is clear that the model matches well the pass-through of shocks to quantities in terms of magnitudes and average quantities. We should note that we use one parameter, the elasticity of the loan demand ζ_2, to try to approximate the response in new loans averaged across both countries.

We further contrast the model and data IRFs of variables that are not at all targets of

Figure 6: Untargeted impulse responses: Loan rates and volumes

our calibration in Figures 6 and 7. These figures allow us to assess the model's fit along other bank-balance sheet variables. In both figures, the panels on the left represent VR countries, whereas the ones on the right represent FR counterparts.

The top and bottom rows of Figure 6 report the response of the rate charged on new loans and the overall quantity of legacy loans over time. First, we should note that, although not targeted, the top row shows an excellent fit, for both types of economies, for the rates charged on new loans, considering that only one parameter governs the loan-demand elasticity while the dynamics of the loan supply is produced by the model's internal propagation. The model captures the fact that the passthrough to new loan rates is higher in VR economies than in FR ones. The fit is excellent for both types of economies.

In turn, we also observe that the response of the quantity of legacy loans, which evolves in tandem with new lending, is also excellent. The model is also capable of generating differences across variable- and fixed-rate economies, in the direction of the data.

Figure 7 displays the IRFs of the net interest margin (NIM), for both new and legacy loans, as well as the capital ratios. Regarding the NIM, while the model IRFs are only capable of generating responses in the order of magnitude of those in the data, missing on the dynamics, remarkably, the model is able to generate the differences observed among FR and VR countries. Panels (c) and (d) show how the response of the NIM in legacy loans is positive for VR countries and negative for FR ones, a feature that we explain in the next section. Likewise, the model is able to produce much larger reductions in capital ratios for FR countries than VR ones (panels e and d).

Given the good fit of untargeted IRFs by ex-ante heterogeneity, as well as the fit to cross-sectional moments which capture ex-post heterogeneity, we are confident that we can use the model to assess the importance of both sources. We proceed to investigate the importance of heterogeneity in the next section.

4. How much does heterogeneity matter?

In this section, we use the model to analyze how ex-ante and ex-post heterogeneity impact the bank-lending channel. We first consider the role of ex-ante heterogeneity by comparing the IRFs in FR and VR economies—to a one percentage point increase in the policy rate (the remuneration rate of central bank reserves). Then, we evaluate the role of ex-post heterogeneity by looking at the IRFs of different banks in different points of the capital-ratio distribution. Finally, we contrast the model with a version without idiosyncratic shocks.

Ex-ante heterogeneity. Figure 8 contrasts the aggregate-level IRFs to a one percentage point contractionary monetary policy shock for VR and FR economies. Following the same path of a policy shock (Panel c), banks' funding costs rise as the interest rate on wholesale debt increases in tandem. In contrast, the pass-through to deposit rates remains gradual, by construction (recall the explanation of Figure 5). This asymmetric response causes the marginal cost of funding to increase sharply, depressing new-loan originations, while the average funding cost remains more contained. The average funding cost is mainly driven by the more gradual increase in deposit rates, due to deposits representing the lion share of banks' liability mix, and, together with loan rates,

