Mortgage Structure, Financial Stability, and Risk Sharing*

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Abstract

Mortgage structure matters not only for monetary policy transmission, but also for financial stability. Adjustable-rate mortgages (ARMs) expose households to rising rates, increasing default risk through higher payments, while fixed-rate mortgages (FRMs) protect households but potentially expose banks to greater interest rate risk. To evaluate these competing forces, we develop a quantitative model with flexible mortgage contracts, liquidity- and net worth-driven household default, and a banking sector with sticky deposits and occasionally binding constraints. We find financial stability risks exhibit a U-shaped relationship with mortgage fixation length. FRMs benefit from deposit rate stickiness, reducing volatility, whereas ARMs provide net worth hedging by concentrating defaults when intermediary net worth is high, thus lowering risk premia. An intermediate fixation length balances these effects, minimizing banking sector volatility and improving aggregate risk-sharing. Our model explains observed differences in delinquencies, house prices, and bank equity prices between ARM and FRM countries during 2022–2023, with implications for mortgage design, macroprudential regulation, and monetary policy.

JEL: E52, G21, G28, R31, E44.

Keywords: mortgages, financial stability, interest rate risk, credit risk, fixed-rate, adjustable-rate, risk sharing, intermediary asset pricing, household finance

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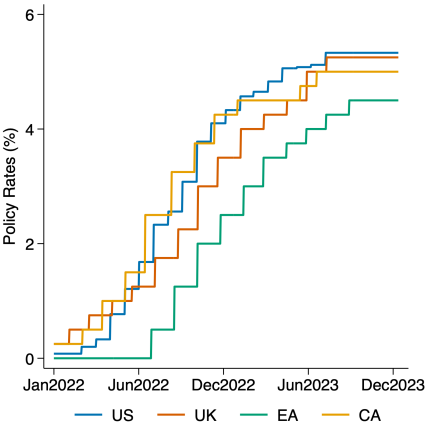
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1 Introduction

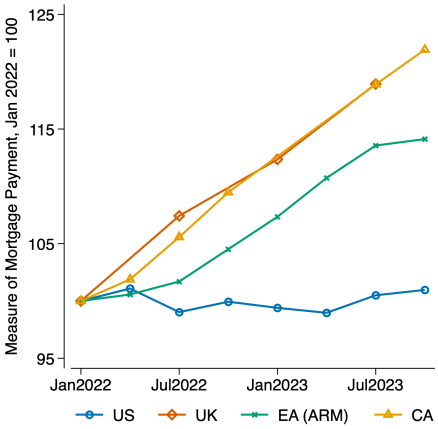
Mortgage structure matters for macroeconomic outcomes. It directly affects the transmission of monetary policy, since adjustable-rate mortgages (ARMs) reset more immediately compared to fixed-rate mortgages (FRMs) (e.g. Calza et al., 2013; Di Maggio et al., 2017; Fuster and Willen, 2017; Garriga et al., 2017). In this paper, we show that mortgage structure also matters for financial stability risks. Differences in mortgage structure were brought into sharp relief by the global monetary tightening cycle between 2022 to 2023. Despite similar policy rate increases of approximately 400–500 basis points across major economies, mortgage payments increased by 15 to 25% in countries with ARMs (U.K., Canada, and Euro Area), while remaining stable in the U.S., where 30-year FRMs are predominant (Figure 1).

Figure 1: Comparison of Policy Rates and Mortgage Payments, 2022–2023

(a) Policy Rates



(b) Measure of Mortgage Payments



Notes: Panel (a) shows main monetary policy rates for the US, United Kingdom (UK), Euro Area (EA), and Canada (CA). Panel (b) shows measures of average mortgage payments. EA ARM aggregates Finland, Italy and Portugal. Data sources: US: 2024Q2 revised mortgage debt service ratio (DSR) from FRED; UK: total expected (incl. agreed changes in payments e.g. due to forbearance) monthly mortgage payment from the Financial Conduct Authority (FCA); Euro Area: total DSR from BIS; Canada: average monthly scheduled outstanding mortgage payments from the Canada Mortgage and Housing Corporation (CMHC).

The contrasting mortgage payment sensitivity to rate changes highlights distinct financial stability risks and risk-sharing properties across mortgage structures. Specifically, rising interest rates in ARM economies directly increase mortgage payments, thereby raising household defaults and bank credit losses. Conversely, FRMs shield households from rising payments but potentially expose banks to greater interest rate risk.

How should one evaluate the implications of mortgage structure for financial stability and risk sharing between households and financial intermediaries? A natural starting point might be to select a mortgage structure that offsets the cash flow sensitivity of bank liabilities, particularly deposits, achieving a "zero duration" financial system that fully hedges interest rate risk. However, such an approach overlooks several channels that likely arise in equilibrium.[1] First, interest rate changes also affect credit risk, as households make endogenous default decisions that differ across macroeconomic environments and mortgage structures (Campbell and Cocco, 2015). For instance, rising rates and ARM payments can trigger defaults among liquidity-constrained households, an effect absent under FRMs. Second, financial intermediaries' willingness to hold mortgages and their mortgage pricing, especially risk premia, depend on intermediary net worth. As a result, overall financial stability depends on both interest rate risk and credit risk, and the correlation of these risks with intermediary net worth.

To embed these channels and evaluate financial stability and risk sharing across different mortgage structures in equilibrium, we develop a quantitative macro-finance model with flexible mortgage contract structures, borrowers, and a financial sector. We calibrate the model to the U.S. FRM economy as a benchmark, and compare it to counterfactual economies with alternative mortgage structures.

The model yields three main results. First, rising interest rates affect households and financial intermediaries in opposite directions depending on mortgage structure: under FRMs, intermediary net worth deteriorates; under ARMs, borrower defaults increase but intermediary net worth improves due to higher mortgage payments. Second, financial stability risks exhibit a U-shaped relationship with mortgage fixation length. While the FRM economy is rendered more stable by sticky deposit rates, ARMs provide inherent net worth hedging given deposit stickiness: defaults typically occur when intermediary net worth is high, when interest income rises relative to deposit funding cost, reducing risk premia. Intermediate fixation lengths of 3 and 5 years minimize intermediary net worth volatility and optimize aggregate risk-sharing. Third, the optimal fixation length depends on the correlation of interest rate risk with aggregate income risk. In a procyclical rate environment, the optimal fixation length is higher – rising to 3.5 and 5.5 years for the 1987 to 2024 sample, for instance.

[1] We develop the intuition behind deviations from this interest rate "immunization" more formally in Section 5.2.

In the model, there are two types of households: borrowers who borrow to finance their housing purchases, and savers, who own intermediaries ("banks"). Households face idiosyncratic income shocks. Borrowers and banks trade in two financial markets: deposits and mortgages. We model realistic and flexible mortgage payment structures. Under FRMs, mortgages have fixed payments. Under ARMs, mortgages are issued with fixed payments in an initial teaser stage, and subsequently convert to floating payments (a fixed spread over the contemporaneous risk-free rate) with some probability, to reflect varying fixed-rate lengths in typical adjustable-rate mortgages.[2]

Given our focus on borrowers' default sensitivity to interest rate changes under ARMs, the model incorporates a realistic notion of liquidity-driven default (Gerardi et al., 2018; Ganong and Noel, 2022), where defaulting allows liquidity-constrained households to increase immediate consumption at the expense of future wealth. Following Diamond et al. (2022), we model household decision-making in two distinct stages with a cash-in-advance-type constraint. In the first stage ("consumption stage"), households must rely on liquid assets – income and deposits – to finance consumption, housing costs, and mortgage payments, and decide whether or not to default. They cannot access illiquid housing wealth at this stage. Default provides immediate liquidity but reduces subsequent wealth. In the second ("trading") stage, households make portfolio decisions to allocate their wealth between deposits, housing, and stocks, and they can adjust their mortgage balance by taking out a new mortgage. Banks lend in the mortgage market subject to a leverage constraint, financing their loan portfolios with savers' equity and deposits, which are risk-free one-period bonds held by households and also elastically demanded by outside investors. ARMs are indexed to the policy rate, while the deposit rate does not necessarily move one-for-one with the policy rate. Our reduced-form model of imperfect pass-through is consistent with banks' market power in deposit markets (Drechsler et al., 2017) and time-varying liquidity premia due to the opportunity cost of holding money (Nagel, 2016; Krishnamurthy and Li, 2022).

To solve the model, we follow Diamond and Landvoigt (2022) and Diamond et al. (2022) and show that, despite idiosyncratic and undiversifiable risks, borrowers make identical choices per

[2]We cast the model in real terms to study the redistributive effects of real interest rate changes on borrowers and savers depending on mortgage structure. The effects of mortgage structure also operate through nominal (Fisherian) channels, as studied by Garriga et al. (2017).

unit of wealth. This removes the borrower wealth distribution as an infinite-dimensional state variable, making the model tractable.

We evaluate the US fixed-rate mortgage regime relative to counterfactual adjustable-rate mortgage economies with varying fixation lengths, starting with the main ARM counterfactual where mortgage rates reset every year. The benchmark FRM economy and ARM counterfactual produce empirically consistent responses to a rise in rates. In the FRM economy, mortgage payments remain stable, slightly reducing defaults since holding on to the current mortgage becomes more valuable, consistent with recent U.S. experience. In contrast, the ARM economy experiences sharply higher mortgage payments, elevated defaults, and a reduction in house values, similar to recent U.K. dynamics (illustrated in Appendix Figures IA.3-IA.5, with the caveat that the model is calibrated to the U.S.).

Under FRMs, banks face unchanged interest income and rising deposit expenses when policy rates increase, reducing net interest margins and profitability despite slight offsetting decreases in credit losses. In addition, FRMs have a long duration. In response to higher rates, the market value of bank assets falls (Jiang et al., 2024). With both lower cash flows and lower asset values, the net worth of the banking sector declines. More constrained banks demand higher compensation to take on mortgage risk, a key implication of intermediary-based asset pricing models (He and Krishnamurthy, 2013; Brunnermeier and Sannikov, 2014; Elenev et al., 2016; Diamond and Landvoigt, 2022).

Note that we model intermediaries to reflect the financial sector as a whole. While US banks have experienced a substantial reduction in on-balance sheet mortgage lending and substitution towards mortgage-backed securities (MBS) over recent decades (Buchak et al., 2018, 2024a,b), the banking sector remains the largest private holder of mortgage-backed securities as a whole. In Appendix Figure IA.1, we show that more than half of all non-government residential mortgages (MBS and portfolio loans) are held by the banking sector, and that share has remained relatively stable over the past decade.[3]

Conversely, in the ARM economy, the net interest margin of banks increases as mortgage payments rise faster than deposit costs, effectively creating negative mortgage duration and

[3]We also conduct robustness exercises where we allow for greater pass-through of policy rates to deposit rates, capturing the notion that other financial intermediaries and holders of MBS may have less sticky sources of funding compared to banks.

enhancing intermediary net worth despite higher defaults.

We next evaluate how these dynamics translate into financial stability outcomes by evaluating counterfactual economies with mortgage fixation lengths ranging from pure ARMs (annual resets) to the benchmark fully fixed-rate economy. Financial stability, measured primarily by the volatility of intermediaries' return on equity (ROE), exhibits a "U-shaped" relationship with mortgage structure. Volatility is highest in a pure ARM economy where intermediary net worth is very sensitive to interest changes, leading to large negative duration. It is somewhat lower in an FRM economy as sticky deposits provide a hedge to the large positive duration of fixed-rate mortgages.

Because mortgages carry credit risk, bank asset sensitivity to interest rates depends not only on policy rates but also on expected credit losses and time-varying risk premia linked to intermediary net worth. Under FRMs, risk premia rise when intermediaries become constrained, typically in high-rate environments. In contrast, ARM intermediaries are constrained primarily when rates and defaults are low; thus, rising rates and defaults coincide with periods of high intermediary net worth, providing a net-worth hedge. An intermediate fixation length (around 3 years) minimizes intermediary ROE volatility by balancing these opposing forces, reducing the cyclicality of defaults and net worth in response to interest rate fluctuations.

We further assess how mortgage structure determines risk-sharing between households.[4] To quantify the degree of risk sharing, we measure intra-borrower risk-sharing of idiosyncratic risks via individual versus aggregate borrower consumption variance, and borrower-saver aggregate risk-sharing through borrower versus saver aggregate consumption variance. Mortgage structure predominantly affects borrower-saver sharing of interest rate risk, optimized at a fixation length of around 5 years – slightly longer than the volatility-minimizing fixation length, suggesting a modest trade-off between financial stability and risk-sharing. In this economy with low effective mortgage duration and default rates that respond little to interest rates, rate shocks have the weakest redistributive effect.[5] However, low exposure to aggregate risk leads borrowers to endogenously choose higher exposure to idiosyncratic risk, highlighting a somewhat subtle downside in equilibrium.

[4]Our focus on interest rate risk sharing through mortgages of various fixation lengths is complementary to Greenwald et al. (2019)'s study of contracts that share house price risks.

[5]See e.g. Auclert (2019).

Lastly, we investigate how results vary with different macroeconomic scenarios, by introducing aggregate income shocks which correlate with interest rate shocks. In the data, this correlation is time-varying and depends on the sample period, reflecting underlying demand or supply shocks (leading to a positive or negative correlation, respectively). We find that a positive correlation between aggregate income and interest rate shocks of 0.3 (reflecting the correlation in the 1987 to 2024 sample) makes FRM economies relatively more stable and ARM economies relatively riskier.[6] Intuitively, higher rates in an FRM economy come with even lower default risks due to increased borrower incomes. In contrast, this positive correlation weakens the net-worth hedging property of ARMs, as higher incomes mitigate payment-driven defaults (and lower incomes exacerbate defaults when rates are low, when ARM intermediaries have low net worth). Thus, a positive correlation between income and rate shocks increases the optimal mortgage fixation length. Quantitatively, the fixation length that minimizes intermediary net worth volatility rises from approximately 2.7 to 3.9 years as the correlation increases from -0.3 to 0.5. Overall, these effects are modest and reinforce the central finding that an intermediate fixation length (around 3 to 5 years) best balances financial stability and risk sharing.

Our work has implications for monetary policy and macroprudential regulation of financial stability risks. The paper provides a framework for analyzing how interest rate fluctuations differentially affect financial stability depending on mortgage structure. It thus helps formalize monetary policy and financial stability linkages, and underlying mechanisms. We propose a flexible modeling framework to study the effect of mortgage structure on financial stability, which takes into account endogenous household default decisions, interaction effects between interest rate and credit risk, and the capitalization of the banking system. Our findings highlight how intermediate fixation lengths, common in many countries, can balance sources of volatility in both pure ARM and FRM structures.

Related Literature Our paper makes several contributions to the existing literature. First, we assess macroeconomic implications of different mortgage contract designs, similar to Garriga et al. (2017); Greenwald et al. (2019); Campbell et al. (2021); Guren et al. (2021), but focusing

[6] In the data, this correlation varies over time, taking positive or negative values in demand or supply-shock driven macroeconomic contexts, respectively. In a finance context, Campbell et al. (2009, 2017, 2020) show that inflation and monetary policy can explain this time variation and variation in the sign of stock-bond return correlation.

on the novel channel of interest rate and credit risk sharing between households and banks. Conceptually, we thus integrate features of existing quantitative macro-models with financial intermediaries (e.g. Elenev et al., 2016; Diamond et al., 2022; Sanchez Sanchez, 2023[7]) into a framework with flexible mortgage structures and liquidity-driven default, matching empirical evidence (Gerardi et al., 2018; Ganong and Noel, 2022). Our mechanism is closely related to Campbell and Cocco (2015) who show that fixed- and adjustable-rate mortgages default in different macroeconomic states of the world, and we integrate this intuition into a macroeconomic framework with a banking sector.

Both Campbell et al. (2021) and Guren et al. (2021) focus on the role that mortgage structure can play at providing liquidity to households in downturns when interest rates are low while default rates are high, given the context of the 2008–2009 financial crisis. In contrast, we study how mortgage structure affects household and intermediary outcomes in response to isolated rate shocks given a low historical correlation of income with real rates overall and also given the 2022–2023 rate hike cycle, where both rates and defaults rose in ARM but not in FRM countries. Like Campbell et al. (2021), we study how different mortgage structures expose not just borrowers but lenders to risk. These exposures not only affect the ex-ante prices of mortgages but have implications for the stability of financial intermediary balance sheets, a particular focus of our paper.

We contribute to existing work on mortgage choice (Campbell and Cocco, 2003; Koijen et al., 2009; Badarinza et al., 2018; Liu, 2022; Albertazzi et al., 2024; Boutros et al., 2025) as well as optimal mortgage contract design (Piskorski and Tchistyi, 2010; Campbell, 2012; Eberly and Krishnamurthy, 2014; Mian and Sufi, 2015; Piskorski and Seru, 2018). Our work is further related to papers that emphasize the role of the mortgage market (Scharfstein and Sunderam, 2016; Di Maggio et al., 2017; Fuster and Willen, 2017; Greenwald, 2018; Chen et al., 2020; Di Maggio et al., 2020; Berger et al., 2021; Garriga et al., 2021; Eichenbaum et al., 2022; Altunok et al., 2024) and financial intermediaries (Wang, 2018; Di Tella and Kurlat, 2021;

[7]These papers also study the effect of the Government-Sponsored Enterprises (GSEs). In case of default, they guarantee to an MBS trust the "timely payments of principal and interest", but typically repurchase a defaulted mortgage loan within 24 months, meaning that default leads to missed interest payments akin to prepayment (e.g. Fannie Mae, 2023). As a result, GSEs only partially protect intermediaries from cash flow shortfalls in our framework. For FRMs, defaults are higher when rates are low, making prepayment costly. For ARMs, defaults are higher when rates are high (i.e. when mortgage payments are high), also making prepayment costly.

Wang et al., 2022; Diamond et al., 2024) on monetary policy transmission.

The paper offers a novel lens to interpret linkages between monetary policy and financial stability (Adrian and Shin, 2008; Hanson et al., 2011; Stein, 2012; Borio, 2014; Jiménez et al., 2014; Garriga and Hedlund, 2018; Smets, 2018; Caballero and Simsek, 2019; Martinez-Miera and Repullo, 2019; Ajello et al., 2022; Boyarchenko et al., 2022; Gomes and Sarkisyan, 2023), highlighting that mortgage structure can mediate how changes in interest rates affect financial stability.

Lastly, we contribute to a growing body of work on the financial stability implications (Jiang et al., 2024; Drechsler et al., 2023; Haas, 2023; Varraso, 2023; Begenau et al., 2024; DeMarzo et al., 2024) and transmission mechanism (Fonseca and Liu, 2024; Greenwald et al., 2023; Bracke et al., 2024; De Stefani and Mano, 2025) of recent rate rises.

2 Motivating Facts on Mortgage Structure

This section illustrates variation in mortgage structure across a range of different countries which motivates the counterfactual mortgage structures that we study using our model.

2.1 Mortgage Structure Across Countries

There is substantial variation in mortgage market systems and contract structures across countries (Campbell, 2012; Badarinza et al., 2016).[8] Figure 2 shows the average fixed-rate length across countries from different data sources.

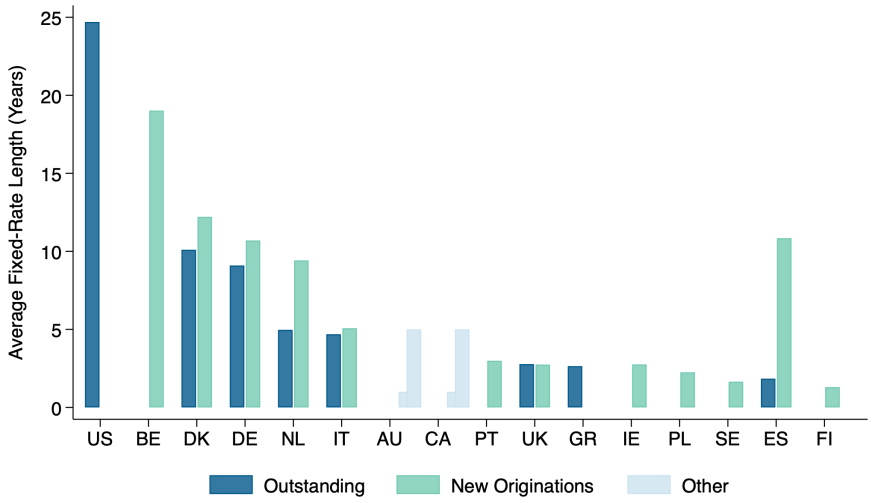
A striking fact noted by Campbell (2012) is that the US appears as an outlier in international comparison, with an average fixed-rate length of almost 25 years, driven by the reliance on 30-year FRMs and 15-year FRMs.[9] The US is followed by a group of countries including Denmark,

[8] In this paper, we will not take a stance on the drivers of the underlying structure and take prevalent contract structures as given. Reasons that have been put forward to explain cross-country heterogeneity in mortgage structure include historical path dependence, the availability of long-term mortgage funding, historical inflation experiences (Badarinza et al., 2018), as well as variation in underwriting standards and the role of credit risk (Liu, 2022).

[9] The only country with a comparable average fixed-rate length is typically thought of as France. While data for average fixation lengths is not available for France, the typical mortgage is a 30-year fixed-rate mortgage according to the European Mortgage Federation.

Germany, Belgium, and the Netherlands, which offer mortgages with fixation lengths of up to 30 years, but the average mortgage outstanding has a length typically closer to 10 years. For Belgium, data is available only for new mortgage originations, which have been close to 20 years. The vast majority of all remaining mortgage markets have fixed-rate lengths between 2 to 5 years, including countries such as Australia, Canada, the UK, Ireland, Portugal, Greece, and Spain. Other Scandinavian countries such as Finland, Sweden, and Norway (the latter with no data on average fixed-rate lengths) are typically thought of as originating many pure adjustable-rate mortgages, with rates resetting at least every year.

Figure 2: Average Mortgage Fixed-Rate Lengths Across Countries



Notes: "Outstanding" reflect data from Badarinza et al. (2016) ("BCR") as of 2013, while "New Originations" reflect data from the European Mortgage Federation for new mortgage originations, as of 2023Q1, from the EMF Quarterly Review of European Mortgage Markets 2023 Q2. Figure adapted from Liu (2022).