Figure 7: Untargeted impulse responses: NIM and capital ratio

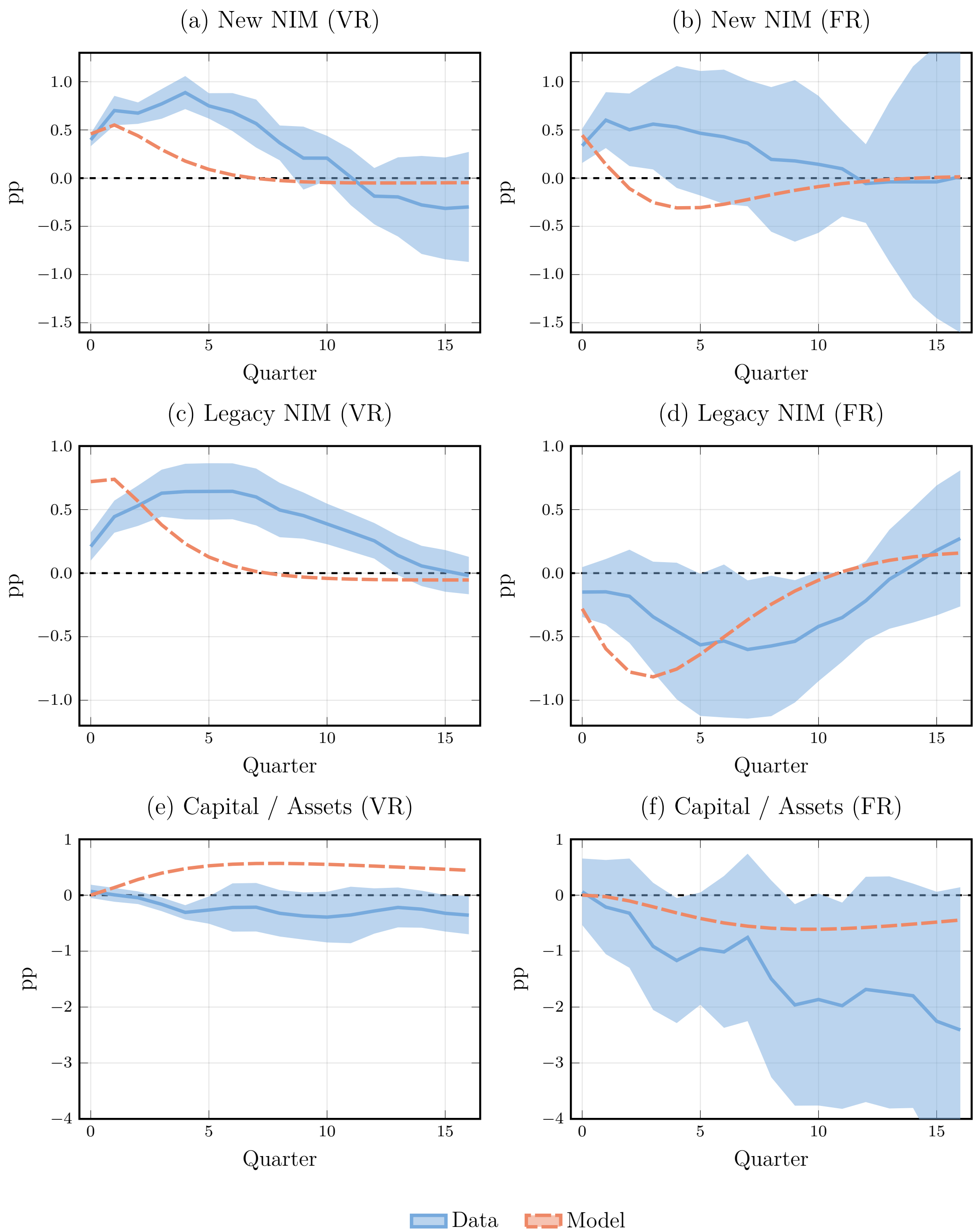
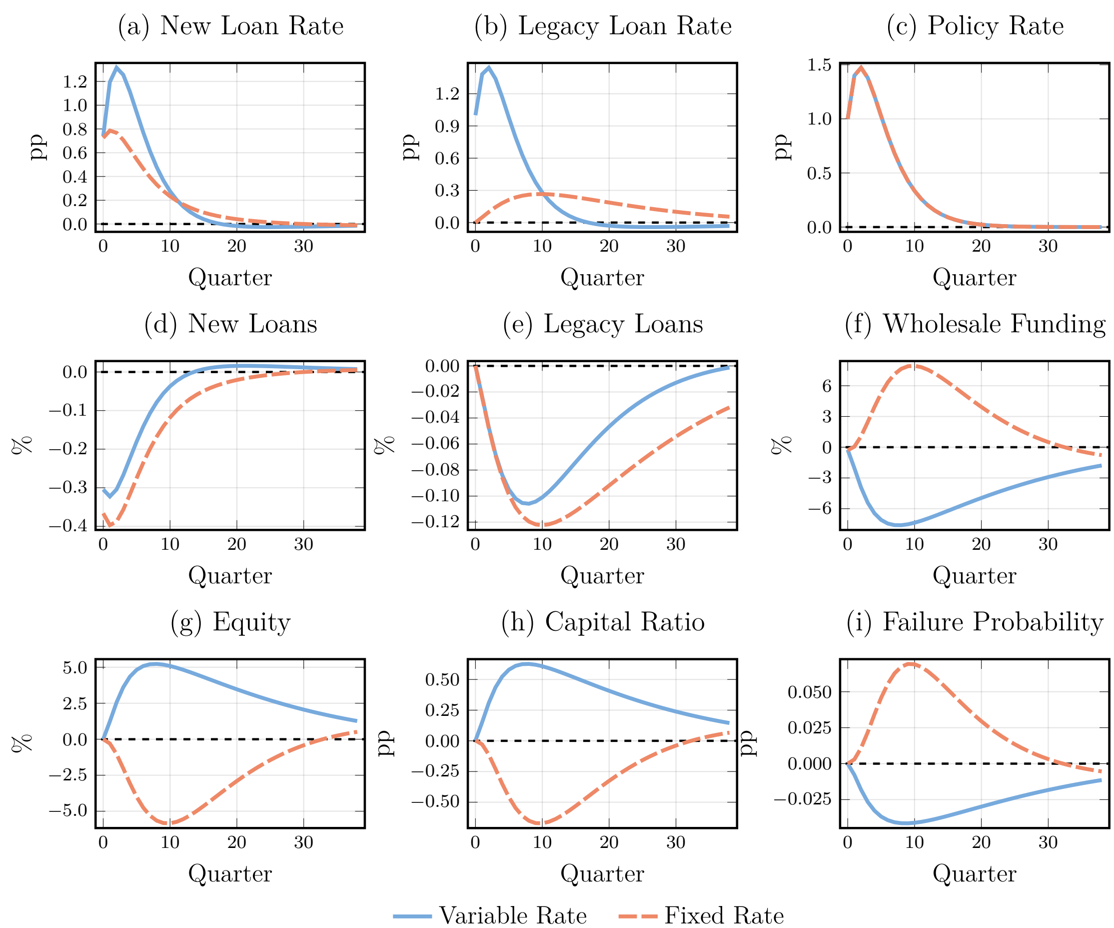


Figure 8: Aggregate impulse response functions



determines the impact on profitability.

For variable-rate banks (blue solid line), the initial pressure on funding costs is offset by a rapid pass-through of the policy rate to both new and legacy loans (Panels a and b). This widens their net interest margin (NIM), translating into higher profitability, which in turn increases their equity and capital ratios (Panels g and h). In stark contrast, fixed-rate banks experience a severe and prolonged compression in their NIM, as their funding costs rise while income from their fixed-rate legacy portfolio remains stagnant (the higher interest rate on new loans only increases the average rate in the banks' portfolio as new loans slowly replace maturing legacy ones). This dynamic precipitates an erosion of their equity and capital ratios. The asymmetry in the response of equity represents the main amplification channel explaining the diverging responses across the two types of banking sectors. Ultimately, the deterioration in bank capitalization under a fixed-rate regime leads to a significantly sharper and more prolonged contraction in new loan origination compared to the variable-rate system (Panel d), as well as an increase in their reliance on wholesale funding (Panel f).

Finally, the monetary tightening has opposing effects on financial stability: the probability of bank failure increases markedly in the fixed-rate system, owing to the decrease in banks' capitalization, whereas it declines for variable-rate banks for the opposite reason (Panel i). This heterogeneity in loan rate fixation patterns is therefore a critical determinant of both the amplification of monetary policy and its consequences for financial stability.