Even within the common currency Euro Area, countries vary from longer-term fixed-rate mortgage systems (such as Germany and France) to largely adjustable-rate mortgage systems such as Finland, Greece, Ireland and Portugal, which is reflected in the divergence in mortgage payments in 2022 in Figure 1.[10]

As a result, mortgages typically exist on a spectrum from fully adjustable-rate mortgages

[10]Spain has seen much longer fixation lengths in newly originated mortgages compared to past mortgage originations, likely a result of government interventions in 2022 that allow conversion of adjustable to fixed-rate mortgages, aimed at protecting vulnerable borrowers from interest rate rises, see e.g. Financial Times, November 2022.

common in countries such as Finland, Sweden and Norway which reset every year (or depending on contract terms, semi-annually), to intermediate fixation periods of two to five years common in many countries including the UK, Canada, Australia and most Eurozone countries, to the 30-year fixed-rate mortgage common in the US. We think of mortgages with intermediate fixation periods as sitting between pure ARM and FRM structures from an interest rate risk perspective, as these will allow households to fix their mortgage rate for some, but typically not all, of the term over which the mortgage is repaid.[11]

However, mortgage structure is certainly not the only economic fundamental that differs across countries. To assess how differential mortgage structures lead to differences in economic outcomes, financial stability, and risk-sharing properties more formally, in the next section we develop and calibrate a quantitative model of an FRM economy, and evaluate counterfactual economies with a pure ARM structure as well as intermediate fixation lengths.

3 Model

In this section, we develop a rich quantitative dynamic model of the mortgage market.[12]

Time is infinite and discrete $t = 0, 1, \ldots$. The economy is populated by continuums of two types of households with preferences over housing and non-durables – borrowers labeled B indexed by $i \in [0, \ell]$ and savers labeled S indexed by $i \in (\ell, 1]$.

Households' utility function is given by

$$\sum_{t=0}^{\infty} \beta^t u^B(c_t^i, h_{t-1}^i)$$

$$u^B(c_t^i, h_{t-1}^i) = \frac{\left((c_t^i)^{1-\theta}(h_{t-1}^i)^{\theta}\right)^{1-\gamma} - 1}{1-\gamma}$$

where β is the discount factor, θ governs the share of housing in the utility function, and γ is the coefficient of relative risk aversion.

The aggregate supply of houses is exogenous and fixed at $\bar{H}$, with a fraction α_H owned by

[11] Thus fixation length is a distinct feature and different from the choice of the loan repayment window, which is typically 30 years on average for most countries (see Liu (2022) for a more detailed discussion).

[12] Key qualitative insights also emerge from a stylized two-period model, which we relegate to Appendix V.

borrowers while the remaining fraction $1-\alpha_H$ belongs to savers. Only borrowers trade houses. Each unit of housing requires a maintenance payment of δ_h every period to prevent its full depreciation.

Non-durable goods are produced by a continuum $k \in [0,1]$ of Lucas trees, whose aggregate yield each period is given by Y_t. Borrowers own a total of α trees, while savers owns the remaining $1-\alpha$. Each type of agent can trade trees within their type, but not across types. The yield of borrower-owned trees is subject to an idiosyncratic shock ε_t^i, which is i.i.d. across borrowers and time. Saver-owned trees are not subject to idiosyncratic shocks. Therefore, each household's income is given by

$$\begin{aligned} y_t^i &= s_{t-1}^i(Y_t + \varepsilon_t^i) && \forall i \in [0,\ell] \\ y_t^i &= s_{t-1}^i Y_t && \forall i \in (\ell,1] \end{aligned}$$

where s_{t-1}^i is the share of trees owned by each agent type at the start of period t, so that $\int_0^\ell s_{t-1}^i di = \alpha$ and $\int_\ell^1 s_{t-1}^i di = 1-\alpha$.

In addition to trading houses, borrowers trade in two financial markets – deposits and mortgages. Deposits are one-period risk-free bonds, while mortgages are long-term, defaultable, and may have fixed or adjustable payments.

Their counterparties in these markets are banks labeled I (short for "intermediaries"). Banks are firms who issue equity to saver households.

3.1 Borrowers

Following Diamond et al. (2022), we split each period into two subperiods – *consumption* and *trading*. In the consumption subperiod, shocks are realized, and borrowers make mortgage payments or default. In the trading subperiod, all households make portfolio choices.

Borrowers enter the period with a house h_{t-1}^i, a mortgage with outstanding balance m_{t-1}^i, and deposits d_{t-1}^i. They receive income y_t^i after the realization of aggregate and idiosyncratic income shocks.

Mortgage Regimes We consider two mortgage regimes. In the fixed-rate mortgage regime (FRM), the outstanding balance of the mortgage implies a fixed mortgage payment $x_t^i = \iota_f + \delta_m \bar{q}^m$ per unit of mortgage m_{t-1}^i, where ι_f denotes the interest component and the principal component is normalized to a fraction δ of the steady-state mortgage price $\bar{q}^m$. In the adjustable-rate mortgage regime (ARM), the mortgage payment is determined by whether or not the adjustable rate mortgage is in its *teaser* stage τ.

In the teaser stage, ARM payments are fixed at $(\iota_\tau + \delta_m \bar{q}^m) m_{t-1}^i$ with ι_τ the initial fixed "teaser" rate of the mortgage. After the teaser stage, the mortgage payment is determined by the policy (risk-free) rate r_t^f plus the spread ι_a on adjustable-rate mortgages.

$$x_t^i = \begin{cases} \iota_\tau + \delta_m \bar{q}^m, & \mathbb{1}_\tau = 1 \\ \iota_\tau + \delta_m \bar{q}^m, & \mathbb{1}_\tau = 1 \end{cases}$$

An adjustable-rate mortgage is always issued in the teaser stage and it becomes a regular ARM with probability π_τ at the end of the second (trading) subperiod. Therefore, the expected duration of the teaser stage, or "fixation period," is $\frac{1}{\pi_\tau}$.

After payments are made, the mortgage balance decreases by δ_m, such that the remaining balance is $(1 - \delta_m) m_{t-1}^i$.

Consumption Stage In the consumption stage, households use income y_t^i and their deposits holdings d_{t-1}^i to make mortgage payments $x_t^i m_{t-1}^i$ and housing maintenance payments $\delta_h h_{t-1}^i$.

Households can choose to default. If they default by failing to make the mortgage payment, they lose their house and their mortgage balance is written off. They also lose a fraction λ of their endowment of Lucas trees and face a continuous idiosyncratic shock to their post-default value function. In other words, default carries both a pecuniary and a non-pecuniary cost.

A household that repays the mortgage faces a consumption-stage budget constraint given by:

$$c_t^{i,nd} + x_t^i m_{t-1}^i + \delta_h h_{t-1}^i + a_t^i = y_t^i + d_{t-1}^i$$

where $a_t^i \geq 0$ is the household's holdings of intra-period deposits that a household can bring

into the trading stage in lieu of consuming. It enters the trading stage with wealth:

$$w_t^{i,nd} = a_t^i - (1-\delta_m) m_{t-1} q_t^m + p_t^h h_{t-1}^i + p_t^s s_{t-1}^i$$

where q_t^m is the price of the mortgage, p_t^h is the price of housing, and p_t^s is the price of the Lucas trees. The nonnegativity constraint $a_t^i \geq 0$ operates similarly to cash-in-advance or working capital constraints, requiring borrowers to have enough liquidity to finance their consumption before being able to rebalance their portfolios by selling assets or borrowing.

A household that defaults faces a budget constraint given by:

$$c_t^{i,d} = y_t^i + d_{t-1}^i$$

Having expunged their mortgage, lost their house, and given up a fraction of future income, it enters the trading stage with wealth:

$$w_t^{i,d} = (1-\lambda) p_t^s s_{t-1}^i$$

The default decision depends on the utility of consumption plus the continuation value as represented by the trading stage value function $V_t^i(w_t^i, \mathcal{Z}_t)$, where $\mathcal{Z}_t$ denotes state variables exogenous to an individual borrower.

Denote the value of default by $V^{i,d}$ and the value of repayment by $V^{i,nd}$. The value of making the mortgage payment is given by:

$$V_t^{i,nd}(d_{t-1}^i, m_{t-1}^i, \mathbb{1}_\tau, h_{t-1}^i, \epsilon_t^i, \mathcal{Z}_t) = \max_{a_t^i \geq 0} u^B(c_t^{i,nd}, h_{t-1}^i) + V(w_t^{i,nd}, \mathcal{Z}_t)$$

while the value of default is given by:

$$V_t^{i,d}(d_{t-1}^i, m_{t-1}^i, \mathbb{1}_\tau, h_{t-1}^i, \epsilon_t^i, \mathcal{Z}_t) = u^B(c_t^{i,d}, h_{t-1}^i) + V(w_t^{i,d}, \mathcal{Z}_t)$$

subject to the budget constraints and wealth evolution equations above. Households default iff:

$$\eta_t^i V_t^d(\cdot) > V_t^{nd}(\cdot)$$

where η_t^i is the household's idiosyncratic default shock.

Trading Stage In the trading stage households make portfolio decisions. They allocate their wealth w_t^i between deposits d_t^i, housing h_t^i, and Lucas trees s_t^i. They can also revise their mortgage balance from $(1-\delta_m)m_{t-1}^i$ to m_t^i at current price q_t^m.[13]

Borrowers are subject to a cost of deviating from a target loan-to-value ratio, given by $\Phi\left(\frac{q_t^m m_t^i}{p_t^h h_t^i} - L\bar{T}V\right)$. This cost, rebated $\mathcal{R}_t^i$ to the household in proportion to wealth to neutralize income effects, captures the notion of a mortgage rate schedule in reduced form and rules out equilibria in which borrowers take on LTV ratios $>> 1$ at very high rates in the expectation that they will likely default.

The trading stage budget constraint is given by:

$$w_t^i + \mathcal{R}_t^i = \frac{d_t^i}{1+r_t^d} + q_t^m m_t^i + p_t^h h_t^i + p_t^s s_t^i + \Phi\left(\frac{q_t^m m_t^i}{p_t^h h_t^i} - L\bar{T}V\right)$$

and the value function is:

$$V(w_t^i, \mathcal{Z}_t) = \max_{d_t^i, h_t^i, s_t^i, m_t^i} \beta \mathrm{E}_t \left[\max\left\{\max_{a_t^i \geq 0} u^B(c_{t+1}^{i,nd}, h_t^i) + V(w_{t+1}^{i,nd}, \mathcal{Z}_t), \eta_t^i\left(u^B(c_{t+1}^{i,d}, h_t^i) + V(w_{t+1}^{i,d}, \mathcal{Z}_t)\right)\right\}\right]$$

where the innermost maximization indicates the optimal consumption-savings choice in next period's consumption stage, the middle maximization indicates the default decision, and the outermost maximization indicates portfolio choices in the current period.

3.2 Banks

Banks are owned by savers so maximize the stream of dividends discounted at the saver's stochastic discount factor.

They lend in the mortgage market, financing their loan portfolios with equity and deposits, which are risk-free one-period bonds held by borrowers and outside investors. Outside investors have perfectly elastic demand for deposits at a price of $\frac{1}{1+r_t^d}$. The deposit rate r_t^d may differ

[13] We note here that FRMs would be less attractive with households refinancing, as the option to prepay limits intermediary gains from rate cuts in the FRM economy (e.g. Hanson, 2014; Diep et al., 2021).

from the policy rate r_t^f to which adjustable mortgages are indexed. Recent work has shown that changes to policy rates do not pass through one-for-one to deposits, complicating banks' exposure to interest rate risks.[14] We model the relationship in reduced form as

$$r_t^d = (\bar{r}^f - \alpha_d) + \beta_d(r_t^f - \bar{r}^f)$$

with $\alpha \geq 0$ and $\beta_d \in (0, 1]$. The parameter α_d captures the average spread between policy and deposit rates, while β_d capture the degree of deposit rate sensitivity to policy rate deviations from its mean. When $\alpha_d = 0$ and $\beta_d = 1$, the two rates are always equal.[15]

Banks portfolios are perfectly diversified and hence identical across banks, so we can write the bank's problem without i subscripts. They enter a period with a stock of outstanding mortgages m_{t-1}^I, of which a fraction F_t^η default. On mortgages that do not default, banks receive a payment x_t per unit of mortgage m_{t-1}^I and have an ex-payment value $(1 - \delta_m)q_t^m$.

Mortgage defaults lead lenders to seize the house, on which they must make a maintenance payment before selling it in foreclosure at a price $p_t(1 - \zeta)$ per unit, where ζ represents a foreclosure cost. The total foreclosure proceeds are

$$\int_0^\ell \mathbb{1}^i_{\text{default}} h^i_{t-1} p_t((1 - \zeta) - \delta_h) di$$

The payoff per unit of mortgage is therefore:

$$\mathcal{X}_t = (1 - F_t^\eta)(x_t + (1 - \delta_m)q_t^m) + \int_0^\ell \mathbb{1}^i_{\text{default}} \frac{h^i_{t-1}}{m^I_{t-1}} p_t((1 - \zeta) - \delta_h) di$$

Running the intermediation technology is costly. Banks must pay a fraction ν of the value of their mortgage portfolio as intermediation costs. Their net worth is then given by:

$$w_t^I = (1 - \nu)\mathcal{X}_t m_{t-1}^I + d_{t-1}^I$$

[14] E.g., Nagel (2016), Drechsler et al. (2017), and Krishnamurthy and Li (2022)

[15] The discounted present value of all future payments $r_t^f - r_t^d$ has been referred to as (gross) franchise value in the literature (e.g. Drechsler et al., 2017, 2023; Haddad et al., 2023; DeMarzo et al., 2024; Jiang et al., 2024). In our framework with FRMs, this present value is increasing in rates, i.e. has negative duration, as the relevant discount rate, governed by the saver's SDF, does not move one-for-one with r_t^f. In addition, changes in rates are mean-reverting rather than permanent.

where negative values of d_t^I represent borrowing by the lender.

Banks use their equity deposits to finance dividends and mortgage purchases, maximizing

$$\max_{m_t^I, d_t^I} \mathrm{E}_t \left[\sum_{s=t}^{\infty} \mathcal{M}_{t,s}^S \mathrm{Div}_t \right]$$

subject to a budget constraint:

$$w_t^I = \frac{d_t^I}{1 + r_t^d} + q_t^m m_t^I + \mathrm{Div}_t$$

and a capital requirement:

$$-d_t \leq \xi(\kappa \bar{q}^m + (1 - \kappa) q_t^m) m_t^I$$

where ξ represents the maximum leverage ratio and κ represents the fraction of the mortgage portfolio that is carried at book value on the lender's balance sheet. A value of $\kappa = 1$ indicates that mark-to-market losses on the mortgage portfolio do not tighten leverage constraints, while $\kappa = 0$ indicates a fully mark-to-market regime.

3.3 Savers

Saver households have the same preferences as borrowers, but receive income from their shares of Lucas trees free from idiosyncratic risk. As owners of bank equity, they also receive net dividends from the banks. Finally, they are rebated lump-sum the costs associated with mortgage default – both the pecuniary cost of default faced by borrowers and the foreclosure cost faced by banks – as well as the cost of intermediation. Their budget constraint is simply:

$$c_t^s = \mathrm{Div}_t + \frac{\alpha}{\ell} Y_t + \mathrm{Rebates}_t.$$

3.4 Equilibrium

Given the exogenous processes for aggregate income Y_t and risk-free rate r_t^f and given the idiosyncratic income shocks ε_t^i and ARM reset shocks $\mathbb{1}_\tau$, and the idiosyncratic default shocks η_t^i, an equilibrium is a set of borrower household allocations $\{c_t^i, h_t^i, s_t^i, m_t^i, d_t^i, a_t^i\}_{t=0}^\infty$, borrower default decisions $\{\mathbb{1}_d\}_{t=0}^\infty$ bank allocations $\{\text{Div}_t, m_t^I, d_t^I\}_{t=0}^\infty$, saver allocations $\{c_t^S\}_0^\infty$, and prices $\{p_t^h, p_t^s, q_t^m\}_{t=0}^\infty$ such that each agent maximizes their value function subject to their constraints, and the following market-clearing conditions hold:

1. The mortgage market clears:

$$(1-\ell)m_t^I = M_t^B \equiv \int_0^\ell m_t^i di$$

2. The borrower housing market clears:

$$\alpha_H \bar{H} = H_t^B \equiv \int_0^\ell h_t^i di$$

3. The market for borrower Lucas trees shares clears:

$$\alpha = \int_0^\ell s_t^i di$$

Note that the elastic demand for deposits by outside investors at rate r_t^f implies that the deposit market within the model does not need to clear.

Appendix III contains the derivation of the equilibrium conditions and the solution to the model.

4 Calibration

We calibrate the model at an annual frequency in two steps. Table 1 displays parameters whose values we choose outside the model based on external sources. Table 2 displays "internally" calibrated parameters, whose values are chosen so that the model with fixed-rate mortgages ($\pi_\tau = 0$) matches moments estimated in the data. We discuss each set of parameters in turn.

Stochastic Environment Aggregate dynamics of the model are governed by shocks to aggregate income Y_t and the interest rate r_t^f. In our baseline calibration, we abstract away from income shocks, setting $Y_t = 1$. The risk-free rate process is parameterized by an AR(1) process with mean μ_r, standard deviation σ_r, and persistence ρ_r, calibrated to match the dynamics of the 1-year Treasury constant maturity rate from 1987 to 2024. We estimate a mean rate of 0.034, an unconditional standard deviation of 0.014, and a persistence of 0.724. The standard deviation and persistence parameters imply the standard deviation of interest rate shocks.

We normalize the idiosyncratic income shocks to have a mean of 0, which means that they are governed by two parameters. The probability of a low income realization π_L is set to 0.058, which is the average post-war unemployment rate. The magnitude of the low income shock ϵ_L is set based on the Ganong and Noel (2019) estimates of the income loss from unemployment. They find that income loss occurs gradually over the first year as unemployment insurance expires. Since our model is annual, we average the income loss in months after UI kicks in as reported in Figure 2, Panel A of that paper, producing a value of -0.456. The high income shock ϵ_H is set to ensure that the expected value of the idiosyncratic income shock is zero.

Deposit Rates Bank deposit rates are lower than risk-free rates, such as T-Bill and Fed Funds, on average and adjust less than one for one with those rates. We estimate deposit rates using quarterly Call Reports data from 1987 to 2024 as the ratio of interest expense to previous quarter's balance on all non-time deposits. The main role deposits play in our model is liquidity – they are the only asset that can be liquidated to finance consumption in the consumption stage. Time deposits incur penalties for liquidation before maturity, motivating their exclusion. We set α_d to the average spread between the Fed Funds rate and the deposit rate of 0.018.

It often takes multiple quarters for deposit rates to adjust after a change in the Fed Funds rate. Our specification of r_t^d as a linear function of r_t^f does not allow for such intertia, and contemporaneous responses of deposit rates may understate the sensitivity of the deposit rate to the risk-free rate. We estimate a VAR(1) of Fed Funds and deposit rates and set $\beta_d = 0.340$, the peak of the deposit rate impulse response to a one-unit shock to the Fed Funds rate.

Table 1: Externally Calibrated Parameters

Parameter		**Value**
Panel A: Stochastic Processes		
Mean of risk-free rate process	μ_r	0.034
Std. dev. of risk-free rate process	σ_r	0.014
Persistence of risk-free rate process	ρ_r	0.724
Probability of low idiosyncratic income shock (ϵ_L)	π_L	0.058
Idiosyncratic income drop in low state	ϵ_L	-0.456
Idiosyncratic income increase in high state	ϵ_H	Set such that E[ϵ] = 0
Panel B: Deposit Rates		
Deposit spread w.r.t. base interest rate	α_d	0.018
Deposit sensitivity w.r.t. base interest rate	β_d	0.340
Panel C: Borrowers and Savers		
Borrower population share	ℓ	0.400
Borrower income share	α	0.600
Borrower housing share	α_h	0.500
Risk aversion	γ	1.5
Panel D: Housing, Mortgages and Banks		
Housing maintenance payment	δ_h	0.020
Mortgage rate reset probability	π_τ	0.000
Deviation from target LTV cost	ϕ	0.050
Max. leverage ratio	ξ	0.920
Share at book value	κ	0.000

Population, Income, and Housing Shares Using 2023 SCF data, we set $\ell = 0.400$ to the approximate share of homeowners that have a mortgage LTV of at least 30%. Given this definition of borrowers, $\alpha = 0.600$ and and $\alpha_h = 0.500$ are set to the approximate shares of income and housing, respectively, held by borrowers in the SCF data.

Banks Banks are subject to a capital requirement that limits their leverage. We set the maximum leverage ratio ξ to 0.920, which is the maximum Tier 2 capital ratio for banks under Basel III. This calibration effectively assumes a mortgage risk weight of 100%, which is the standard risk weight for residential mortgages. In the baseline calibration, we set the book value share κ to 0.000, meaning that mortgages are held at market value.

Borrower Preferences, Housing, and Defaults Housing maintenance payments as a fraction of housing are set to 0.020 based on the post-war average residential housing depreciation rate. Our model does not include housing investment, so the maintenance payment can be thought of as investment needed to offset depreciation and maintain housing stock at its steady-

Table 2: Internally Calibrated Parameters

Parameter		**Value**	**Target**	**Value (FRM Bench)**
Panel A: Borrowers				
Borrower patience	β	0.969	Mortgage/income	145.16
Housing utility weight for borrowers	θ	0.183	Housing/income	268.10
Std. dev of idiosyncratic default shock	σ_η	0.045	Default rate	2.07
Income loss upon default	λ	0.148	Deposits/income	25.74
Panel B: Intermediaries				
Foreclosure cost	ζ	0.530	LGD	14.00
Banker intermediation cost	ν	0.034	Mortgage rates	0.059
Principal payment share	δ_m	0.034	Mortgage duration	6.9

state value.

We set household risk aversion γ to 1.5, a standard value in the literature.