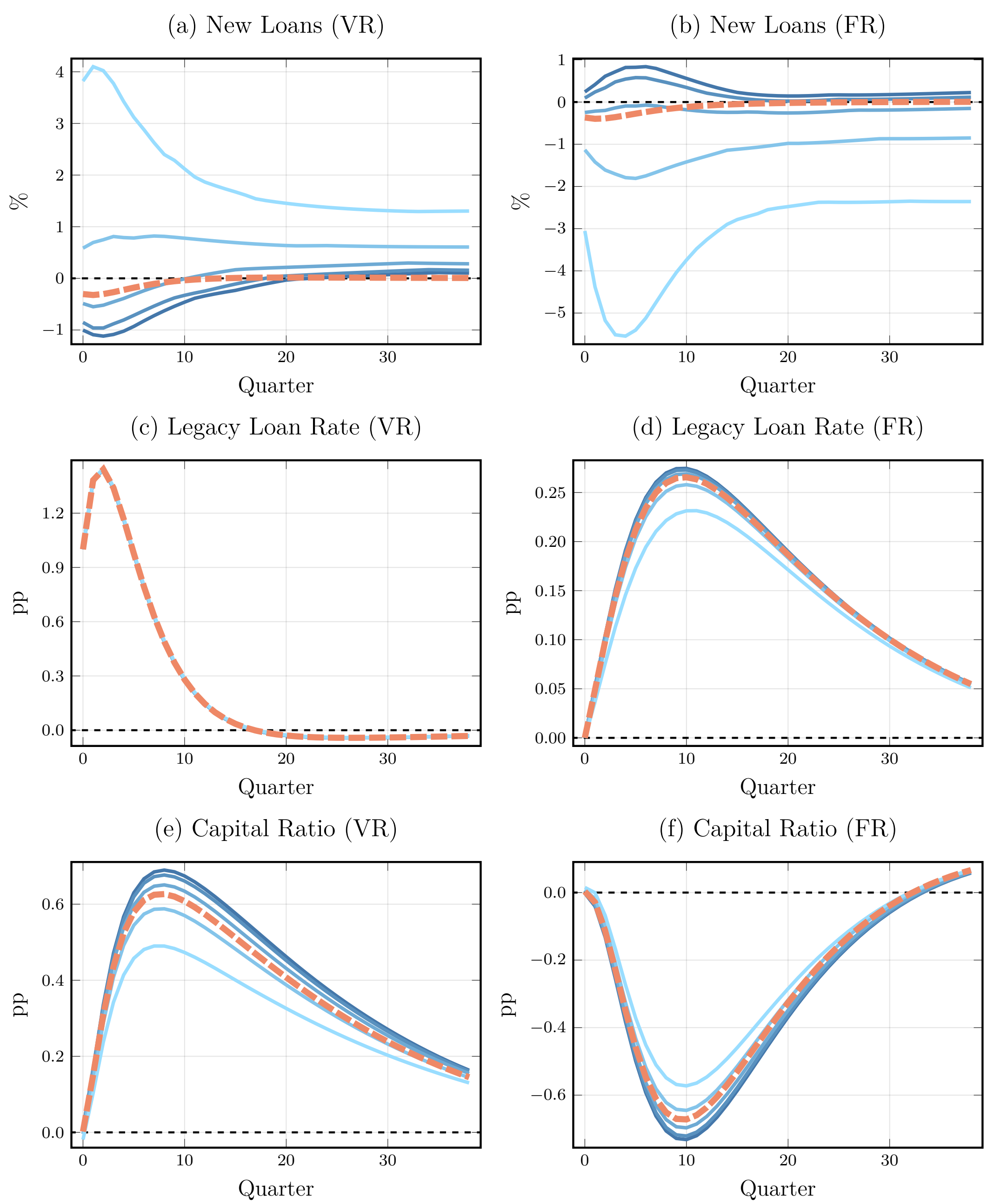
All in all, we can conclude that ex-ante heterogeneity leads to a quantitative difference in the bank lending channel: the elasticity of new lending is about 1/3 larger in fixed-rate economies. Beyond this significant quantitative difference, the implications of bank capital, critical for financial stability, go in opposite directions.

Ex-post heterogeneity. The aggregate responses mask a substantial degree of heterogeneity in the transmission of monetary policy to bank lending. To show this, we disaggregate the responses to explore the role of ex-post heterogeneity in bank leverage. Figure 9 presents the impulse responses for banks in different quantiles of the steady-state capital-ratio distribution, where lighter shades represent more highly leveraged institutions.

The results highlight two key findings. First, consistent with the empirical literature, higher-leverage banks are a key margin of transmission. In both fixed-rate (FR) and variable-rate (VR) systems, these banks exhibit a stronger lending response to the monetary policy shock.

Second, ex-post heterogeneity is substantially amplified within a fixed-rate system. For FR banks, the shock-induced capital erosion (Panel f) is most severe for institutions that are already highly leveraged. Consequently, these banks are forced into a starkly more profound and more prolonged contraction in new lending (Panel b) as they move to restore their capital buffers. In contrast, while all VR banks see their capital ratios improve (Panel e), higher-leverage institutions exhibit a stronger marginal propensity to lend (as shown in Figure 4), leading to a more aggressive expansion in new loans (Panel a). The heterogeneity in lending responses is therefore driven by proximity to capital constraints of high- and low-leverage institutions. All in all, the interaction between

Figure 9: Individual impulse response functions



high leverage and fixed-rate loan portfolios acts as a powerful amplifier of monetary policy shocks.