The remaining set of borrower preference and default-related parameters are calibrated internally. Panel A of Table 2 displays four parameters that must be calibrated jointly. We set patience β to 0.969, which yields a mortgage/income ratio of 145.16% given the values of other parameters, matching its value in the 2023 SCF. The value of housing to income is determined in equilibrium by the present value of user costs parameterized by the utility weight on housing θ, discounted at the rate implied by β and the probability of losing the house in foreclosure (i.e, default rate). We set θ to 0.183 such that, at the target default rate and given the calibrated value of β, the value of housing/income matches 268.10% in the SCF.

Housing- and mortgage-to-income ratios imply a LTV ratio of approximately 60%. The mapping of this ratio into default rates depends on two parameters – the standard deviation of the idiosyncratic default shock σ_η and the share of future income lost in default λ. The pecuniary cost of default motivates agents to hold deposits so that they can decrease their default probability in the event of a low income realization. We set σ_η to 0.045 and λ to 0.148 to match the average 2003-2023 flow into 90-day delinquency in the New York Fed's Quarterly Report on Household Debt and Credit (QRHDC) of 2.07%, and the deposits-to-income ratio of 25.74% in the SCF.

Mortgages In our model, there are no idiosyncratic shocks to home values, so in the cross-section defaulting households have the same LTV ratios as non-defaulting households. Given

the LTV ratio implied by the calibration of housing and mortgage-to-income ratios, we set foreclosure cost ζ to 0.530, which implies a loss given default (LGD) of 14.00%. This is consistent with the average LGD in the data, computed as average charge-off rate on mortgages held by depository institutions, from the St. Louis Fed FRED database, divided by the average default rate from the NY Fed QRHDC.

The mortgage interest payment in the FRM economy ι_f is set so that the steady-state mortgage price $\bar{q}^m$ is equal to 1, and thus ι_f can be interpreted as the steady-state mortgage yield, or par rate. The historical average rate is 0.059. In the model, the mortgage yield, defined as the discount rate, which discounts expected future cash flows to par, depends on (1) the intermediary's cost of funding, a leverage-weighted average of the equity cost of capital implied by β and the deposit cost of capital $\bar{r} - \alpha_d$, (2) expected losses, a function of the default rate and LGD, and (3) the cost of intermediation parameterized by ν. Given a calibration that matches target default rates and LGD, we set ν to 0.034 so that $\bar{q}^m = 1$ at $\iota_f = 0.059$.

In counterfactual exercises with adjustable rate mortgages, we set $\iota_a = \iota_f - \bar{r}$, making payments the same on average. In the baseline calibration, we set interest payments in the teaser/fixed stage of an ARM ι_τ to ι_f so that the end of the fixation period does not cause a jump in payments.[16]

Borrowers in our model do not endogenize the effect of their demand on *their*, rather than the equilibrium, mortgage rate.[17] As a result, at low equilibrium rates, they may face an incentive to take on a large mortgage that implies a high default probability and hence a low expected cost of borrowing. One way to address this issue is to set a maximum LTV constraint, that would be slack in steady state but bind in some states of the dynamic model. To simplify model solution, we follow a different approach and impose a per-housing-dollar quadratic cost of deviating from the steady-state book LTV ratio $\frac{\phi}{2}\left(\frac{q_t^m}{p_t h_t^i} - L\bar{T}V\right)^2$. We set ϕ to a small positive value, 0.050. It has negligibly small effects on equilibrium dynamics but improves our ability to solve the model by ruling out equilibria with counterfactually high LTV ratios.

The last mortgage contract feature is the fraction of the principal paid in each period, δ_m.

[16] In the data, teaser rates are often set lower such that a jump does occur, but we abstract from this feature in the baseline to develop intuition about the effects of stochastic, rather than predictable, rate changes.

[17] Models with an endogenous debt schedule and long-term debt must tackle dilution incentives and the optimal contract can be difficult to solve. In our framework, such a model would be intractable.

This parameter determines the duration of the mortgage, which we set to match the duration of a 30-year fixed rate mortgage in the data. Our model generates an endogenous reduction in duration relative to its contractual value that occurs because of default, but we do not capture the reduction due to moving-induced prepayments. To calculate the correct target duration in the data, we compute an amortization schedule for a 30-year fixed rate mortgage with a rate of ι_f and an annual prepayment probability of 6%, close to the unconditional annual moving probability of mortgage borrowers reported by Fonseca and Liu (2024). This procedure yields δ_m equal to 0.085, which implies a duration of 6.9 years. We describe the procedure in more detail in Appendix IV.

4.1 Model Solution

The model is solved numerically using the global Transition Function Iteration method of Elenev et al. (2021). Our main experiments compare the performance of the economy across a range of mortgage fixation lengths parameterized by π_τ. When this parameter is equal to 0, the economy is in a fully fixed-rate mortgage (FRM) regime. At the other extreme when π_τ is equal to 1, the economy is in an adjustable-rate mortgage (ARM) regime where mortgage payments reset every year. For each economy considered below, we simulate 16 paths of 5,000 periods each after discarding the first 1,000 and report unconditional moments of the long simulation. We also consider impulse responses to interest rate shocks at the stochastic steady state of each model.

5 Results

We first show that rising interest rates affect households and financial intermediaries in opposite directions depending on mortgage structure, using impulse responses. Under FRMs, intermediary net worth deteriorates; under ARMs, borrower defaults increase but intermediary net worth improves due to higher mortgage payments. Second, we show outcomes on financial stability and risk-sharing based on unconditional moments of a long simulation, across a range of counterfactual mortgage structures. We find that mortgages with intermediate fixation lengths balance sources of volatility in pure ARM and FRM structures, minimizing intermediary net

worth volatility and optimizing aggregate risk sharing. Lastly, we show that the optimal fixation length depends on the macroeconomic environment, reflected by the correlation of interest rate risk with aggregate income risk.

5.1 FRM vs. ARM Economies Respond Differently to Rate Shocks: Impulse Responses and Mechanisms

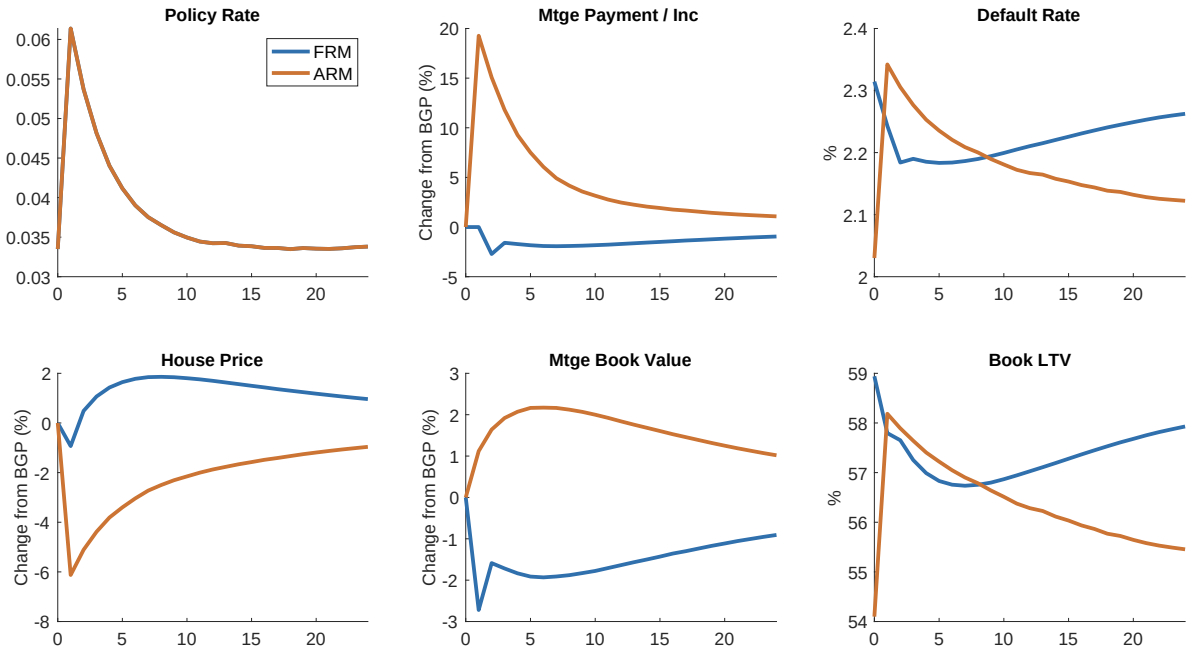
First, to understand how mortgage structure mediates interest rate shocks, we analyze impulse responses of the pure FRM and ARM economies to a positive shock to the policy rate r_t^f from 3.1% to 6%.[18] Figures 3 displays the results for borrower variables, while 4 displays the results for banks.

Borrowers When rates are fixed ("FRM"), total mortgage payments remain unchanged on impact and borrower liquidity is unaffected. Mortgage rates go up, but existing borrowers are shielded from the increase. In contrast, when mortgage payments reset every year ("ARM"), borrowers face higher payments immediately. The liquidity burden of higher payments causes a spike in default rates with higher defaults persisting as long as rates and hence payments remain higher. With FRMs, higher rates raise the opportunity cost of default, as holding on to their current mortgage becomes more valuable. As a result, borrowers are less likely to default for strategic reasons. At the same time, new borrowers face higher mortgage rates and are less likely to take out a loan, decreasing the aggregate mortgage balance and driving down demand for housing, leading to a slight decrease in house prices. However, the persistent decrease in default rates due to lower LTVs raises house prices subsequently.[19] For ARMs, the reduction in household liquidity has two consequences for credit demand. On one hand, persistently higher default rates lower house prices restricting the available supply of mortgage collateral. But on the other hand, the need to spend a larger share of their liquid assets on mortgage payments disproportionately reduces borrower consumption relative to wealth. The desire to smooth

[18] To compute impulse responses, we initialize the economy at the stochastic steady state of a long simulation at $t = 0$ and compute its $t = 1$ transition given a particular realization of exogenous variables. Subsequently, we let the economy evolve stochastically, simulating 5,000 paths of 25 years each. The average path constitutes the plotted impulse response.

[19] We do not model explicit mortgage lock-in effects (Fonseca and Liu, 2024) and their impact on house prices in an FRM economy, see e.g. Fonseca et al. (2024).

Figure 3: Impulse Responses to a Positive Interest Rate Shock: Borrowers

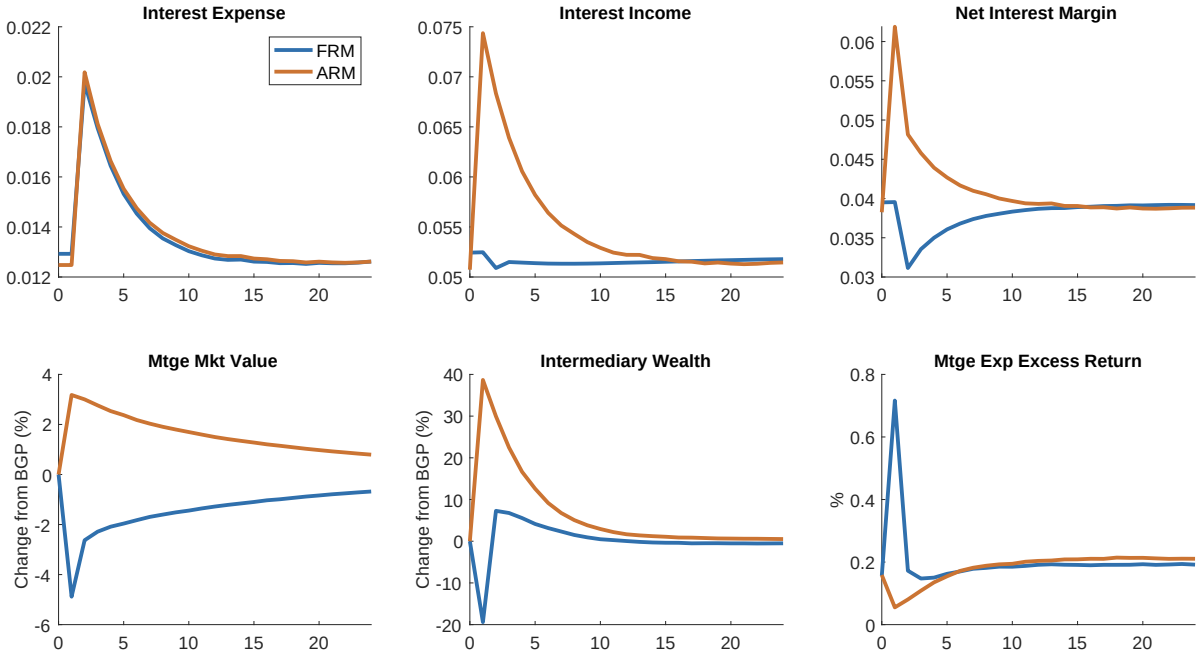


Notes: Impulse Response Functions for a positive shock to the interest rate r_t^f. "FRM" (blue) denotes an economy in which mortgage payments remain fixed at $\iota_f + \delta_m \bar{q}^m$. "ARM" (red) denotes an economy with a rate fixation length of 1 year ($\pi_\tau = 1.0$) in which mortgage payments mortgages increase with rates $r_t^f + \iota_a + \delta_m \bar{q}^m$.

consumption raises demand for credit. On net, the demand effect wins out, resulting in larger mortgage balances relative to the FRM economy.

Banks The different dynamics of default and credit demand have consequences for the financial sector. The top row of Figure 4 plots banks' net interest margin and its components in output units, to aid comparison. When rates go up, the cost of deposit funding – the banks' interest expenses – also increases, though less than one for one. When mortgage rates are fixed, interest income remains unchanged, leading to a drop in banks' net interest margin. Banking becomes less profitable, despite the slight offsetting decrease in credit losses discussed above (due to borrowers defaulting less because their low-rate mortgage becomes more valuable). Moreover, fixed-rate mortgages have a long duration. The bottom row of Figure 4 plots asset pricing moments. In response to higher rates, the price and market value of long-dated bank assets falls. With both lower cash flows due to smaller net interest margins, and lower asset values due to higher discount rates, the net worth of the banking sector declines. More

Figure 4: Impulse Responses to a Positive Interest Rate Shock: Banks



Notes: Impulse Response Functions for a positive shock to the interest rate r_t^f. "FRM" (blue) denotes an economy in which mortgage payments remain fixed at $\iota_f + \delta_m \bar{q}^m$. "ARM" (red) denotes an economy with a rate fixation length of 1 year ($\pi_\tau = 1.0$) in which mortgage payments mortgages increase with rates $r_t^f + \delta_m \bar{q}^m$.

constrained banks demand higher compensation to take on mortgage risk, a result common to intermediary-based asset pricing models. The spike in risk premia, i.e. expected excess returns on mortgages, amplifies mortgage duration, further contributing to market value losses of banks as it increases discount rates.

In contrast, in the ARM economy, higher rates lead to higher mortgage payments. Since mortgages are indexed to the policy rather than the deposit rate, the net interest margin of banks increases as mortgage income received rise by more than deposit expense paid. Banks become more profitable even though credit losses rise due to a rise in defaults. Intuitively, banks' credit losses in the ARM economy are more "hedged" across states since they precisely arise in states of the world where cash flows from mortgage payments are high. The increase in cash flows outpaces the increase in the deposit rate, reflecting the deposit part of the bank cost of funds. Stronger cash flow news than discount rate news raise bank net worth. Savers, who own bank equity, consume more. As a result, they expect their consumption to grow less in

the future, and a consumption-smoothing motive lowers the rate at which they discount bank equity. Both cash flow and discount rate effects imply that adjustable-rate mortgages effectively have negative duration: their value increases with higher rates. With higher cash flows and higher asset values, the net worth of the banking sector increases. The increase in intermediary net worth lowers mortgage risk premia. But risk premia are nonlinear in intermediary net worth. An improved capital position of already healthy banks in the ARM economy does not reduce risk premia much, but a deterioration in the capital position with impaired balance sheets in the FRM economy leads to a sharp spike in risk premia.

Cross-Country Evidence Do these model predictions have empirical support? We show illustrative evidence consistent with predicted differences in FRM and ARM economies using differential developments in US and UK delinquencies, house prices, and bank equities over 2022 to 2023, as well as other ARM economies. Appendix Figure IA.3 shows that delinquencies in the UK rose by more than 60% from their 2022 levels by the beginning of 2024, whereas US delinquencies actually declined by almost 20% (albeit from a higher level). Figure IA.4 shows that US real house prices outperformed house prices in ARM economies by 10 to 15% between 2022 and 2024. Similarly, UK, Australia, and Euro Area bank equities outperformed bank equity indices in the US (and also Canada) by almost 40 per cent.

While merely suggestive (since the model ARM economy is a U.S. counterfactual, not a calibration, e.g., to, the U.K.), we consider the cross-country evidence in outcomes following the 2022 to 2023 tightening cycle as highly consistent with our model's predictions.

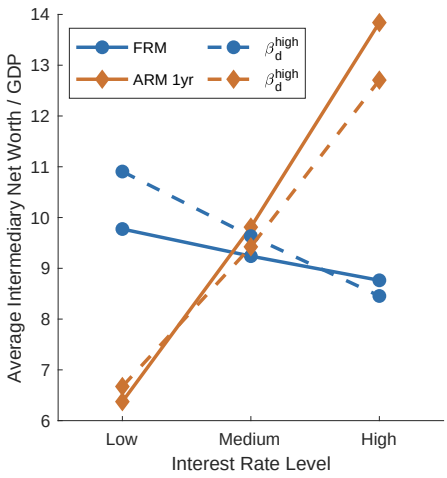
5.2 Financial Stability

We start by building intuition for mechanisms in the full FRM and ARM economies, before evaluating financial stability across mortgage structures. We measure financial stability as the volatility of intermediary net worth, capturing that financial stability goals by central banks typically relate to the volatility and cost of credit provision.[20]

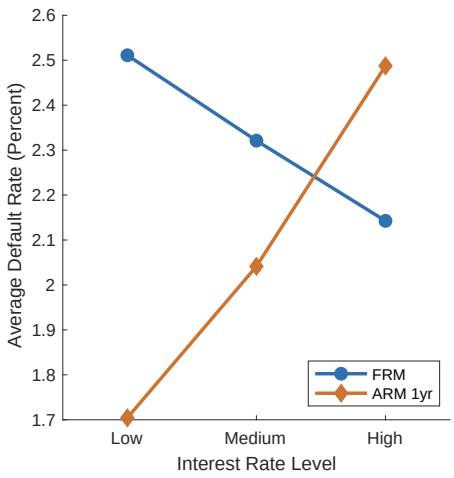
[20]For instance, the Federal Reserve monitors risks to the financial system "to help ensure the system supports a healthy economy for U.S. households, communities, and businesses", and is "resilient and able to function even following a bad shock" (https://www.federalreserve.gov/financial-stability.htm). The European Central Bank aims to "[mitigate] the prospect of disruptions in the financial intermediation process that

Figure 5: Intermediary Net Worth and Default By Level of Interest Rate

(a) Intermediary Net Worth



(b) Default Rates



5.2.1 Interest Rate Levels, Intermediary Net Worth, and Default

The impulse responses suggest that intermediary net worth is differentially correlated with interest rates depending on the underlying mortgage structure. Figure 5 illustrates this intuition, showing average levels of intermediary net worth to GDP by interest rate levels (Panel a). Intermediary net worth is strongly increasing in interest rates for ARM economies, meaning it has large negative net worth duration. Interest income rises by more than deposit funding cost increases, which outweighs the rise in defaults (Panel b). Conversely, net worth is somewhat decreasing in interest rates for FRM economies, meaning it has positive net worth duration.

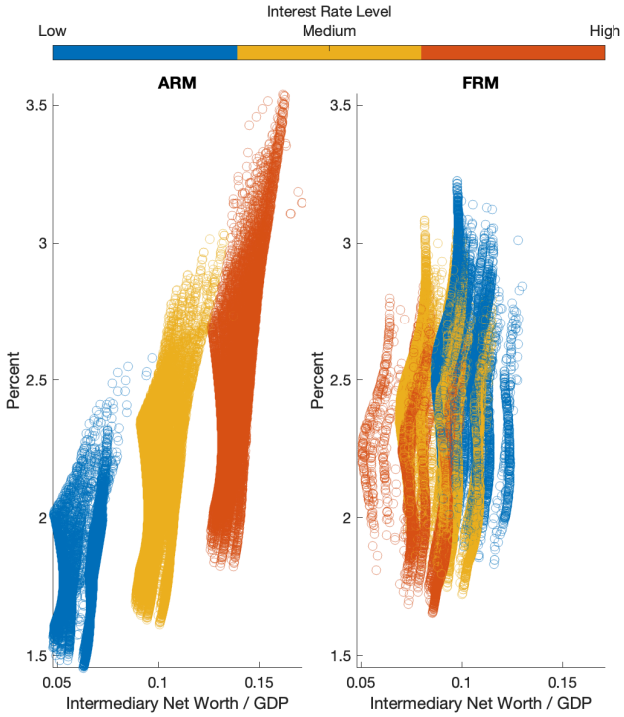
Deposit Sensitivity Figure 5a also shows that the level of intermediary net worth seems to be more sensitive to interest rate changes in the pure ARM economy, i.e. its absolute duration is larger. The lower volatility of FRMs is related to the calibrated degree of deposit stickiness with $\beta_d = 0.34$. $\beta_d \leq 1$ governs the pass-through of interest rate changes to deposit rates, and thus affects how much less sensitive interest expense (as measured by deposit rates) is to rate shocks than interest income. In a counterfactual where deposits are more sensitive to policy rates ($\beta_d^{High} = 0.67$, shown in dashed lines in Figure 5a), FRM intermediary net worth becomes more sensitive to changes in interest rates. Intuitively, a greater deposit sensitivity aligns the

are severe enough to adversely impact real economic activity" (https://www.ecb.europa.eu/paym/financial-stability/html/index.en.html).

duration of liabilities under an ARM structure more with the duration of assets, while the reverse is true in an FRM regime, consistent with findings by Drechsler et al. (2017, 2024).

Mortgage Default and Risk Premia Figure 5b suggests a hedging mechanism in both economies: defaults are high when intermediary net worth tends to be high. Figure 6 illustrates this further by comparing default rates across simulations by interest rate level (color) and intermediary net worth (x-axis). In both ARM and FRM economies, defaults are positively correlated with net worth.

Figure 6: Default Rates By Level of Interest Rate and Intermediary Net Worth



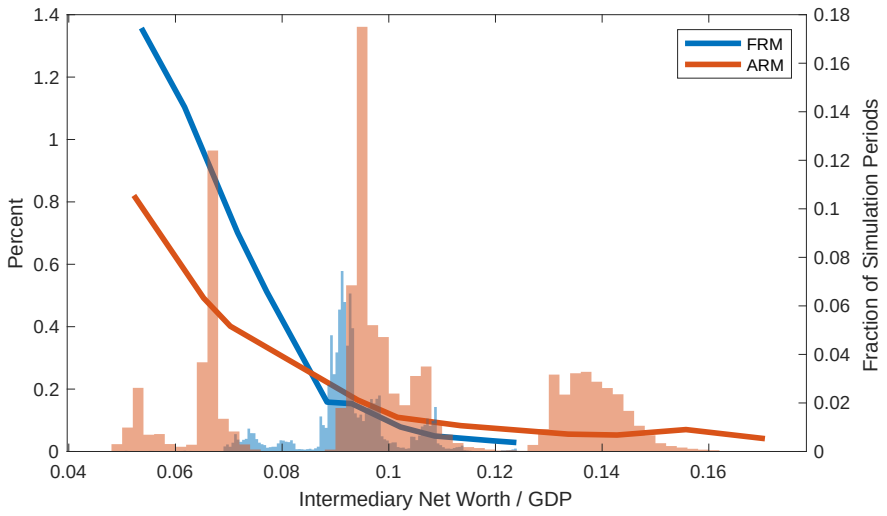
Notes: This figure shows simulation scatter plots of default rates by the level of intermediary net worth (x-axis) and interest rates (color: blue is low, yellow is medium, orange is high). The left plot shows the ARM economy, while the right plot shows the FRM economy.

However, Figure 6 also reveals substantial differences between FRM and ARM economies. Consistent with Campbell and Cocco (2015), default occurs in different macroeconomic states across mortgage structures, and is more rate-sensitive in the ARM economy. With ARMs, the level of defaults is highest at high levels of interest rates (in orange). These are also states of the world in which intermediary net worth is high given higher net interest margins. Thus, ARM

defaults are net-worth hedged – credit losses offset interest rate gains. With FRMs, defaults are higher when rates are low, which are also states in which net worth is high, but defaults are less sensitive to rates in the FRM economy, illustrated by greater dispersion of defaults across interest rate states. This means that the hedging force is smaller in the FRM world.

The relative strength of net worth hedging forces affects risk premia. Figure 7 shows that the weaker FRM net-worth hedging channel makes risk premia (left y-axis) more sensitive to intermediary net worth (x-axis) at low values. In the FRM economy (blue), risk premia are high in constrained states of the world, i.e. when rates are high and intermediary net worth is low, while in the ARM economy (red) risk premia are only moderately elevaed when rates and intermediary net worth are low. However, Figure 7 also shows that ARMs make intermediary net worth more volatile on average, with a higher probability of being in a low intermediary net worth state compared to the FRM economy (shown as frequency distribution of simulation periods on the right-hand y-axis), meaning that risk premia in the ARM economy are not necessarily lower on average.

Figure 7: Mortgage Risk Premia Decrease with Intermediary Net Worth



Notes: This figure shows conditional means of mortgage excess returns by the level of intermediary net worth, for ARM and FRM economies.

5.2.2 Net Worth Duration and Volatility Across Mortgage Structures

Thus far, we assessed the pure FRM and ARM economies which lie on two ends of the mortgage structure spectrum. To evaluate the full range of mortgage structures, we next compare financial stability outcomes in the benchmark FRM economy with several counterfactual economies where we vary mortgage fixation length. To do so, we solve the model and simulate outcomes for economies with values of $\pi_\tau \in [0, 1]$ where π_τ reflects the annual probability of the rate resetting, and $1/\pi_\tau$ the (expected) fixation length. For instance, a full ARM economy has a rate that resets every year with $\pi_\tau = 1.0$, a 10-year fixed-rate mortgage economy has $\pi_\tau = 0.1$, while the full FRM economy has $\pi_\tau = 0$.

Figure 8a shows results across mortgage structure for the duration of intermediary net worth δ, measured as the negative of the regression coefficient of log wealth on interest rates, i.e. the OLS estimate of $\log W_t^I = \text{const.} - \delta r_t^f + \epsilon_t^w$. Net worth duration reflects by what percentage intermediary net worth declines in response to a 1 percentage point increase in rates. The pure ARM economy with a fixation length of one year has large negative duration, meaning that net worth increases substantially when interest rates go up (and vice versa), consistent with the evidence from before. The pure FRM economy with an infinite fixation length has moderate positive duration, meaning net worth declines when rates go up. Net worth duration is 0 with an intermediate fixed-rate length of seven years.

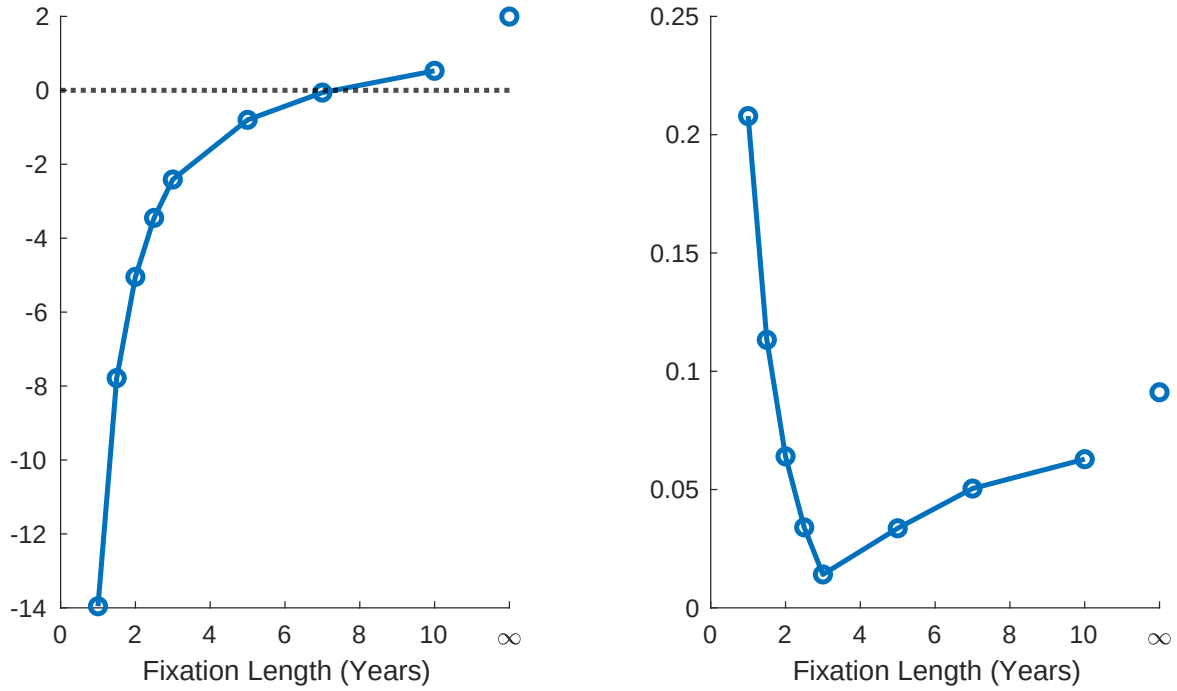
However, net worth duration is an incomplete measure of risk as the regression only measures the contemporaneous effect of interest rates. The R^2 of the duration regression in the benchmark FRM economy is only 0.164, suggesting that there are dynamic and persistent effects of rate changes on net worth that are not captured by duration and possibly other state variables that could be correlated with interest rates, such as the effect of credit risk and risk premia. We expand on this intuition more formally in Section II in the Appendix.

As a result, our preferred measure of financial stability is the volatility of banks' return on equity (ROE), shown in Figure 8b. This measure captures the combined equilibrium effects of asset and liability-side volatility as well as leverage on the volatility of intermediary net worth.[21] The volatility of banks' ROE has a "U-shape" pattern, that is, volatility measures are higher

[21] This is consistent with the intuition in Meiselman et al. (2023), who show that banks' ROE is a strong predictor for systematic tail risks.

Figure 8: Measures of Financial Stability Across Mortgage Structures

(a) Intermediary Net Worth Duration (δ) (b) Volatility of Intermediary ROE



Notes: This figure shows the duration of intermediary net worth as the negative regression coefficient δ from a regression of log wealth on interest rates: $\log W_t^I = \text{const.} - \delta r_t^f + \epsilon_t^w$ (Panel (a)) and the volatility of intermediary return on equity, measured as the standard deviation of net income over net worth (Panel (b)). The x-axis reflects an annual rate reset probability of $\pi_\tau \in \{1, 2/3, 0.5, 0.4, 1/3, 0.2, 1/7, 0.1, 0\}$, which corresponds to fixed-rate lengths of 1, 1.5, 2, 2.5, 3, 5, 7, 10 years and ∞, respectively.

on both extremes of mortgage structure, fully adjustable or fully fixed, than at an intermediate fixation length. Banks' ROE volatility is minimized at a fixation length of approximately 3 years, which is shorter than the zero-duration fixation length of 7 years. This discrepancy highlights the importance of evaluating financial stability in equilibrium, taking into account endogenous default and pricing of risk premia.

The findings suggest that *an intermediate fixation length balances sources of volatility in ARM and FRM structures.* Figure IA.7 in the Appendix adds the 3-year fixed-rate economy ("ARM 3yr") to the plot that shows intermediary net worth and default by interest rate levels. Compared to both the full FRM and ARM economy, both intermediary net worth and default are relatively stable across interest rate states in the 3-year fixed-rate economy. The results suggest that an intermediate fixation length broadly balances the different mechanisms in both

Table 3: Measures of Financial Stability

Deposit Sensitivity:	Low ($\beta_d = 0.34$)			High ($\beta_d = 0.67$)		
Mortgage Structure:	ARM (1yr)	ARM (3yr)	FRM	ARM (1yr)	ARM (3yr)	FRM
Excess ROE (mean)	2.26	1.50	1.70	1.65	1.70	2.29
ROE (st. dev.)	20.79	1.41	9.11	12.74	8.05	16.89
Excess ROA (mean)	0.22	0.16	0.19	0.16	0.19	0.25
ROA (st. dev.)	2.20	0.66	1.17	1.73	1.58	2.25
Fraction of constraint binding	27.45	86.50	49.99	24.61	45.31	36.10
Duration of bank net worth	-13.96	-2.41	1.99	-11.51	-0.70	4.82
PTI (OLS coef.)	1.61	0.45	-0.17	1.48	0.28	-0.33
LTV (OLS coef.)	2.47	0.17	-1.19	1.52	-0.99	-2.19
Default Rate (mean)	2.07	2.36	2.32	2.21	2.30	2.19
Default Rate (std. dev.)	0.36	0.07	0.26	0.19	0.29	0.48
Default Rate (OLS coef.)	0.14	0.01	-0.07	0.09	-0.05	-0.12
DTI (mean)	145.16	151.15	150.37	148.16	149.80	147.38
LTV (mean)	55.15	59.68	59.08	57.48	58.68	56.86
Deposits / Income (mean)	25.74	24.36	24.49	25.16	24.76	25.24

Notes: Unconditional moments from a long simulation of the model. Except for the duration of bank net worth, all quantities are reported in percent. Rows marked "OLS coef." report the coefficient of a regression of the variable on the policy rate r_t^f.

extremes of mortgage structure, making the intermediary sector more stable across states of the world with different interest rate levels.

5.3 Risk Sharing

Our analysis on financial stability thus far highlights the risks borne by savers, who hold bank equity. To better understand risk sharing across mortgage structures, we compare outcomes for both borrowers and banks in Table 3. The top panel reports bank-related metrics, and the bottom panel shows borrower-related metrics. The first three columns present results for our baseline scenario with low calibrated deposit sensitivity: full-ARM (annual resets), intermediate fixation length (3-year) at which net worth volatility is minimized, and full-FRM economies, respectively.

Borrowers and Consumption Mortgage structure shapes both the extent and the nature of borrowers' interest rate exposure, affecting default behavior and portfolio decisions. In ARM economies, mortgage payment-to-income (PTI) ratios increase in rates, exposing borrowers to

liquidity risks, as seen in the "PTI (OLS coef.)" which reports the coefficient of a regression of PTI on interest rates. A 1 percentage point increase in rates corresponds to a 1.61 percentage point increase in PTI in the ARM (1yr) economy, but only a 0.45 percentage point increase in the ARM (3yr) economy, and a -0.17 percentage point change in the FRM economy as households delever. But rate shocks also have wealth effects, which determine borrowers' strategic default behavior. Higher interest rates always lower house prices on impact, but the extent to which they affect the value of the mortgage – and, hence, LTV ratios, depends on the fixation length. In the FRM economy, high rates lead to low mortgage values. This creates LTV ratios that are mildly countercyclical in the interest rate (reflected in a negative "LTV (OLS coef.)", analogously defined to the PTI regression coefficient), and, together with stable payments, yields countercyclical default rates (negative "Default Rate (OLS coef.)", which is consistent with the impulse responses showing a decrease in default rates when rates go up. As fixation length shortens, mortgage duration drops and eventually flips sign. In the full-ARM economy, rate hikes lead not only to higher house prices but higher mortgage values, which implies LTV ratios strongly procyclical in rates. Together with procyclical payments, this leads to procyclical default rates, which are more volatile than in the FRM economy. Conversely, default rates are mildly countercyclical in the FRM economy. At intermediate fixation lengths, default rates are close to acyclical with respect to interest rates, and are least volatile.

Higher exposure to interest rate risk in ARM economies lowers both the supply and the demand for credit. Together with more expensive mortgages due to higher risk premia ("Excess ROA"), volatile default rates cause households to reduce their demand for credit and expand precautionary saving. Relative to the FRM economy, in the full-ARM economy, average mortgage debt falls both relative to income (DTI) and relative to house prices (LTV), while deposits to income increase. As a result, less indebted borrowers default less often on average. The opposite is true for the safer ARM (3yr) economy.

Differences in risk exposures and indebtedness have implications for consumption. Fewer mortgages mean a smaller banking sector, with reduced dividends lowering saver consumption (Panel A) in the ARM economy. While the banking sector is more volatile, its smaller size makes its returns a relatively smaller part of saver consumption, leading to decreased unconditional consumption volatility across time. However, conditional on a particular state of the economy,

Table 4: Consumption Measures

Deposit Sensitivity:	Low ($\beta_d = 0.34$)			High ($\beta_d = 0.67$)		
Mortgage Structure:	ARM (1yr)	ARM (3yr)	FRM	ARM (1yr)	ARM (3yr)	FRM
Panel A: Savers						
Cons. (mean)	49.15	49.93	49.84	49.54	49.78	49.50
Cons. gr. (st. dev.)	2.35	0.52	2.29	0.74	2.74	3.97
Cond. vol of cons. gr.	2.05	0.29	1.83	0.55	2.09	3.22
Panel B: Borrowers						
Cons. (mean)	47.79	47.01	47.10	47.43	47.20	47.49
Cons. gr. (st. dev.)	16.17	17.17	17.12	16.69	16.99	16.70
Cond. vol of cons. gr.	10.46	11.05	10.92	10.89	10.94	10.63

Notes: Unconditional moments from a long simulation of the model.

the volatility of consumption growth – which determines the price of risk in asset pricing models – goes up, consistent with the higher risk premia in the ARM economy discussed above.

The effect on borrowers is the opposite in the ARM economy. With less debt, their interest burden is smaller, and they suffer the pecuniary consequences of default less often. This results in higher average consumption. Having to make larger payments in high rate regimes, borrowers in the ARM economy have higher unconditional consumption volatility, but their endogenous delevering results in the conditional volatility – driven mainly by idiosyncratic shocks – to go down.

Robustness: Deposit Sensitivity An important source of financial stability risk in the ARM economy is the large difference between high sensitivity of mortgage payments to policy rates and the low sensitivity of deposit rates, calibrated to match the empirical evidence. We thus consider a counterfactual in which we double the calibrated benchmark sensitivity of $\beta_d = 0.34$ to $\beta_d = 0.67$ in the fourth through sixth columns of Tables 3 (Financial Stability) and 4 (Consumption).

With more volatile deposit rates at which banks fund themselves, the FRM economy becomes substantially riskier (third vs. sixth columns). Bank equity duration more than doubles, the volatility of both asset and equity returns increases considerably, and banks demand a larger compensation for the risk of holding mortgages. As before, a more volatile economy and more expensive mortgages lead to lower borrower indebtedness, lower default rates, and higher

consumption. The effect of switching from FRMs to ARMs in the high deposit sensitivity counterfactual is opposite to that in the baseline experiment. When policy rates substantially pass through to deposit rates, a mortgage structure in which payments are indexed to the policy rate improves financial stability, reducing the volatility of bank balance sheets and the risk premia associated with them and stimulating mortgage credit. Intuitively, the asset and liability side of bank balance sheets are better aligned with ARMs when deposit rates fluctuate more strongly with interest rates. Hence, a banking sector that faces less sticky deposit rates is rendered most stable by an even shorter fixation length than 3 years, the level for the baseline calibrated economy.

Measuring Risk Sharing Lastly, we assess how mortgage structure determines how risks are shared between households. To quantify the degree of risk sharing, it is instructive to consider a hypothetical complete markets benchmark. A social planner subject to rate shocks but not to any of the economy's frictions would insure households fully against idiosyncratic shocks and award each household a constant fraction of overall consumption. In other words, the difference $\Delta \log c_t^i - \Delta \log c_t^j$ between consumption growth rates of any two households i and j would be zero in all periods.[22]

We can then measure the quality of risk sharing by the unconditional variance of differences in consumption growth rates between households. Recall that borrower households are subject to undiversifiable idiosyncratic risk, while saver households are not. We can define two scale-free measures of risk-sharing:

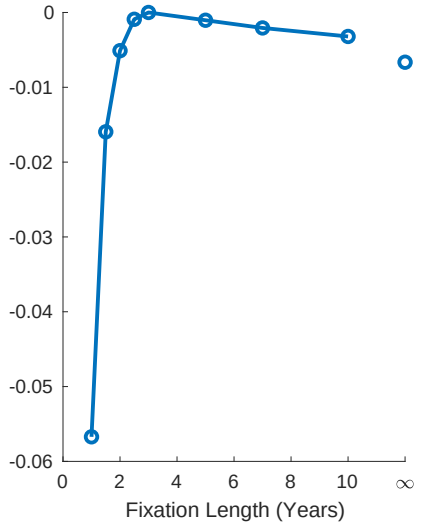
1. Higher values of $\mathcal{R}_{iB} = \text{Var}_0[\Delta \log c_t^i - \Delta \log C_t^B]$, where C_t^B is aggregate consumption of borrowers, indicate worse *intra-borrower* risk-sharing;

2. Higher values of $\mathcal{R}_{BS} = \text{Var}_0[\Delta \log C_t^B - \Delta \log C_t^S]$, where C_t^S is aggregate consumption of borrowers, indicate worse risk-sharing *between borrowers and savers*;

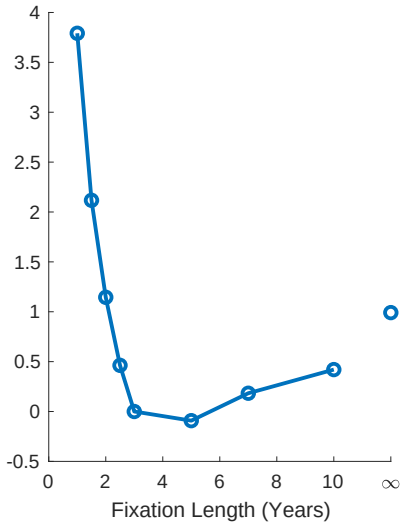
[22]See Appendix III.5 for derivations. Moreover, the planner would optimize the overall economy's exposure to rate shocks. The planner would choose a net deposit position of the economy with respect to the rest of the world to satisfy the consumption-savings Euler equation of the representative agent, whose consumption would be equal to the aggregate consumption of the economy. We also derive these results in Appendix Appendix III.5, but since these effects turn out to be quantitatively negligible, we do not report these separately.

Figure 9: Measures of Risk Sharing across Mortgage Structures

(a) Intra-Borrower ($\mathcal{R}_{iB}$)



(b) Between Borrowers and Savers ($\mathcal{R}_{BS}$)



Notes: $\mathcal{R}_{iB}$ measures the variance of individual consumption growth relative to aggregate consumption growth, and $\mathcal{R}_{BS}$ measures the variance of aggregate consumption growth of borrowers relative to savers. In each panel, $\mathcal{R}$ is reported in deviations from the level in the ROE volatility-minimizing economy.

Figure 9 reports the results in standard deviations from the level in the ROE volatility-minimizing economy.[23]

Considering Panel (b), intermediate mortgage fixation lengths lead to the best attainable risk-sharing arrangements between borrowers and savers as $\mathcal{R}_{BS}$ is minimized at a fixation length of 5 years. This is a slightly longer fixation length relative to the contract that minimizes the volatility of intermediary ROE, suggesting a small trade-off between financial stability and aggregate risk sharing.