Interactions between both types of heterogeneity. Figure 10 compares the responses of loan quantities (bank-lending channel) and financial stability variables in both economies (FR and VR) against a counterpart where we significantly reduce the level of idiosyncratic risk.

Regarding the bank-lending channel, differences in ex-ante heterogeneity disappear when ex-post risk is reduced. Moreover, bank failure rates disappear entirely even though the effects on capital ratios remain the same.

Why is this interaction so stark? First, we clarify that this answer critically depends on the calibration. Second, and most importantly, loan origination costs play a fundamental role: Without idiosyncratic risk, banks would ideally want to maximize leverage as there is no risk-return tradeoff. However, the loan-origination costs that, together with the observed default risk rationalize the capital buffer, are relatiely large in our calibration. For that reason, even without idiosyncratic risk, bank remain substantially far from their regulatory capital limits.

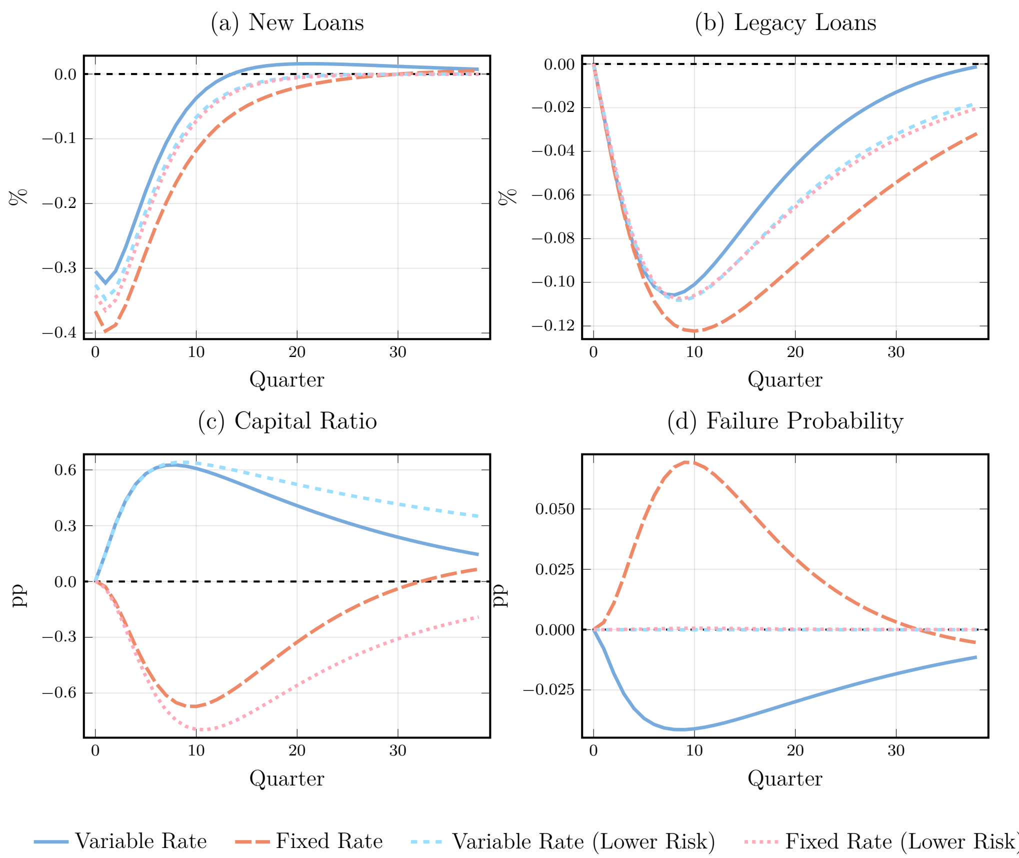
For this reason, IRFs across FR and VR countries are identical once idiosyncratic risk is muted. Since, when the volatility of idiosyncratic shocks is small enough, no bank risks liquidation, their new lending responds exclusively to changes in the NIM of new loans, even though the policy rate shock moves their capital ratios in opposite directions.

The key lesson of this section is that ex-ante heterogeneity is relevant only because there is ex-post heterogeneity.