To illustrate this trade-off directly, we plot the responses of borrower and saver consumption to a positive rate shock for the benchmark FRM economy, the volatility-minimizing ARM 3yr economy, and the risk-sharing optimizing ARM 5yr economy in Figure 10. In the FRM economy, savers – who own banks – have a much greater exposure to this shock than borrowers. When the fixation length is chosen to minimize bank volatility (ARM 3yr, green), savers become almost insulated from the shock, but it is now borrowers whose consumption suffers. From

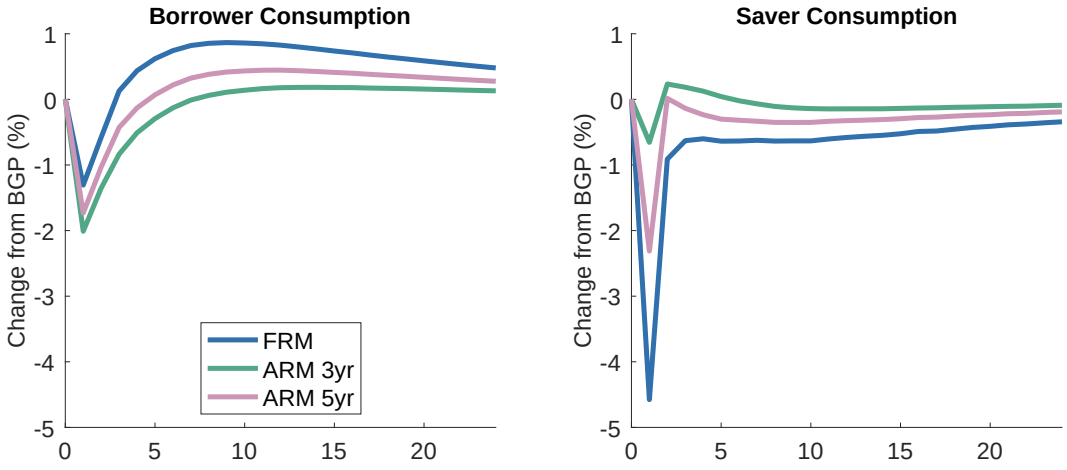
[23] At a fixation length of 3 years, $\mathcal{R}_{iB}$ is 0.17, and $\mathcal{R}_{BS}$ is 0.005. Since these measures are scale-free, the level of undiversifiable idiosyncratic risk faced by borrowers is considerably larger than aggregate risk shared between borrowers and savers, consistent with many macroeconomic models.

a risk-sharing perspective, lowering the fixation length to 3 years leads to an over-correction. A less aggressive choice of 5 years (purple) leads to similar consumption responses for both borrowers and savers, and thus minimizes $\mathcal{R}_{BS}$.

However, low exposure to aggregate risk leads borrowers to endogenously choose higher exposure to idiosyncratic risk (Panel (a) of Figure 9). At intermediate fixation lengths, they choose the largest mortgages, and hence the largest mortgage payments, should they choose to make them rather than defaulting. When payments constitute a larger fraction of liquid income, the effect of idiosyncratic income shocks on consumption is amplified. Moreover, higher mortgage balances lead to a higher probability of default. Since consumption levels in and out of default are different, a higher probability of default also leads to higher consumption volatility. This is reflected in the higher $\mathcal{R}_{iB}$ at intermediate fixation lengths.

Overall, mortgage structure most strongly affects the sharing of interest rate risk between borrowers and savers, with the best attainable outcome occurring at an intermediate fixation length of 5 years. The findings on idiosyncratic risk sharing between borrowers highlight a somewhat subtle downside: a more efficient (aggregate) risk-sharing arrangement leads borrowers to take on more idiosyncratic risk, which the mortgage structures under consideration

Figure 10: Consumption Responses To Positive Rate Shock



Notes: The figure shows impulse responses to a positive interesr rate shock. The left panel shows the response of aggregate borrower consumption C_t^B, while the right panel shows the response of aggregate saver consumption C_t^S. Benchmark FRM economy is in blue. Volatility-minimizing ARM 3yr economy is in green, and the $\mathcal{R}_{BS}$-minimizing ARM 5yr economy is in purple.

cannot diversify away.

5.4 Role of Aggregate Income Shocks

The results above show how financial stability and risk sharing are affected by mortgage structure in an environment in which the only source of aggregate risk is shocks to interest rates. It is the source of risk whose allocation between borrowers and savers is most directly affected by mortgage fixation length.

In the data, households also face aggregate income shocks, and these shocks may be correlated with interest rates. For instance, times when interest rates rise may also be times when incomes rise, as would be the case in an economy dominated by aggregate demand shocks. Alternatively, interest rate increases may coincide with income declines if supply shocks predominate.[24] How do our results change if we allow for the possibility of correlated aggregate income and interest rate shocks?

To answer this question, we relax the restriction $Y_t = 1$ and calibrate a VAR(1) process to govern the joint dynamics of $(\log Y_t, r_t^f)$, where $\log Y_t$ is measured as the cyclical component of log GDP and r_t^f is as before. Over the baseline 1987-2024 sample period, we find a positive correlation between innovations to the two series, with a correlation coefficient of 0.313. Relative to the rate-only process in the baseline model, we also find a lower volatility of the innovations in rates – 0.013 vs. 0.014. Intuitively, in a VAR some of the variation in rates is now attributed to the contemporaneous and lagged effects of income innovations. Appendix I.1 contains details on the VAR estimation and the resulting impulse response functions. We then re-solve the model with the new process for each of the mortgage structures.[25]

The results are shown in Table 5. The left panel shows the results for the three main fixation lengths – ARM with a one-year fixation length, ARM with a three-year fixation length, and

[24] In a New Keynesian framework, a positive demand shock increases both output and inflation, to which central banks respond by raising nominal rates. With nominal rigidities, this leads to an increase real rates. In contrast, a negative supply shock increases inflation while reducing output. If the central bank's policy rule responds to inflation more strongly than to output, it would raise nominal rates, leading real rates to rise as well. See Woodford (2003) for a canonical treatment.

[25] As before, the FRM economy represents the data generating process. A change in the exogenous environment leads to different values for the moments governing our internal calibration. In principle, this could require re-calibrating the internally calibrated parameters. However, we find the fit of the model with income shocks to be comparable to the baseline model without. For parsimony, we do not re-calibrate the model.

Table 5: Measures of Financial Stability

Income Correlation:	Calibrated ($\rho_{yr} = 0.313$)			Uncorrelated ($\rho_{yr} = 0$)		
Mortgage Structure:	ARM (1yr)	ARM (3yr)	FRM	ARM (1yr)	ARM (3yr)	FRM
Excess ROE (mean)	2.16	1.56	1.62	2.00	1.56	1.66
ROE (st. dev.)	18.04	4.51	8.04	16.37	4.82	8.65
Excess ROA (mean)	0.22	0.16	0.18	0.20	0.17	0.18
ROA (st. dev.)	1.93	0.73	1.03	1.74	0.76	1.08
Fraction of constraint binding	32.08	55.38	52.02	37.94	53.71	47.95
Duration of bank net worth	-12.58	-2.57	1.53	-11.01	-1.75	2.21
PTI (OLS coef.)	1.44	0.33	-0.27	1.45	0.35	-0.23
LTV (OLS coef.)	1.67	-0.18	-1.23	1.63	-0.08	-1.03
Default Rate (mean)	2.12	2.34	2.34	2.15	2.34	2.33
Default Rate (std. dev.)	0.37	0.23	0.31	0.40	0.25	0.30
Default Rate (OLS coef.)	0.10	-0.01	-0.07	0.09	-0.00	-0.05
DTI (mean)	146.57	150.85	150.42	147.02	150.81	150.58
LTV (mean)	55.95	59.45	59.22	56.35	59.37	59.23
Deposits / Income (mean)	25.55	24.48	24.51	25.47	24.51	24.51

Notes: Unconditional moments from a long simulation of the model. Except for the duration of bank net worth, all quantities are reported in percent. Rows marked "OLS coef." report the coefficient of a regression of the variable on the policy rate r_t^f.

FRM – in the exogenous environment with both income and rate shocks, calibrated to the data. The right panel shows the results for the same three fixation lengths when the correlation of income and rate innovations is counterfactually set to zero. This allows us to separately consider the effect of introducing an extra source of aggregate risk into the model from the effect of it being correlated with interest rates.

In the presence of income shocks, changing mortgage fixation becomes somewhat less effective at reducing volatility than it was in the baseline, whether of intermediary returns on equity (top panel, second row) or default rates (bottom panel, fourth row). In the baseline economy, going from an economy with FRMs to an economy with a 3-year fixation length lowers intermediary ROE volatility from 9.11 to 1.41. With uncorrelated income shocks, the corresponding reduction is from 8.65 to only 4.82. This smaller effect occurs for two reasons. First, unlike rate shocks, income shocks affect both households in a similar way. A positive rate shock benefits borrowers at the expense of savers in the FRM economy, but a positive income shock benefits both. Shortening the fixation length improves the sharing of interest rate risk because that risk is allocated asymmetrically to begin with, but has little effect on the sharing of income risk.

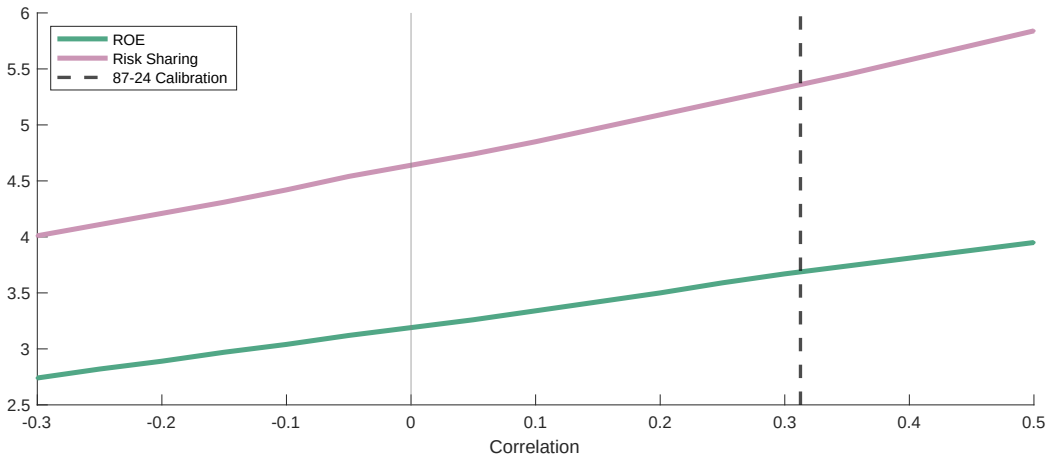
Second, the reduction in endogenous volatility achieved by intermediate fixation length (ARM (3y) column vs. FRM column) reduces incentives for precautionary savings. Both borrowers and savers take on more debt, with mortgage DTI and LTV slightly higher (bottom panel, rows 6-7) and with intermediary constraints binding more often (top panel, row 5). These riskier portfolios leave households more exposed to income shocks, partly offsetting the reduction in volatility due to better sharing of interest rate risk.

Next, consider what happens to financial stability in the FRM economy when income and rate shocks become positively correlated, as they are in the data. An increase in rates now lowers default rates not just because it lowers market-value LTVs (bottom panel, row 2), as in the baseline with only rate shocks, but also because of a concurrent increase in income. Default rates become more countercyclical in rates (bottom panel, row 5) leading to a stronger hedging force offsetting the market value losses on long-term mortgages stemming from a rate hike. As a result, intermediary ROE volatility in the FRM economy is lower than in the uncorrelated case (top panel, row 2).

The opposite is true for ARMs. A rate hike increases borrower payments but they can afford more of that increase because their incomes also rise. Intermediaries earn higher cash flows because promised mortgage payments are less offset by rising default rates, weakening the default hedging force that was present in the baseline model. In addition, defaults rise in the state of the world when net worth is low, namely when rates are low, due to lower incomes. In sum, positive correlation makes the FRM economy safer and the ARM economy riskier, suggesting that a higher fixation length may be optimal.

To confirm this intuition, we solve a grid of economies with different fixation lengths and different correlations between income and rate shocks. For each correlation, we find (1) the fixation length that minimizes the volatility of intermediary ROE, and (2) the fixation length that optimizes risk sharing between borrowers and savers (minimizes $\mathcal{R}_{BS}$). The results are shown in Figure 11. Indeed, as we increase the correlation from -0.3 to 0.5, the ROE-minimizing fixation length rises from 2.7 to 3.9 years. The fixation length that optimizes risk sharing rises from 4 to 5.8 years, consistently remaining 1-2 years higher than the ROE-minimizing value as in the baseline. At the calibrated correlation of 0.313, the ROE volatility is minimized by a fixation length of 3.6 years while risk sharing is optimized by a lengh of 5.3 years.

Figure 11: Optimal Fixation Lengths as a Function of Correlation



Notes: For each correlation (x-axis), blue line plots the fixation length that minimizes ROE volatility, and red line plots the fixation length that minimizes $\mathcal{R}_{BS}$ (lower values mean better risk sharing between borrowers and savers). The vertical dashed line shows the calibrated correlation of 0.313. To determine minima, we solve a grid of economies with different fixation lengths and different correlations between income and rate shocks and fit cubic splines to the ROE and risk sharing measures.

The magnitude of these effects are not large enough to overturn the main findings of the paper. A mortgage with an intermediate fixation length of a few years does the best job of promoting financial stability and risk sharing in the presence of income shocks, whether the correlation is positive, as it has been in the recent sample, or zero, as it has been on average in a longer 1962-2024 period.[26]

6 Conclusion

This paper highlights the effect of mortgage structure on financial stability and risk sharing between households and financial intermediaries. To evaluate these effects in equilibrium, we build a quantitative model with flexible mortgage contract structures, borrowers, and an intermediary sector. Borrowers endogenously default for liquidity and net worth-related reasons, and default is more sensitive to interest rates in the adjustable-rate mortgage regime. In addition, intermediary distance to capital constraints affects equilibrium mortgage pricing. As a

[26] Appendix I.1 contains estimation details.

result, our model captures complex interaction effects between interest rate and credit risk, and intermediary net worth.

Our findings reveal that mortgage structure is key to understanding differential financial stability risks in response to interest rate fluctuations. In an ARM economy, rising rates lead to increased household mortgage payments, higher default rates, and declining house prices. Despite higher credit losses, banks benefit from increased net interest margins and asset values, ultimately raising their net worth. Conversely, an FRM economy shields households from higher payments, thereby reducing defaults, but banks experience rising deposit costs and falling asset values, reducing their net worth and profitability.

We identify a "U-shaped" relationship between mortgage structure and financial stability risks. Pure ARM economies exhibit high net worth volatility due to strong interest rate sensitivity, whereas FRM economies partially hedge risks through sticky deposit rates. Yet ARM economies better hedge defaults by concentrating them in states when banks' net worth is high. Intermediate fixation lengths, around 3 to 5 years, optimally balance these opposing forces, minimizing volatility and maximizing aggregate risk-sharing. Additionally, introducing correlated aggregate income and interest rate shocks suggests that a more positive correlation increases the optimal fixation length.

Overall, our findings have implications for monetary policy and macroprudential regulation. Our model provides a framework for understanding how changes in policy rates affect financial stability differentially across mortgage structures. Our paper informs optimal mortgage design that aims to improve financial stability and risk-sharing between households and financial intermediaries.

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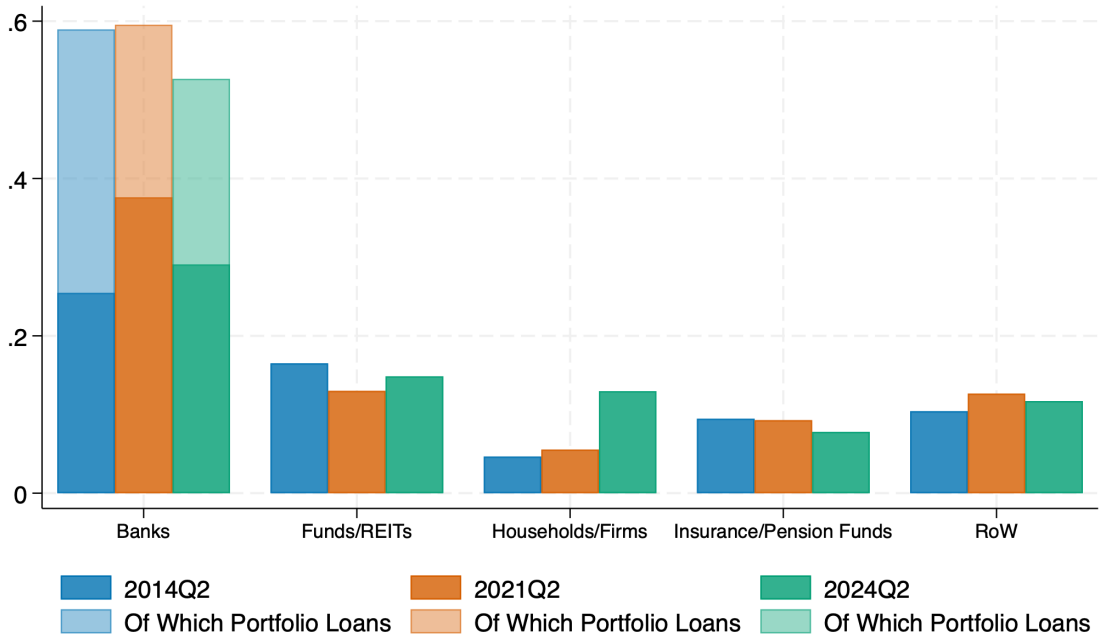
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Internet Appendix for "A Macro-Finance Model of Mortgage Structure: Financial Stability & Risk Sharing"

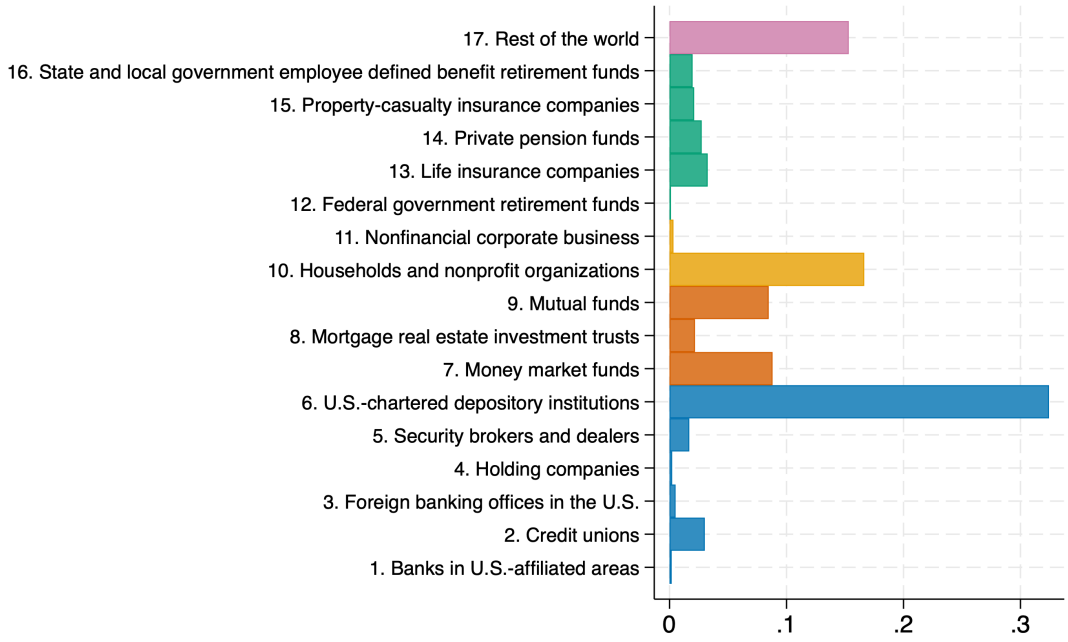
I Additional Figures and Tables

Figure IA.1: Non-Government Residential Mortgage Holdings by Sector (Portfolio & MBS)



Notes: This figure shows the composition of non-government residential mortgage holdings, including bank portfolio loans (I) and agency- and GSE-backed securities holdings (II), excluding direct government holdings, and holdings by the GSEs and the Federal Reserve. Data for (I) is based on the Urban Institute Housing Chartbook ("Unsecuritized First Liens (Bank Portfolio)"). Data for (II) comes from Table L211 from the US Financial Accounts (Flow of Funds) split into Banks, Funds/REITs, Households/Firms, Insurance/Pension Funds, and the Rest of World (RoW) in 2014Q2, 2021Q2, and 2024Q2. A detailed breakdown of constituent sector definitions for (II) is provided in Table IA.I. The data is retrieved from the Federal Reserve. Since (II) is reported at quarterly frequency, we obtain (I) from the Urban Institute Housing Chartbook from August 2014, and September 2021 and 2024, which reflect data as of 2014, 2021, and 2024 for the second quarter of the year, respectively.

Figure IA.2: Non-Government MBS Holdings (Detailed Sector Breakdown)



Notes: This figure shows the composition of non-government agency- and GSE-backed securities holdings from Table L211 from the US Financial Accounts (Flow of Funds), with a breakdown into underlying sectors that form the groups of Banks, Funds/REITs, Households/Firms, Insurance/Pension Funds, and the Rest of World (RoW) in Figure IA.1, in 2024Q2.

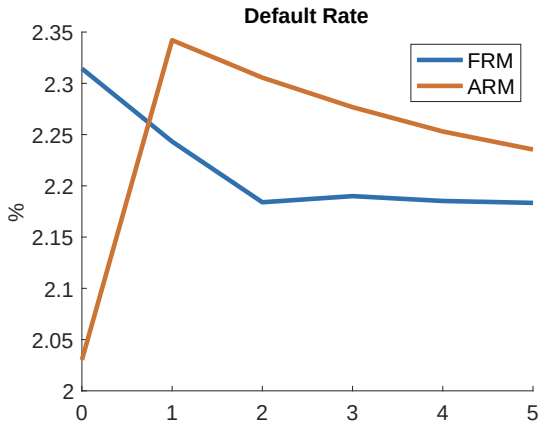
Table IA.I: Overview of Sector Definitions for Non-Government MBS Holdings

Sector	**Constituent Groups**
Banks	U.S.-chartered depository institutions
	Foreign banking offices in the U.S.
	Banks in U.S.-affiliated areas
	Credit unions
	Security brokers and dealers
	Holding companies
Funds/REITs	Mutual funds
	Mortgage real estate investment trusts
	Money market funds
Households/Firms	Households and nonprofit organizations
	Nonfinancial corporate business
Insurance/Pension Funds	Property-casualty insurance companies, including those held by U.S. residual market reinsurers
	Life insurance companies
	Private pension funds
	Federal government retirement funds
	State and local government employee defined benefit retirement funds
Rest of World (RoW)	Rest of the world

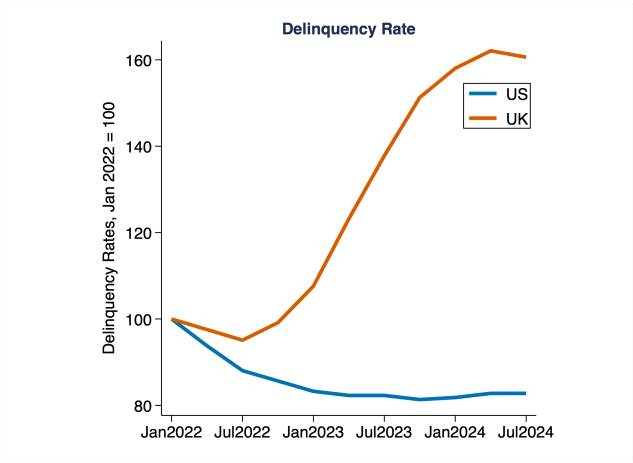
Notes: Constituent groups from Table L211 of the US Financial Accounts (Flow of Funds).