5. Implications: a discussion

Financial stability and monetary policy conflicts. Our findings have important implications for the design and coordination of bank regulation and monetary policy. Changes in capital requirements can amplify the differential effects of monetary policy across banking systems: tighter capital requirements increase the fraction of banks operating near regulatory constraints, making fixed-rate economies even more vulnerable to monetary tightening while having little effect on variable-rate systems. This asymmetry makes the trade-offs facing monetary policymakers in a monetary union

Figure 10: Impulse response functions — Lower idiosyncratic risk



more acute, as regulatory changes can inadvertently increase the divergence in regional responses to uniform policy.

Gradualism doctrine. Our analysis provides, in principle, a theoretical foundation for gradualism in monetary policy conduct. Rapid policy rate increases prevent banks from anticipating and preparing for regulatory pressures, forcing abrupt deleveraging that amplifies the contractionary effects. In contrast, gradual and well-communicated policy adjustments allow banks to rebuild capital buffers and adjust their portfolios more smoothly, reducing the severity of the lending contraction while achieving the same cumulative policy stance. These insights suggest that effective macroeconomic stabilization requires careful coordination between monetary and prudential authorities, with particular attention to the timing and sequencing of policy interventions across these domains.

The model can be used to study experiments to shed light on these questions, by comparing different levels of capital requirements and more gradual policy hikes.

6. Conclusion

This paper investigates how bank heterogeneity shapes the transmission of monetary policy.

Our central finding is that the ex-ante heterogeneity between loan-pricing regimes is quantitatively important for the bank lending channel. In a fixed-rate system, banks are unable to reprice legacy assets to offset rising funding costs after a monetary tightening, reducing their profitability and their capital positions. This forces a sharper credit contraction relative to variable-rate systems, in which loan repricing combined with a gradual pass-through to deposit rates makes the effect of a monetary tightening positive for profitability. Furthermore, the shock also also raises the probability of bank failure in fixed-rate systems, highlighting the financial stability risks.

Furthermore, the model demonstrates that banks' leverage acts as a powerful amplifier, but its effects are contingent on the loan-pricing regime. Consistent with the literature, high-leverage banks are the primary margin of transmission. However, in a fixed-rate system, their proximity to regulatory constraints forces them to cut lending most aggressively in response to capital depletion. Conversely, in a variable-rate system where monetary tightening boosts profitability, these same high-leverage banks, exhibiting a higher marginal propensity to lend out of equity, expand their loan origination most. Our analysis thus reveals that the interplay between loan pricing and bank capitalization is fundamental to understanding both the aggregate strength of the transmission and the heterogeneous impact of monetary policy.

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Appendices

A. Model derivations

A.1 A microfundation for aggregate deposits demand

TBC.

A.2 Bank problem

TBC.

A.3 Conditions for risk-free wholesale debt

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

$$L_t + N_t + \theta\alpha L_t = \alpha L_t + B_t + E_t.$$

Solving for B_t:

$$B_t = [1 + \alpha(\theta - 1)]L_t + N_t - E_t.$$

Consider the worst possible realization for the iid shock ($\omega_{t+1} = 1$). Then debt holders recover at most:

$$(1 + r_t^M)M_t + (1 - \lambda)(L_t + N_t).$$

For debt to be risk free, we need:

$$(1 + r_t^B)\underbrace{\{[1 + \alpha(\theta - 1)]L_t + N_t - E_t\}}_{B_t} \le (1 + r_t^M)\theta\alpha L_t + (1 - \lambda)(L_t + N_t),$$

which, imposing the equilibrium condition $r_t^B = r_t^M$, simplifies to the following condition:

$$(1 + r_t^B)\,[(1 - \alpha)L_t + N_t - E_t] \le (1 - \lambda)(L_t + N_t).$$

A.4 Law of motion of a bank's equity

TBC.

A.5 Derivation of Resource Constraint

TBC.

A.6 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:

$$\xi_{ijt+1} = -\Phi^{-1}(p) + \sqrt{\rho} z_{jt+1} + \sqrt{1-\rho}\varepsilon_{it+1}, \tag{21}$$

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 (21) ensures that the unconditional probability of failure of project i satisfies:

$$\Pr(\xi_{ijt+1} < 0) = \Pr\left[\sqrt{\rho} z_{jt+1} + \sqrt{1-\rho}\varepsilon_{it+1} < \Phi^{-1}(p)\right] = \Phi\left[\Phi^{-1}(p)\right] = p. \tag{22}$$

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,

$$\begin{aligned}\omega_{jt+1} =&\xi(z_{jt+1}) = \Pr\left(-\Phi^{-1}(p)+\sqrt{\rho}z_{jt+1}+\sqrt{1-\rho}\varepsilon_{it+1}<0|z_{jt+1}\right)\\ =&\Phi\left(\frac{\Phi^{-1}(p)-\sqrt{\rho}z_{jt+1}}{\sqrt{1-\rho}}\right).\end{aligned} \tag{23}$$

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

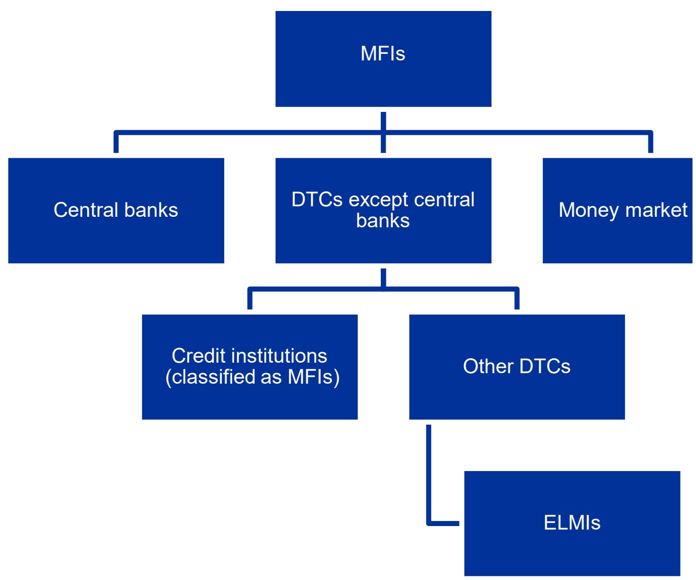
$$\begin{aligned}F(\omega_{jt+1}) =&\Pr\left[\xi(z_{jt+1})\leq\omega_{jt+1}\right] = \Pr\left[z_{jt+1}\geq\xi^{-1}(\omega_{jt+1})\right]\\ =&\Phi\left(\frac{\sqrt{1-\rho}\Phi^{-1}(\omega_{jt+1})-\Phi^{-1}(p)}{\sqrt{\rho}}\right).\end{aligned} \tag{24}$$

B. Data Appendix

B.1 Consolidated banks balance sheet: Data sources

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

Figure 11: Components of the MFIs sector



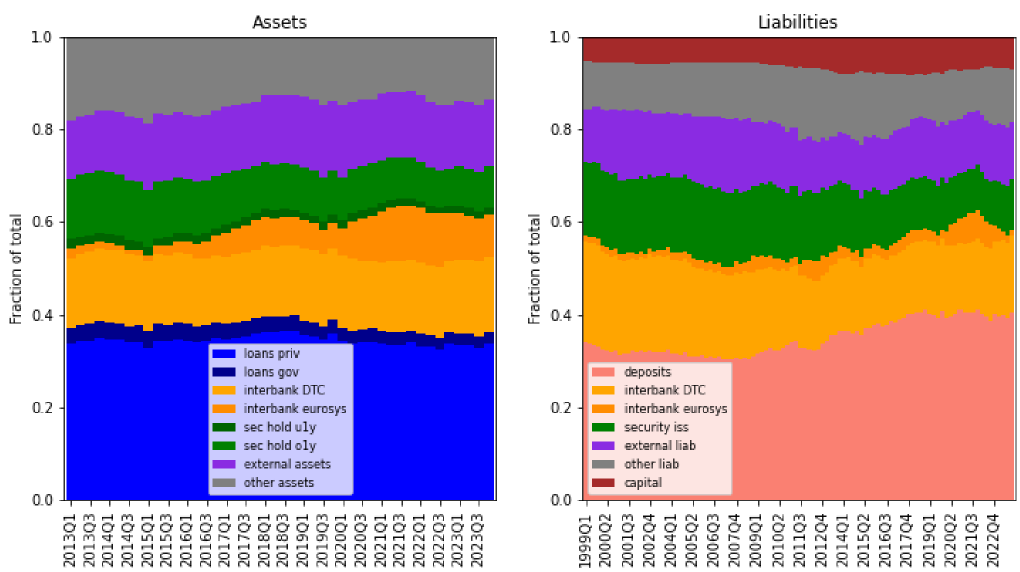
Note: DTC stands for deposit-taking corporation. ELMI stands for electronic money institution.