Figure IA.3: Model Predictions & Evidence: Delinquencies

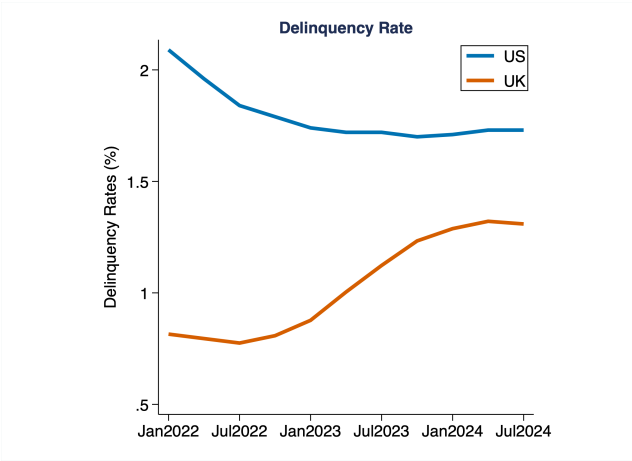
(a) IRF for Defaults (FRM vs. ARM)



(b) Delinquencies since 2022 (US vs. UK)



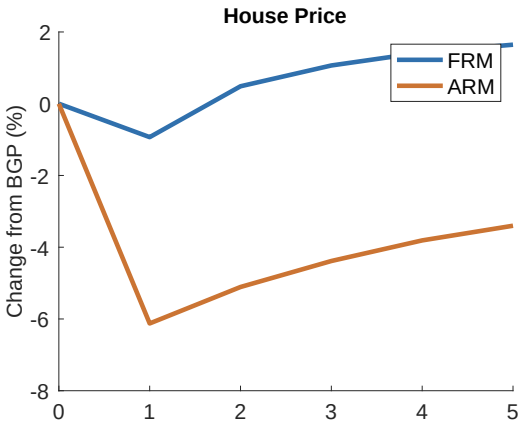
(c) Delinquencies since 2022 (US vs. UK) - Levels



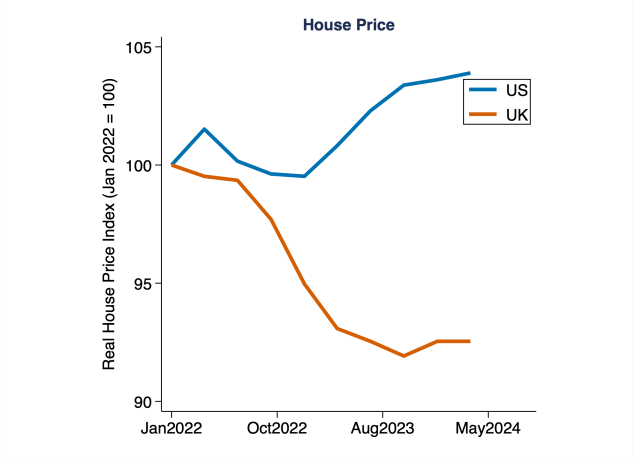
Notes: Panel (a) shows the impulse response function for default rates in response to an exogenous interest rate shock as shown in section 5.1. Panel (b) shows delinquency measures in the US and UK, indexed to 2022 Q1. Panel (c) shows these delinquency measures in levels. US delinquencies are measured on single-family residential mortgages from FRED, reflecting loans past due 30 days or more and still accruing interest as well as those in nonaccrual status. UK delinquencies are arrears balances as percent of total outstanding balances reported by the FCA, reflecting loans where the amount of actual arrears is 1.5% or more of the borrower's current loan balance.

Figure IA.4: Model Predictions & Evidence: House Prices

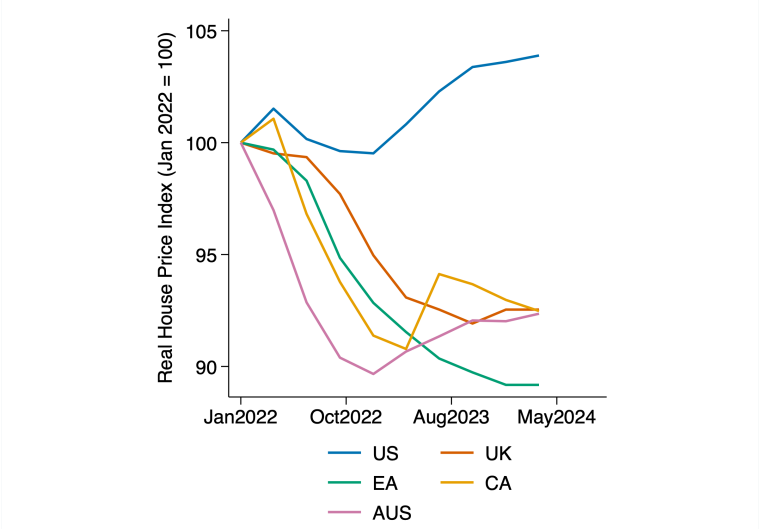
(a) IRF for House Prices (FRM vs. ARM)



(b) Real House Prices since 2022 (US vs. UK)



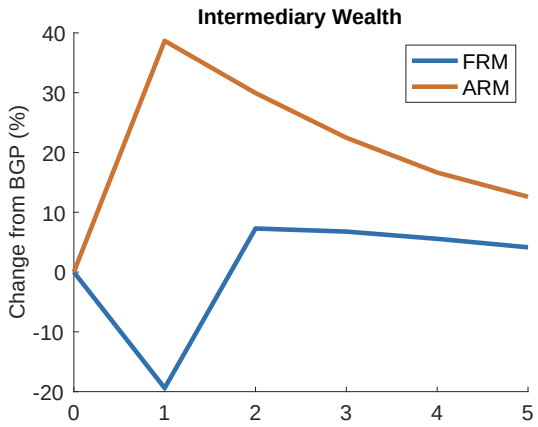
(c) Real House Prices since 2022 (Cross Country)



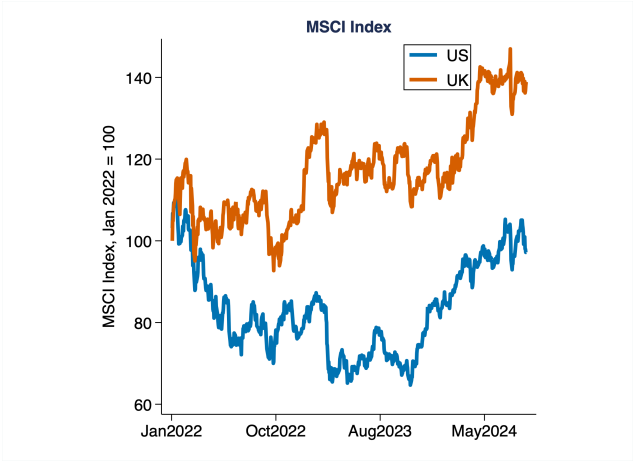
Notes: Panel (a) shows the impulse response function for house prices in response to an exogenous interest rate shock as shown in section 5.1. Panel (b) shows real house prices in the US and UK indexed to 2022 Q1, and Panel (c) shows real house prices in the US, UK, Canada, Australia, and Euro Area indexed to 2022 Q1.

Figure IA.5: Model Predictions & Evidence: Bank Equity Prices

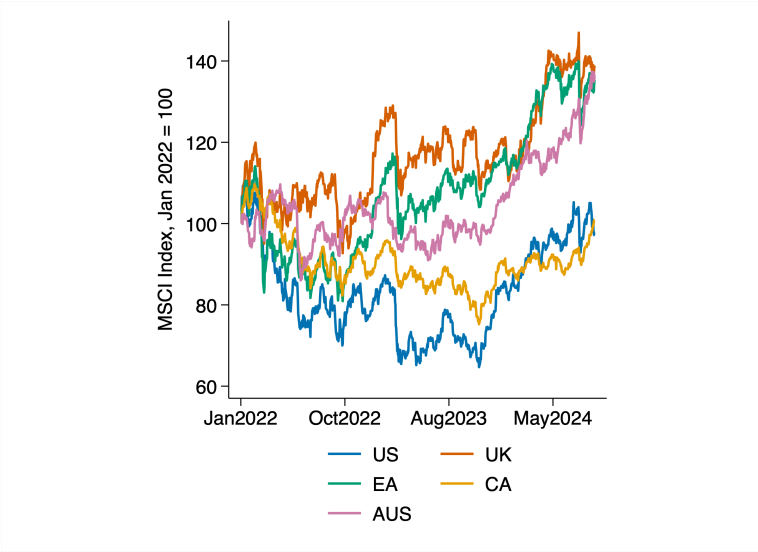
(a) IRF for Intermediary Net Wealth (FRM vs. ARM)



(b) Bank Equities since 2022 (US vs. UK)

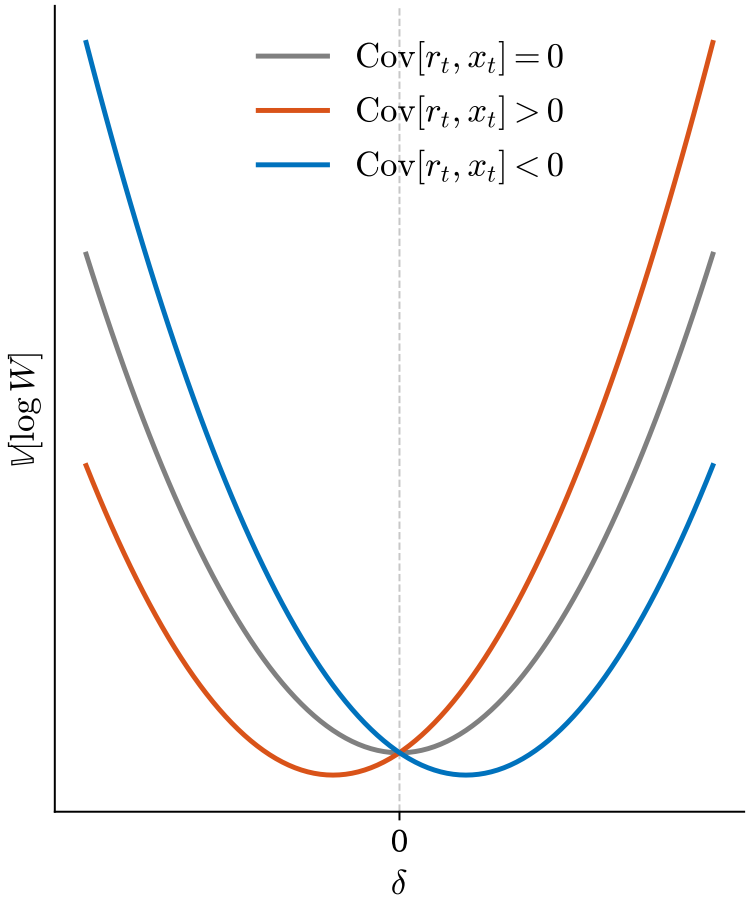


(c) Bank Equities since 2022 (Cross Country)



Notes: Panel (a) shows the impulse response function for intermediary net wealth in response to an exogenous interest rate shock as shown in section 5.1. Panel (b) shows MSCI bank equity indices in the US and UK indexed to January 1, 2022, and Panel (c) shows MSCI bank equity indices in the US, UK, Canada, Australia, and Euro Area indexed to January 1, 2022.

Figure IA.6: Illustration of Net Worth Volatility and Duration

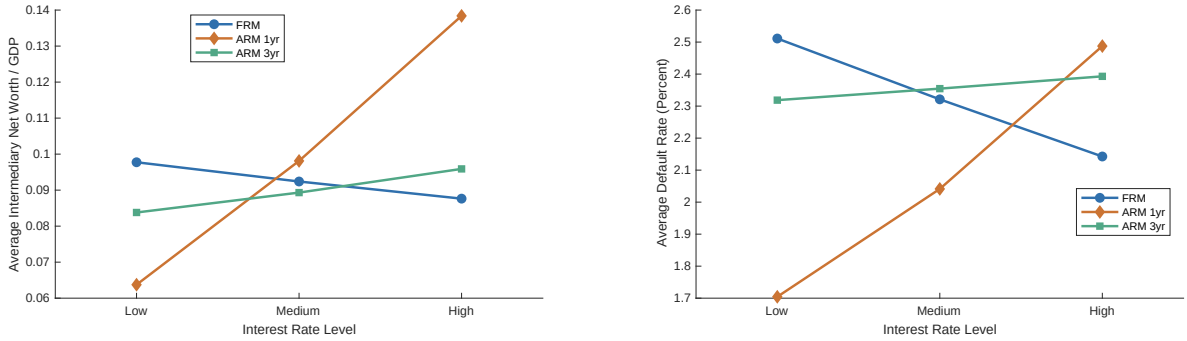


Notes: This figure plots the relationship between $\mathrm{V}[\log W_t]$ and duration δ from Equation IA.1, for fixed values of $\mathbb{V}[r_t]$, γ, and $\mathbb{V}[x_t]$, for $\mathrm{Cov}[r_t, x_t] = 0$, $\mathrm{Cov}[r_t, x_t] > 0$, and $\mathrm{Cov}[r_t, x_t] < 0$.

Figure IA.7: Net Worth and Default by Interest Rate Level (Intermediate ARM)

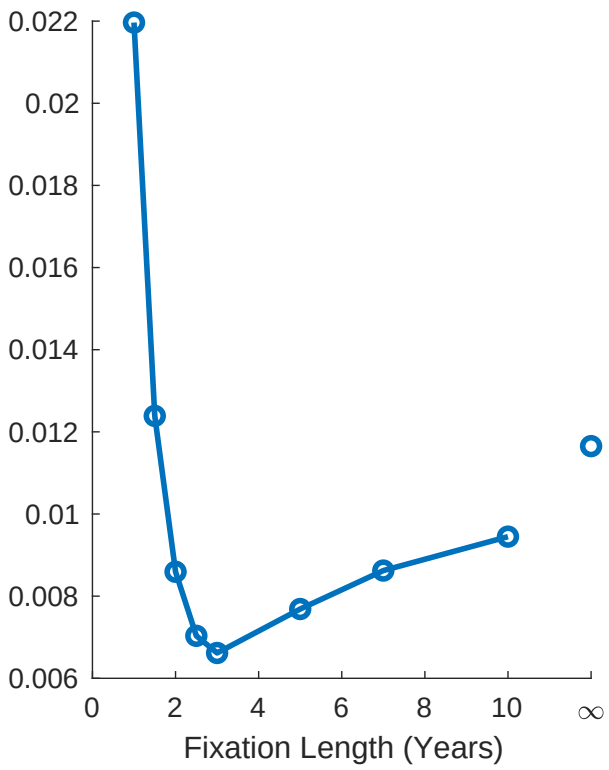
(a) Intermediary Net Worth / GDP

(b) Default Rate



Notes: This figure shows simulation-based average rates of default and levels of intermediary net worth across different levels of interest rates, for the full-ARM (1-year fixation length), intermediate ARM (3-year fixation length), and full-FRM (infinite fixation length) economies.

Figure IA.8: Mortgage Return Volatility



Notes: This figure shows the volatility of mortgage returns, measured as the standard deviation of net income over total assets, i.e. reflecting volatility of return on assets (ROA). The x-axis reflects an annual rate reset probability of $\pi_\tau \in \{1, 2/3, 0.5, 0.4, 1/3, 0.2, 1/7, 0.1, 0\}$, which corresponds to fixed-rate lengths of 1, 1.5, 2, 2.5, 3, 5, 7, 10 years and ∞, respectively.

I.1 Estimation of Income and Interest Rate Process

We estimate the following VAR(1) for $y_t = \log Y_t$ and r_t, where y_t is the cyclical component of log Real GDP and r_t is the real interest rate, using annual data from 1987 to 2024. Cyclical component of GDP is extracted using the one-sided Hodrick-Prescott filter. Real rates are 1-year real rates from the Federal Reserve Bank of Cleveland.

$$\begin{bmatrix} y_t \\ r_t \end{bmatrix} = \left(I_2 - \begin{bmatrix} \phi_{yy} & \phi_{yr} \\ \phi_{ry} & \phi_{rr} \end{bmatrix} \right) \begin{bmatrix} 0 \\ \bar{r} \end{bmatrix} + \begin{bmatrix} \phi_{yy} & \phi_{yr} \\ \phi_{ry} & \phi_{rr} \end{bmatrix} \begin{bmatrix} y_{t-1} \\ r_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon_{y,t} \\ \epsilon_{r,t} \end{bmatrix},$$

where

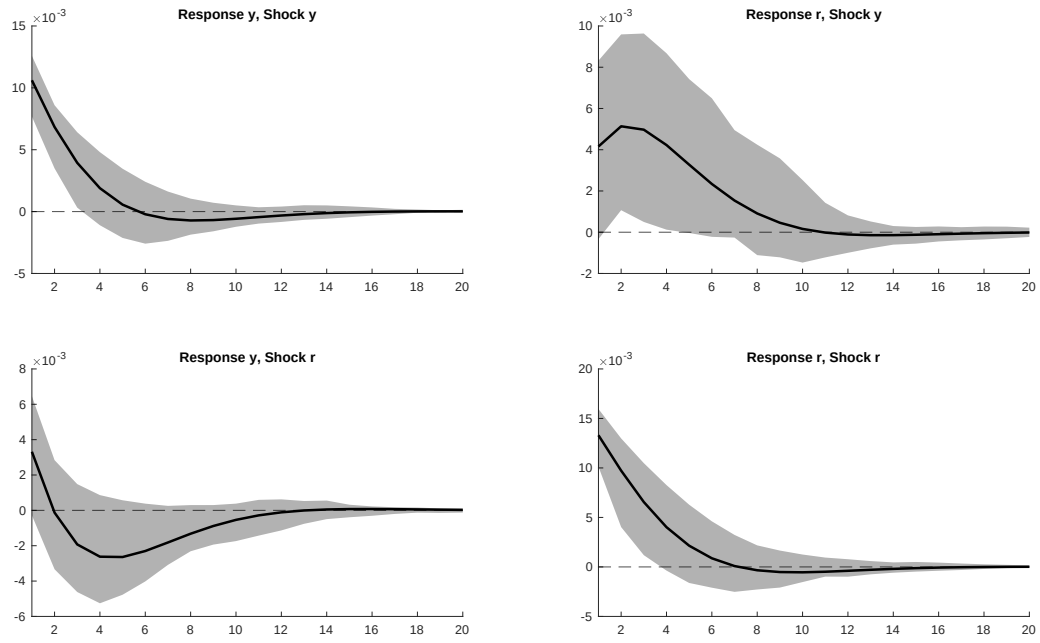
$$\begin{bmatrix} \epsilon_{y,t} \\ \epsilon_{r,t} \end{bmatrix} \sim \mathcal{N}\left(\mathbf{0}_2, \begin{bmatrix} \sigma_y^2 & \rho_{yr}\sigma_y\sigma_r \\ \rho_{yr}\sigma_y\sigma_r & \sigma_r^2 \end{bmatrix} \right)$$

The estimated values are $\phi_{yy} = 0.718$, $\phi_{yr} = -0.189$, $\phi_{ry} = 0.219$, $\phi_{rr} = 0.677$, $\sigma_y = 0.011$, $\sigma_r = 0.013$, and $\rho_{yr} = 0.313$. $\bar{r}$ is unchanged from the baseline estimation of the AR(1) process for rates.

These estimates yield generalized (not orthogonalized) impulse responses shown in Figure IA.9. Positive correlation yields positive comovement of the two series on impact, with the effect being more persistent in rates for innovations to income rather than vice versa.

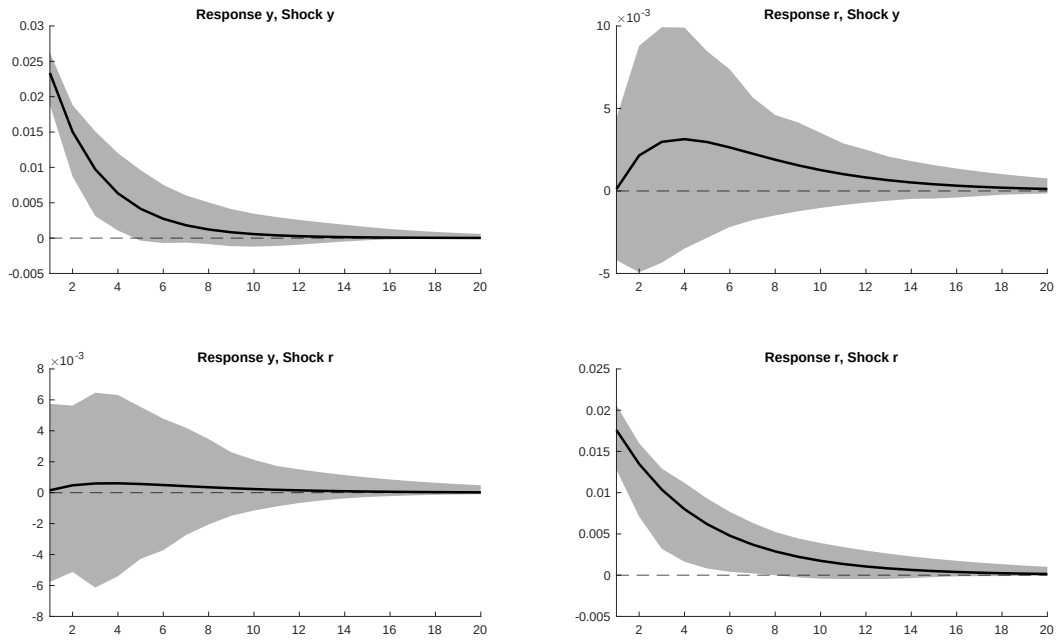
We also estimate the VAR(1) process for a longer sample 1962-2024. Because real rates from the Cleveland Fed are not available prior to 1982, we instead construct real rates as nominal constant maturity 1-year rates less realized inflation over the year. In the longer sample, the innovations are uncorrelated ($\rho_{yr} = 0.0066$) and impulse responses of one innovation on the other variable are not significant (see Figure IA.10).