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:

- Aggregate 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

Figure 12: MFIs Aggregate 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.

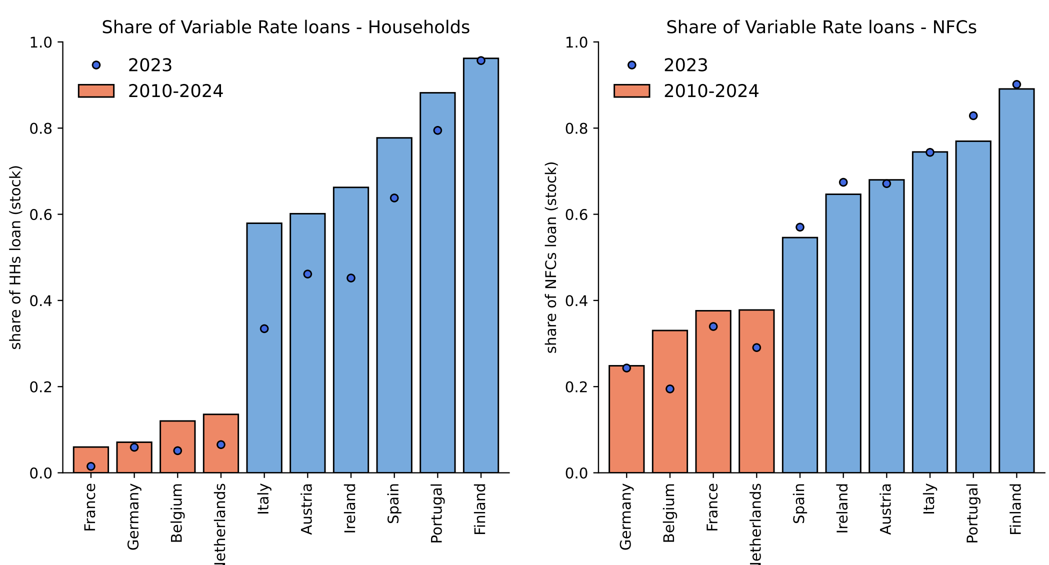
Table 3: MFIs Balance Sheet Composition (2013–2023)

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

Authors elaboration. 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 gov. + 85% of external assets (i.e. operations with non-euro area residents) + 85% of 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 + 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 Loan Rate Fixation Patterns

Figure 13: Composition of lending stocks by interest rate fixation period.



Authors elaboration. 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.4 Estimating Local Projections

We estimate Local Projections a là Jordà (2005) and Jordà et al. (2015). As it is standard in the literature, we instrument the first differences in the deposit facility rate (DFR) with a measure of monetary surprises. Our instrument is the monetary policy component from Jarociński and Karadi (2020). We built a balanced panel for ten largest euro are countries (Austria, Belgium, Germany, Finland, France, Italy, Ireland, Netherlands, Portugal, and Spain) using data on lending rates, deposit rates, among others, from 2000 to 2023. For these estimations, we aggregate the data to quarterly frequency.

We classify countries as variable-raters (VR) if their share of variable-rate lending is above 50%. VR countries are Spain, Portugal, Italy, Finland, Ireland, and Austria. Fixed-raters (FR) are Germany, France, Belgium, and the Netherlands.

Prices. For interest rates, we estimate the following local projection specification:

$$r_{c,t+h} = \alpha_{c,h} + \beta_{1h}\varepsilon_t^{MP} + \beta_{2h}\left[\varepsilon_t^{MP} \times I_c^{FR}\right] + \Gamma_h X_{c,t} + e_{c,t+h} \tag{25}$$

where $r_{c,t+h}$ denotes the variable of interest (lending rates, deposit rates, NIM) 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. I_c^{FR} is a dummy variable that takes the value of one if 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. 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:

$$\log Y_{c,t+h} = \alpha_{c,h} + \beta_{1h}\epsilon_t^{MP} + \beta_{2h}\left[\epsilon_t^{MP} \times I_c^{FR}\right] + \Gamma_h X_{c,t} + e_{c,t+h}. \tag{26}$$

For these IRFs, we directly use the monetary surprises (ϵ_t^{MP}) 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.