Figure IA.9: Impulse Responses of Income and Interest Rates: 1987-2024



Notes: Impulse responses of income and interest rates to innovations in each series, given the estimated VAR(1) process. Shaded regions represent bootstrapped 95% confidence intervals. Innovations are not orthogonalized.

Figure IA.10: Impulse Responses of Income and Interest Rates: 1962-2024



Notes: Impulse responses of income and interest rates to innovations in each series, given the estimated VAR(1) process. Shaded regions represent bootstrapped 95% confidence intervals. Innovations are not orthogonalized.

II Simple Zero-Duration Benchmark

Our starting point for measuring financial stability is the volatility of intermediary net worth: $\mathbb{V}[\log W_t]$. In a world where $\log W_t$ only depends on current interest rates r_t, we have:

$$\log W_t = \alpha - \delta r_t$$

As a result, we can interpret δ as the duration of intermediary net worth: $-\frac{\mathrm{d}\log W_t}{\mathrm{d}r_t} = \delta$. δ measures the percent decline in net worth for a 1 percentage point increase in rates. Minimizing $\mathbb{V}[\log W]$ is achieved when $\delta^* = 0$, i.e. in a "zero duration" financial system, the volatility-minimizing mortgage fixation length would match the duration of deposits.[27]

However, $\log W_t$ may further depend on other state variables represented by x_t, which yields:

$$\log W_t = \alpha - \delta r_t + \gamma x_t$$

The variance of $\log W_t$ is:

$$\mathbb{V}[\log W_t] = \delta^2 \mathbb{V}[r_t] + \gamma^2 \mathbb{V}[x_t] + \delta\gamma \mathrm{Cov}[r_t, x_t] \tag{IA.1}$$

To find the new volatility-minimizing duration δ^{**}, we can take the first-order condition with respect to δ to obtain:

$$\delta^{**} = -\frac{\gamma}{2}\frac{\mathrm{Cov}[r_t, x_t]}{\mathbb{V}[r_t]}$$

As a result, the volatility-minimizing duration is not zero, but instead also depends on $\mathrm{Cov}[r_t, x_t]$. For $\mathrm{Cov}[r_t, x_t] > 0$, the volatility-minimizing duration is smaller than zero, and for $\mathrm{Cov}[r_t, x_t] < 0$, it is greater than zero. Equation IA.1 further shows that net worth variance is quadratic in duration, meaning duration is increasing in the absolute distance to the volatility-minimizing duration δ^{**}. Figure IA.6 in the appendix illustrates this intuition for different values of $\mathrm{Cov}[r_t, x_t]$.

As noted previously, "state variables" that may affect intermediary net worth beyond interest

[27] This duration-matching strategy to minimize the effect interest rate changes on portfolio values is also referred to as "immunization" by practitioners.

rates but that may be correlated with rates are endogenous default behavior by households, as well as equilibrium pricing of mortgage rates, both of which may differ across mortgage structures.

III Model Derivations

III.1 Borrowers

The complete borrower's problem is given by:

$$V(w_t^i, \mathcal{Z}_t) = \max_{d_t^i, h_t^i, s_t^i, m_t^i} \beta \mathrm{E}_t \left[\max \left\{ \max_{a_t^i \geq 0} u^B(c_{t+1}^{i,nd}, h_t^i) + V(w_{t+1}^{i,nd}, \mathcal{Z}_t), \eta_t^i \left(u^B(c_{t+1}^{i,d}, h_t^i) + V(w_{t+1}^{i,d}, \mathcal{Z}_t) \right) \right\} \right] \tag{IA.2}$$

where

$$u^B(c_t^i, h_{t-1}^i) = \frac{\left[(c_t^i)^{1-\theta} (h_{t-1}^i)^{\theta} \right]^{1-\gamma}}{1-\gamma}$$

such that

$$w_t^i + \mathcal{R}_t^i = \frac{d_t^i}{1+r_t^d} + q_t^m m_t^i + p_t^h h_t^i + p_t^s s_t^i + \Phi \left(\frac{q_t^m m_t^i}{p_t^h h_t^i} - L\bar{T}V \right) \tag{IA.3}$$

$$c_t^{i,nd} + x_t^i m_{t-1}^i + \delta_h h_{t-1}^i + a_t^i = s_{t-1}(Y_t + \epsilon_t^i) + d_{t-1}^i \tag{IA.4}$$

$$c_t^{i,d} = s_{t-1}(Y_t + \epsilon_t^i) + d_{t-1}^i \tag{IA.5}$$

$$w_t^{i,nd} = a_t^i - (1-\delta_m) m_{t-1}^i q_t^m + p_t^h h_{t-1}^i + p_t^s s_{t-1}^i \tag{IA.6}$$

$$w_t^{i,d} = (1-\lambda) p_t^s s_{t-1}^i \tag{IA.7}$$

$$a_t^i \geq 0 \tag{IA.8}$$

where $\mathcal{R}_t^i$ is a rebate of the LTV adjustment cost Φ proportional to wealth w_t^i. With this parametrization, the adjustment cost does not have income effects.

Notice that $u(c,h)$ is homogeneous of degree $1-\gamma$ in c and h and that all constraints are linear in wealth w_t^i in the sense that if a given allocation is feasible for a wealth of 1, then w_t^i times that allocation is feasible for a wealth of w_t^i. By Proposition 1 of Diamond and Landvoigt (2022), these two properties imply that the borrower's value function can be decomposed into $\frac{(w_t^i)^{1-\gamma}}{1-\gamma}$ and a term $v(\mathcal{Z})$ that only depends on state variables exogenous to the borrower.

For a given choice g_t^i, define $\hat{g}_t^i = \frac{g_t^i}{w_t^i}$. Then, the value function can be rewritten as:

$$v(\mathcal{Z}_t)\frac{(w_t^i)^{1-\gamma}}{1-\gamma} = \max_{\hat{d}_t^i,\hat{h}_t^i,\hat{s}_t^i,\hat{m}_t^i} \beta \mathrm{E}_t \left[\max \left\{ \max_{\hat{a}_t^i \geq 0} (w_t^i)^{1-\gamma} u^B(\hat{c}_{t+1}^{i,nd}, \hat{h}_t^i) + v(\mathcal{Z}_{t+1}) \frac{(w_t^i \hat{w}_{t+1}^{i,nd})^{1-\gamma}}{1-\gamma}, \right. \right.$$
$$\left. \left. \eta_t^i \left(u^B(\hat{c}_{t+1}^{i,d}, \hat{h}_t^i) + v(\mathcal{Z}_{t+1}) \frac{(w_t^i \hat{w}_{t+1}^{i,nd})^{1-\gamma}}{1-\gamma} \right) \right\} \right]$$

Divide both sides by $(w_t^i)^{1-\gamma}$ and drop i subscripts on hatted trading stage choice variables following the proposition cited above, getting the following recursion:

$$v(\mathcal{Z}_t) = (1-\gamma) \max_{\hat{d}_t,\hat{h}_t,\hat{s}_t,\hat{m}_t} \beta \mathrm{E}_t \left[\max \left\{ \max_{\hat{a}_t \geq 0} u^B(\hat{c}_{t+1}^{i,nd}, \hat{h}_t) + v(\mathcal{Z}_{t+1}) \frac{(\hat{w}_{t+1}^{i,nd})^{1-\gamma}}{1-\gamma}, \right. \right.$$
$$\left. \left. \eta_t^i \left(u^B(\hat{c}_{t+1}^{i,d}, \hat{h}_t) + v(\mathcal{Z}_{t+1}) \frac{(\hat{w}_{t+1}^{i,d})^{1-\gamma}}{1-\gamma} \right) \right\} \right]$$

such that

$$1 = \frac{\hat{d}_t}{1+r_t^d} + q_t^m \hat{m}_t + p_t^h \hat{h}_t + p_t^s \hat{s}_t + \Phi \left(\frac{q_t^m \hat{m}_t^i}{p_t^h \hat{h}_t^i} - L\bar{T}V \right) - \hat{\mathcal{R}}_t \tag{IA.9}$$

$$\hat{c}_t^{i,nd} + x_t^i \hat{m}_{t-1} + \delta_h \hat{h}_{t-1} + a_t^i = \hat{s}_{t-1}(Y_t + \epsilon_t^i) + \hat{d}_{t-1} \tag{IA.10}$$

$$\hat{c}_t^{i,d} = \hat{s}_{t-1}(Y_t + \epsilon_t^i) + \hat{d}_{t-1} \tag{IA.11}$$

$$\hat{w}_t^{i,nd} = \hat{a}_t^i - (1-\delta_m)\hat{m}_{t-1} q_t^m + p_t^h \hat{h}_{t-1} + p_t^s \hat{s}_{t-1} \tag{IA.12}$$

$$\hat{w}_t^{i,d} = (1-\lambda) p_t^s \hat{s}_{t-1} \tag{IA.13}$$

$$\hat{a}_t^i \geq 0 \tag{IA.14}$$

$$\tag{IA.15}$$

The remaining dependence on i is in consumption stage shock realizations and choices, which enter the value function through the continuation values inside the expectations operator. Therefore, if we can write the consumption stage problem as a function of state variables exogenous to the borrower and i.i.d. idiosyncratic shocks, we will have confirmed the validity of our aggregation.

No Default Branch Consumption Decision If the borrower chooses not to default, they choose $\hat{c}_t^{i,nd}$ and $\hat{a}_t^i$ to maximize $u^B(\hat{c}_{t+1}^{nd}, \hat{h}_t) + v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^{nd})^{1-\gamma}}{1-\gamma}$ subject to the budget constraint (IA.10), wealth evolution (IA.12), and the non-negative intraperiod savings constraint (IA.14). The first order condition for $\hat{a}_t^i$ is:

$$u_c^B(\hat{c}_{t+1}^{i,nd}, \hat{h}_t) = v(\mathcal{Z}_{t+1})\left(\hat{w}_{t+1}^{i,nd}\right)^{-\gamma} + \kappa_{t+1}^{i,nd}$$

where $\kappa_{t+1}^{i,nd}$ is the Lagrange multiplier on the nonnegativity constraint (IA.14). We will use the functions $\hat{c}_{t+1}^{nd}(y_t^i, \mathbb{1}_\tau^i)$ and $\hat{w}_{t+1}^{nd}(y_t^i, \mathbb{1}_\tau^i)$ to explicitly denote the dependence of the consumption decision on the idiosyncratic realizations borrower's income and the mortgage regime.

Default Decision Given the consumption decision above, a household decides to default iff

$$\underbrace{u^B(\hat{c}_{t+1}^{nd}(y_t^i, \mathbb{1}_\tau^i), \hat{h}_t) + v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^{nd}(y_t^i, \mathbb{1}_\tau^i))^{1-\gamma}}{1-\gamma}}_{v^{nd}(d_t^i, h_t^i, s_t^i, m_t^i, \epsilon_t^i, \mathbb{1}_\tau^i)} < \eta_t^i \underbrace{\left[u^B(\hat{y}_t^i + \hat{d}_{t-1}, \hat{h}_t) + v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^{d}(y_t^i))^{1-\gamma}}{1-\gamma}\right]}_{v^{d}(d_t^i, h_t^i, s_t^i, m_t^i, \epsilon_t^i)}$$

This expression implies that there exist a default threshold $\eta^*(\epsilon_t^i, \mathbb{1}_\tau^i)$ at which the household is indifferent between defaulting and not defaulting. Which side of the threshold leads to a default vs. no-default decision depends on the sign of the value function, which depends on whether or not $\gamma > 1$. For the rest of these derivations, assume that $\gamma > 1$, the more common case, in which case value functions are negative, and so the default region is given by $[0, \eta^*(y_t^i, \mathbb{1}_\tau^i)]$.

Using the Law of Iterated Expectations, we can separate the conditional expectation E_t in the definition of the value function into an expectation over the realization of aggregate shocks $\mathrm{E}_t^{\mathcal{Z}}[\cdot]$, the expectation over the realizations of i.i.d. idiosyncratic shocks to income ϵ_t^i and reset probability $\mathbb{1}_\tau^i$ denoted by $\mathrm{E}_i[\cdot]$, and the expectation over i.i.d. default utility shocks η^i denoted by $\mathrm{E}_\eta[\cdot]$. Let F_η denote the c.d.f. of the η^i distribution. Then the expectation in the value function can be written as:

$$\mathrm{E}_t^{\mathcal{Z}}\Bigg[\mathrm{E}_i\Bigg[F_\eta(\eta^*(\epsilon,\tau))\mathrm{E}_\eta\Bigg[\eta_t^i\left(u^B(\hat{s}_{t-1}(Y_t+\epsilon_t^i)+\hat{d}_{t-1},\hat{h}_t)+v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^d)^{1-\gamma}}{1-\gamma}\right)|\eta_t^i > \eta^*(\epsilon_t^i,\mathbb{1}_\tau^i)\Bigg]$$
$$+\left(1-F_\eta(\eta^*(\epsilon_t^i,\mathbb{1}_\tau^i))\right)\left(u^B(\hat{c}_{t+1}^{nd}(\epsilon_t^i,\mathbb{1}_\tau^i),\hat{h}_t)+v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^{nd}(\epsilon_t^i,\mathbb{1}_\tau^i))^{1-\gamma}}{1-\gamma}\right)\Bigg]\Bigg]$$

Since idiosyncratic shocks are i.i.d., they affect the household problem only through the laws of motion for wealth, admitting aggregation.

If ϵ_t^i idiosyncratic shocks were continuous, the nested expectations above imply integration over a non-rectangular region of (ϵ_t^i, η_t^i), which can be challenging to calculate numerically. Instead, we model shocks to ϵ_t^i as discrete. Shocks to the ARM stage $\mathbb{1}_\tau^i$ are already Bernoulli. In this case, the expectation $\mathrm{E}_i[\cdot]$ above can be written as:

$$\begin{aligned}
&\sum_{\tau\in\{0,1\}}\sum_{\epsilon\in\mathcal{E}}\mathcal{P}_\epsilon(\epsilon_t^i=\epsilon)\mathcal{P}_\tau(\tau_t^i=\tau)\times \\
&\mathrm{E}_i\left[F_\eta(\eta^*(\epsilon,\tau))\mathrm{E}_\eta\left[\eta_t^i|\eta_t^i>\eta^*(\epsilon,\tau)\right]\left(u^B(\hat{s}_{t-1}(Y_t+\epsilon)+\hat{d}_{t-1},\hat{h}_t)+v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^d)^{1-\gamma}}{1-\gamma}\right)\right. \\
&\left.+(1-F_\eta(\eta^*(\epsilon,\tau)))\left(u^B(\hat{c}_{t+1}^{nd}(\epsilon,\tau),\hat{h}_t)+v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^{nd}(\epsilon,\tau))^{1-\gamma}}{1-\gamma}\right)\right]
\end{aligned}$$

Note that conditional on default, the borrower's value function does not depend on the specific realization of the utility penalty, meaning that $u^B(\hat{s}_{t-1}(Y_t+\epsilon)+\hat{d}_{t-1},\hat{h}_t)+v(\mathcal{Z}_{t+1})\frac{(\hat{w}_{t+1}^d)^{1-\gamma}}{1-\gamma}$ can be brought outside the $\mathrm{E}_\eta[\cdot]$ expectation.

Distribution of η Shocks Let $\log\eta_t^i\sim\mathcal{N}\left(-\frac{\sigma_\eta^2}{2},\sigma_\eta^2\right)$. This implies that the average penalty for default is purely pecuniary and governed by λ, while the dispersion of η shocks given by σ_η governs the sensitivity of default rates to economic conditions.

The log-normal distribution admits a simple expression for the partial expectation of the default penalty:

$$\begin{aligned}
F_\eta^-(\epsilon,\tau)\equiv F_\eta\left(\eta^*(\epsilon,\tau)\right)\mathrm{E}_\eta\left[\eta_t^i|\eta_t^i\leq\eta^*(\epsilon,\tau)\right] &= \int_0^{\eta^*(\epsilon,\tau)}\frac{\eta}{\sigma_\eta\sqrt{2\pi}}\exp\left(-\frac{(\log\eta^*(\epsilon,\tau)+\sigma_\eta^2/2)^2}{2\sigma_\eta^2}\right)d\eta \\
&= \Phi\left(\frac{\log\eta^*(\epsilon,\tau)-\sigma_\eta^2/2}{\sigma_\eta}\right)
\end{aligned}$$

As well as for the survival probability:

$$\tilde{F}_\eta(\epsilon,\tau) \equiv 1 - F_\eta\left(\eta^*(\epsilon,\tau)\right) = 1 - \Phi\left(\frac{\log \eta^*(\epsilon,\tau) + \sigma_\eta^2/2}{\sigma_\eta}\right) = \Phi\left(\frac{-\log \eta^*(\epsilon,\tau) - \sigma_\eta^2/2}{\sigma_\eta}\right)$$

Therefore, for a given ϵ and τ, the continuation value of the borrower's problem can be written as:

$$F_\eta^-(\epsilon,\tau) v_t^d(d_t^i, h_t^i, s_t^i, m_t^i, \epsilon) + \tilde{F}_\eta(\epsilon,\tau) v_t^{nd}(d_t^i, h_t^i, s_t^i, m_t^i, \epsilon, \tau)$$

where

$$\eta^*(\epsilon,\tau) = \frac{v_t^d(d_t^i, h_t^i, s_t^i, m_t^i, \epsilon)}{v_t^{nd}(d_t^i, h_t^i, s_t^i, m_t^i, \epsilon, \tau)}$$

ARM Reset Probability For a given individual mortgage, the probability of an ARM reset is π_τ *conditional* on it still being in the teaser stage. Since we are not tracking the distribution of mortgages, we can only calculate the unconditional probability of being in the floating (rather than teaser) stage: $\mathcal{P}_\tau(\tau_t^i = 0) = \pi_\tau\left[1 - \mathcal{S}_t\right] + \mathcal{S}_t$, where $\mathcal{S}_t = \mathcal{P}(\tau(m_t^i) = 0)$ is the share of currently outstanding mortgages that have already reset.

We can define this share recursively. Suppose that at the start of the current period, before reset shocks have been realized, the share was $\mathcal{S}_{t-1}$. As a result of reset shocks, there are now $\pi_\tau\left[1 - \mathcal{S}_{t-1}\right]\hat{m}_{t-1}$ new floating rate mortgages. As a result of balance decay, the balances of these mortgages are $1 - \delta_m$ of what they used to be. Newly issued mortgages are all in the teaser stage so do not enter the numerator. Therefore, the share of already reset mortgages is:

$$\mathcal{S}_t = \frac{\left(\mathcal{S}_{t-1} + \pi_\tau\left[1 - \mathcal{S}_{t-1}\right]\right)(1 - \delta_m)\hat{m}_{t-1}}{\hat{m}_t}$$

This aggregation also implies that the teaser vs. floating stage status of a mortgage is randomly reshuffled between households during the trading stage, so that there is no persistence to their mortgage status. This is necessary for aggregation.

III.1.1 First Order Conditions

Preliminaries For a generic choice variable g, write the continuation value of the borrower's problem as:

$$\mathrm{E}_t \left[\underbrace{\left(\int_0^{\eta^*(g)} \eta dF_\eta(\eta) \right)}_{F_\eta^-(g)} v_{t+1}^d(g) + \underbrace{[1 - F_\eta(\eta^*(g))]}_{\tilde{F}_\eta(g)} v_{t+1}^{nd}(g) \right]$$

Differentiating with respect to g yields and collecting terms:

$$\mathrm{E}_t \left[\frac{\partial v_{t+1}^d(g)}{\partial g} F_\eta^-(g) + \frac{\partial v_{t+1}^{nd}(g)}{\partial g} \tilde{F}_\eta(g) + f_\eta(\eta^*(g)) \frac{\partial \eta^*(g)}{\partial g} \left(-\eta^*(g) v_{t+1}^d(g) + v_{t+1}^{nd}(g) \right) \right]$$

Plugging in the default condition $v_{t+1}^{nd}(g) = \eta^*(g) v_{t+1}^d(g)$ leads the last term to become zero:

$$\mathrm{E}_t \left[\frac{\partial v_{t+1}^d(g)}{\partial g} F_\eta^-(g) + \frac{\partial v_{t+1}^{nd}(g)}{\partial g} \tilde{F}_\eta(g) \right]$$

Which is the expression we will use to calculate the first order conditions below.

Define the LTV adjustment cost Φ to be $\Phi(x) = \frac{\phi}{2} x^2$.

Denote by μ_t the Lagrange multiplier on the time t budget constraint (IA.9).

Deposits Given the realizations of idiosyncratic shocks (ϵ, τ), the marginal values of (inter-period) deposits $\hat{d}_t$ in the default and no-default states, respectively, are given by:

$$\frac{\partial V^d_{t+1}}{\partial \hat{d}_t} = u^B_c(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t) + v(\mathcal{Z}_{t+1}) \left(\hat{w}^{i,d}_{t+1}\right)^{-\gamma} \frac{\partial \hat{w}^{i,d}_{t+1}}{\partial \hat{d}^i_t} = u^B_c(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t)$$
$$\frac{\partial V^{nd}_{t+1}}{\partial \hat{d}_t} = u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t) + v(\mathcal{Z}_{t+1}) \left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma} \frac{\partial \hat{w}^{i,nd}_{t+1}}{\partial \hat{d}^i_t} = u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t)$$

The FOC for (inter-period) deposits $\hat{d}^i_t$ is then given by:

$$\frac{\mu_t}{1+r^d_t} = \beta \mathrm{E}_t \left[F^-_\eta(\epsilon,\tau) u^B_c(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t) + \tilde{F}_\eta(\epsilon,\tau) u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t) \right]$$

Lucas Tree Shares Given the realizations of idiosyncratic shocks (ϵ,τ), the marginal values of Lucas tree shares $\hat{s}_t$ in the default and no-default states, respectively, are given by:

$$\frac{\partial V^d_{t+1}}{\partial \hat{s}_t} = u^B_c(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t)(Y_t + \epsilon) + v(\mathcal{Z}_{t+1}) \left(\hat{w}^{i,d}_{t+1}\right)^{-\gamma} (1-\lambda) p^s_{t+1}$$
$$\frac{\partial V^{nd}_{t+1}}{\partial \hat{s}_t} = u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t)(Y_t + \epsilon) + v(\mathcal{Z}_{t+1}) \left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma} p^s_{t+1}$$

The FOC for shares $\hat{s}^i_t$ is then given by:

$$\mu_t p^s_t = \beta \mathrm{E}_t \left[F^-_\eta(\epsilon,\tau) \left(u^B_c(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t)(Y_t + \epsilon) + v(\mathcal{Z}_{t+1}) \left(\hat{w}^{i,d}_{t+1}\right)^{-\gamma} (1-\lambda) p^s_{t+1} \right) \right.$$
$$\left. + \tilde{F}_\eta(\epsilon,\tau) \left(u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t)(Y_t + \epsilon) + v(\mathcal{Z}_{t+1}) \left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma} p^s_{t+1} \right) \right]$$

Houses Given the realizations of idiosyncratic shocks (ϵ,τ), the marginal values of houses $\hat{h}_t$ in the default and no-default states, respectively, are given by:

$$\frac{\partial V^d_{t+1}}{\partial \hat{h}_t} = u^B_h(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t)$$
$$\frac{\partial V^{nd}_{t+1}}{\partial \hat{h}_t} = u^B_h(\hat{c}^{nd}_{t+1}(\epsilon), \hat{h}_t) - u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t)\delta_h + v(\mathcal{Z}_{t+1})\left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma} p^h_{t+1}$$

The FOC for houses $\hat{h}^i_t$ is then given by:

$$\mu_t p^h_t = \Phi_h \frac{q^m_t \hat{m}^i_t}{(\hat{h}^i_t)^2} + \beta \mathrm{E}_t \Big[F^-_\eta(\epsilon,\tau) u^B_h(\hat{c}^d_{t+1}(\epsilon), \hat{h}_t) + \tilde{F}_\eta(\epsilon,\tau)\left(u^B_h(\hat{c}^{nd}_{t+1}(\epsilon), \hat{h}_t) - u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t)\delta_h + v(\mathcal{Z}_{t+1})\left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma} p^h_{t+1}\right)\Big]$$

Mortgages Given the realizations of idiosyncratic shocks (ϵ, τ), the marginal values of houses $\hat{m}_t$ in the default and no-default states, respectively, are given by:

$$\frac{\partial V^d_{t+1}}{\partial \hat{m}_t} = 0$$
$$\frac{\partial V^{nd}_{t+1}}{\partial \hat{m}_t} = u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t) x^i_t + v(\mathcal{Z}_{t+1})\left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma}(1-\delta_m) q^m_{t+1}$$

The FOC for shares $\hat{s}^i_t$ is then given by:

$$\mu_t q^m_t \left(1 - \Phi_m \frac{q^m_t}{p^m_t \hat{h}^i_t}\right) = \beta \mathrm{E}_t \left[\tilde{F}_\eta(\epsilon,\tau)\left(u^B_c(\hat{c}^{nd}_{t+1}(\epsilon,\tau), \hat{h}_t) x^i_t + v(\mathcal{Z}_{t+1})\left(\hat{w}^{i,nd}_{t+1}\right)^{-\gamma}(1-\delta_m) q^m_{t+1}\right)\right]$$

III.1.2 Market-Clearing Conditions and Aggregation

To calculate intermediary wealth and market clearing, we must integrate over the distribution of borrower shocks. First, note that identical choices by borrowers in per-wealth units mean that for any quantity g^i_t that is a function of borrower choices, we can express it is a product of the common per-wealth choice $\hat{g}_t$ and aggregate borrower wealth w^B_t:

$$\int_0^\ell g_t^i di = \hat{g}_t \int_0^\ell w_t^i di = \hat{g}_t w_t^B$$

Aggregate share of defaulting mortgages F_t^η is given by:

$$F_t^\eta = \int_0^\ell \mathbb{1}_d^i di = \sum_{\tau \in \{0,1\}} \sum_{\epsilon \in \mathcal{E}} \mathcal{P}_\epsilon(\epsilon_t^i = \epsilon) \mathcal{P}_\tau(\tau_t^i = \tau) F_\eta(\eta^*(\epsilon, \tau))$$

Aggregate per-unit mortgage payment x_t is given by:

$$x_t = \mathrm{E}_i[x_t^i | \eta^i \leq \eta^{*,i}(\epsilon_t^i, \mathbb{1}_\tau^i)]$$

For other quantities,

- Mortgages: $\int_\ell^1 m_t^I di = \int_0^\ell m_t^i di$ implies $M_t^I = \hat{m}_t W_t^B$
- Borrower Tree Shares: $\alpha = \hat{s}_t W_t^B$
- Houses: $\bar{H} = \hat{h}_t W_t^B$

Finally, the law of motion for aggregate borrower wealth is:

$$\begin{aligned} W_{t+1}^B &= \int_0^\ell w_{t+1}^i di \\ &= W_t^B \mathrm{E}_i \left[\tilde{F}_\eta((\epsilon_t^i, \mathbb{1}_\tau^i)) \hat{w}_{t+1}^{i,d}(\epsilon_t^i) + F_\eta((\epsilon_t^i, \mathbb{1}_\tau^i)) \hat{w}_{t+1}^{i,nd}(\epsilon_t^i, \mathbb{1}_\tau^i) \right] \end{aligned}$$

III.2 Banks

III.2.1 Problem

Banks are not subject to idiosyncratic shocks and are ex-ante identical. As a result, we can solve the problem for the representative *aggregate* bank. Denote aggregate quantities with capital letters. The bank's complete problem is given by:

$$V^I(W_t^I, \mathcal{Z}_t) = \max_{\text{Div}_t^I, D_t^I, M_t^I} \text{Div}_t^I + \text{E}_t\left[\mathcal{M}_{t+1}^S V^I(W_{t+1}^I, \mathcal{Z}_{t+1})\right] \tag{IA.16}$$

subject to

$$W_t^I = \frac{D_t^I}{1+r_t^d} + q_t^m M_t^I + \text{Div}_t^I \tag{IA.17}$$

$$W_{t+1}^I = (1-\nu)\mathcal{X}_{t+1} M_t^I + D_t^I \tag{IA.18}$$

$$D_t \leq \xi\left(\kappa \bar{q}^m + (1-\kappa) q_t^m\right) M_t^I \tag{IA.19}$$

where $\mathcal{X}_t$ is the aggregate mortgage payment per unit of mortgage debt given borrowers' choices:

$$\mathcal{X}_t = \tilde{F}_t^\eta(x_t + (1-\delta_m)q_t^m) + E_i\left[F_\eta(\epsilon_t^i, \mathbb{1}_t^i)\frac{h_{t-1}^i}{M_{t-1}^I} p_t((1-\zeta)-\delta_h)\right]$$

Since default decisions do not depend on wealth levels and since housing choices $h_t^i = \hat{h}_t w_t^i$ are proportional to borrower wealth for all borrowers,

$$E_i\left[F_\eta(\epsilon_t^i, \mathbb{1}_t^i) h_{t-1}^i\right] = E_i\left[F_\eta(\epsilon_t^i, \mathbb{1}_t^i)\right] E_i\left[h_{t-1}^i\right] = F_t^\eta H_{t-1}^B = F_t^\eta \alpha_h$$

. As a result, the mortgage payoff can be written:

$$\mathcal{X}_t = \tilde{F}_t^\eta(x_t + (1-\delta_m)q_t^m) + F_t^\eta \frac{\alpha_h}{M_t^I} p_t((1-\zeta)-\delta_h)$$

III.2.2 First Order Conditions

Mortgages The FOC for mortgages M_t^I is given by:

$$q_t^m = \mu_t^L \xi\left(\kappa \bar{q}^m + (1-\kappa) q_t^m\right) + E_t\left[\mathcal{M}_{t+1}^S \mathcal{X}_{t+1}\right]$$

where μ_t^L is the Lagrange multiplier on the leverage constraint (IA.19).

Deposits The FOC for deposits D_t^I is given by:

$$\frac{1}{1+r_t^d} = \mu_t^L + \mathrm{E}_t\left[\mathcal{M}_{t+1}^S\right]$$

Note that absent occasionally binding borrowing constraints $V_t^I = W_t^I$. But in their presence, this doesn't hold.

III.3 Savers

Likewise, we write and solve the representative saver's problem using aggregate quantities. For symmetry, we define saver wealth inclusive of their Lucas Tree shares and housing, even though neither is tradeable by them.

$$V^S(W_t^S, \mathcal{Z}_t) = \max_{C_t^S, E_t} u(C_t^S, H_t^S) + \beta E_t[V^S(W_{t+1}^S, \mathcal{Z}_{t+1})]$$

subject to

$$W_t^S = p_t^s S_t^S + p_t^h H_t^S + E_t p_t^e + C_t^S \tag{IA.20}$$

$$W_{t+1}^S = S_t^S(p_{t+1}^s + Y_t) + H_t^S(p_{t+1}^h - \delta_h) + E_t(p_{t+1}^e + \mathrm{Div}_{t+1}^I) + \mathcal{R}_{t+1}^S \tag{IA.21}$$

where $\mathcal{R}_{t+1}$ are (1) borrower costs of default, parametrized by λ, (2) banks' foreclosure costs, parametrized by ζ, and (3) banks' intermediation costs, parametrized by ν, rebated lump-sum:

$$\mathcal{R}_t^S = F_t^\eta\left(\lambda p_t^s \alpha + \zeta p_t^h \alpha_h\right) + \nu \mathcal{X}_t M_t^I$$

The first order condition for bank equity E_t is

$$p_t^e = \mathrm{E}_t\left[\beta\left(\frac{C_{t+1}^S}{C_t^S}\right)^{-\gamma}(\mathrm{Div}_{t+1} + p_{t+1}^e)\right]$$

which implies the saver's stochastic discount factor $\mathcal{M}^S_{t+1} = \beta \left(\frac{C^S_{t+1}}{C^S_t}\right)^{-\gamma}$.

Normalize the supply of bank shares E_t to 1. Then, iterating on both the bank's value function and the saver's FOC for bank equity, we get that $V^I_t = \text{Div}_t + p^e_t$.

III.4 Resource Constraint

In this section, we verify that aggregate consumption and housing investment are financed by the aggregate output of Lucas trees and by changes in the net deposit position of the economy.

Define aggregate borrower consumption in terms of conditional expectations of individual consumption:

$$\begin{aligned} C^B_t &= W^B_{t-1} \text{E}_i \left[F_\eta(\eta^{*,i}) \hat{c}^{i,nd}_t + \tilde{F}_\eta(\eta^{*,i}) \hat{c}^{i,d}_t \right] \\ &= W^B_t \left(F^\eta_t \text{E}_i \left[\hat{c}^{i,d}_t | \eta^i \leq \eta^{*,i} \right] + \tilde{F}^\eta_t \text{E}_i \left[\hat{c}^{i,nd}_t | \eta^i > \eta^{*,i} \right] \right) \end{aligned}$$

From the consumption stage budget constraints:

$$\begin{aligned} \text{E}_i \left[\hat{c}^{i,d}_t | \eta^i \leq \eta^{*,i} \right] &= \hat{s}_{t-1} \text{E}_i \left[Y_t + \epsilon^i_t | \eta^i \leq \eta^{*,i} \right] + \hat{d}_{t-1} \\ \text{E}_i \left[\hat{c}^{i,nd}_t | \eta^i > \eta^{*,i} \right] &= \hat{s}_{t-1} \text{E}_i \left[Y_t + \epsilon^i_t | \eta^i > \eta^{*,i} \right] + \hat{d}_{t-1} - \hat{m}_{t-1} x_t - \delta_h \hat{h}_{t-1} - \text{E}_i \left[\hat{a}^i_t | \eta^i > \eta^{*,i} \right] \end{aligned}$$

From the no-default branch wealth evolution equation, we get that intra-period savings $\hat{a}^i_t = \hat{w}^{i,nd}_t - p^h_t \hat{h}_{t-1} - p^s_t \hat{s}_{t-1} + (1-\delta_m) q^m_t \hat{m}_{t-1}$. Furthermore, observe that

$$\tilde{F}^\eta_t \text{E}_i \left[Y_t + \epsilon^i_t | \eta^i > \eta^{*,i} \right] + F^\eta_t \text{E}_i \left[Y_t + \epsilon^i_t | \eta^i \leq \eta^{*,i} \right] = Y_t + \text{E}_i[\epsilon^i_t] = Y_t$$

Define aggregate borrower deposits $D^B_t = W^B_t \hat{d}_t$. Use market-clearing in Lucas trees and housing to write $W^B_t \hat{s}_t = \alpha$ and $W^B_t \hat{h}_t = \alpha_h$. Use market-clearing in mortgages to write $W^B_t \hat{m}_t = M^I_t$. Assembling,

$$\begin{aligned} C^B = \alpha Y_t + D^B_{t-1} \\ + \tilde{F}^\eta_t \left[\alpha_h (p_h - \delta_h) + \alpha p^s_t - M^I_{t-1} \left(x_t + (1-\delta_m) q^m_t \right) - W^B_{t-1} \text{E}_\tau \left[\hat{w}^{i,nd}_t | \eta > \eta^{*,i} \right] \right] \end{aligned}$$

Recall that $W_t^B = W_{t-1}^B \mathrm{E}_i\left[\hat{w}_t^i\right]$. We can break up the expectation as follows:

$$\mathrm{E}_i\left[\hat{w}_t^i\right] = \tilde{F}_t^\eta \mathrm{E}_i\left[\hat{w}_t^{i,nd} | \eta > \eta^{*,i}\right] + F_t^\eta \mathrm{E}_i\left[\hat{w}_t^{i,d} | \eta \leq \eta^{*,i}\right]$$

Solving for the aggregate wealth of non-defaulters $\tilde{F}_t^\eta W_{t-1}^B \mathrm{E}_i\left[\hat{w}_t^{i,nd}| >\leq \eta^{*,i}\right]$,

$$\tilde{F}_t^\eta W_{t-1}^B \mathrm{E}_i\left[\hat{w}_t^{i,nd} | \eta > \eta^{*,i}\right] = W_t^B - W_{t-1}^B F_t^\eta \mathrm{E}_i\left[\hat{w}_t^{i,d} | \eta \leq \eta^{*,i}\right]$$

Use the default-branch wealth evolution equation and market clearing in Lucas trees to substitute

$$W_{t-1}^B \mathrm{E}_i\left[\hat{w}_t^{i,d} | \eta \leq \eta^{*,i}\right] = (1-\lambda) p_t^s \alpha$$

Multiply the trading stage budget constraint by W_t^B and plug in market-clearing conditions to get

$$W_t^B = \frac{D_t^B}{1+r_t^d} - q_t^m M_t^I + p_t^h \alpha_h + p_t^s \alpha$$

Combining,

$$\tilde{F}_t^\eta W_{t-1}^B \mathrm{E}_i\left[\hat{w}_t^{i,nd} | \eta > \eta^{*,i}\right] = \frac{D_t^B}{1+r_t^d} + q_t^m M_t^I + p_t^h \alpha_h + p_t^s \alpha - F_t^\eta (1-\lambda) p_t^s \alpha$$

Plugging back into the expression for C^B,

$$\begin{aligned}
C^B &= \alpha Y_t + D_{t-1}^B - \frac{D_t^B}{1+r_t^d} + q_t^m M_t^I - p_t^h \alpha_h - p_t^s \alpha + F_t^\eta (1-\lambda) p_t^s \alpha \\
&\quad + \tilde{F}_t^\eta \left[\alpha_h (p_h - \delta_h) + \alpha p_t^s - M_{t-1}^I \left(x_t + (1-\delta_m) q_t^m\right)\right] \\
&= \alpha Y_t + D_{t-1}^B - \frac{D_t^B}{1+r_t^d} + q_t^m M_t^I - F_t^\eta (p_h \alpha_h + \lambda p_t^s \alpha) \\
&\quad - \tilde{F}_t^\eta \left[\delta_h \alpha_h + M_{t-1}^I \left(x_t + (1-\delta) q_t^m\right)\right]
\end{aligned}$$

This expression admits an economic interpretation. Borrowers earn income from their Lucas trees αY_t and deposits D_{t-1}^B. Those repaying their mortgages – a fraction $\tilde{F}_t^\eta$ – expend resources

on housing maintenance $\delta_h \alpha_h$ and mortgage payments $M^I_{t-1}\left(\mathrm{E}_\tau\left[x^i_t | \eta > \eta^{*,i}\right] + (1-\delta_m) q^m_t\right)$. Those who default – a fraction $\tilde{F}^\eta_t$ – lose the value of their houses $p_h \alpha_h$ and a fraction λ of the value of their Lucas trees $p^s_t \alpha$. In the trading stage, they take out new mortgages $q^m_t M^I_t$ and make new deposits $\frac{D^B_t}{1+r^d_t}$.

Next, consider saver consumption. From the budget constraint and wealth evolution equation of savers,

$$C^S_t = S^S_{t-1}(p^s_t + Y_t) + H^S_{t-1}(p^h_t - \delta_h) + E_{t-1}(p^e_t + \mathrm{Div}^I_t) + \mathcal{R}^S_t - p^s_t S^S_t - p^h_t H^S_t - E_t p^e_t$$

Plug in market clearing conditions $E_t = 1$, $S^S_t = 1 - \alpha$, $H^S_t = 1 - \alpha_h$, to get

$$C^S_t = (1-\alpha) Y_t - (1-\alpha_h)\delta_h + \mathrm{Div}^I_t + \mathcal{R}^S_t$$

From the budget constraint for banks,

$$\mathrm{Div}^I_t = (1-\nu)\mathcal{X}_t M^I_{t-1} + D^I_{t-1} - \frac{D^I_t}{1+r^d_t} - q^m_t M^I_t$$

Plugging for Div^I_t and $\mathcal{R}_t$ and collecting terms,

$$C^S_t = (1-\alpha) Y_t - (1-\alpha_h)\delta_h + \mathcal{X}_t M^I_{t-1} + D^I_{t-1} - \frac{D^I_t}{1+r^f_t} - q^m_t M^I_t + F^\eta_t \left(\lambda p^s_t \alpha + \zeta p^h_t \alpha_h\right)$$

Next, subtitute the definition of $\mathcal{X}_t$:

$$\begin{aligned} C^S_t = (1-\alpha) Y_t + D^I_{t-1} - \frac{D^I_t}{1+r^d_t} - q^m_t M^I_t + F^\eta_t \lambda p^s_t \alpha \\ - (1-\alpha_h)\delta_h + \tilde{F}^\eta_t (x_t + (1-\delta_m) q^m_t) M^I_{t-1} + F^\eta_t p_t \alpha_h (1-\delta_h) \end{aligned}$$

Define aggregate deposits as $D_t = D^B_t + D^I_t$. Then, adding C^B_t and C^S_t and collecting terms, we get the resource constraint:

$$\underbrace{C^B_t + C^S_t}_{\text{Aggregate Consumption}} + \underbrace{\delta}_{\text{Housing Investment}} = \underbrace{Y_t}_{\text{Output}} + \underbrace{D_{t-1} - \frac{D_t}{1+r^d_t}}_{\Delta\text{Net Foreign Assets}}$$

III.5 Risk Sharing Measures

III.5.1 Complete Markets Benchmark

An unconstrained social planner chooses allocations for each agent that are proportional to the weight that the planner puts on the utility of that agent.

Define the social welfare problem:

$$\max_{\{\{(c_t^i,h_{t-1}^i)\}_{i=0}^1\}_{t=0}^\infty} E_0\left[\int_{i=0}^1 \lambda_i \sum_{t=1}^\infty \beta^t \frac{\left((c_t^i)^{1-\theta}(h_t^i)^\theta\right)^{1-\gamma}-1}{1-\gamma} di\right]$$

such that the resource constraints for each good, in each period and each state of the world are satisfied:

$$\int_0^1 c_t^i = Y_t \quad \forall t, s^t$$
$$\int_0^1 h_{t-1}^i = \bar{H} \quad \forall t, s^t$$

where every variable x_t is implicitly a function of the random variable s^t, denoting the history of the economy up to time t.

Assign μ_t and ν_t as Lagrange multipliers to each of the constraints at time t, history s^t, respectively. Use $\pi(s^t)$ to denote the density of the unconditional history distribution at a given s^t. The first order condition for consumption for agent i at time t are:

$$\lambda_i \beta^t \pi(s^t)\left((c_t^i)^{1-\theta}(h_{t-1}^i)^\theta\right)^{-\gamma}(1-\theta)(c_t^i)^{-\theta}(h_{t-1}^i)^\theta = \mu_t$$

The first order condition for housing for agent i at time $t-1$ are:

$$\lambda_i \beta^t \pi(s^t)\left((c_t^i)^{1-\theta}(h_{t-1}^i)^\theta\right)^{-\gamma}\theta(c_t^i)^{1-\theta}(h_{t-1}^i)^{\theta-1} = \nu_{t-1}$$

Dividing them by each other, we get the optimal MRS between consumption and housing for

a given state of the world, which is the same for all households:

$$\frac{c_t^i}{h_{t-1}^i} = \frac{1-\theta}{\theta}\frac{\mu_t}{\nu_{t-1}}$$

Substitute for housing in the consumption FOC:

$$h_{t-1}^i = \frac{\theta}{1-\theta}\frac{\mu_t}{\nu_{t-1}}c_t^i$$

$$\lambda_i \beta^t \pi^(s^t) \left((c_t^i) \left[\frac{\theta}{1-\theta}\frac{\mu_t}{\nu_{t-1}} \right]^\theta \right)^{-\gamma} (1-\theta)^{1-\theta}\theta^\theta = \mu_t^{1-\theta}\nu_{t-1}^\theta$$

Dividing the consumption FOCs for agents i and j at time t by each other, we get:

$$\frac{\lambda_i}{\lambda_j}\left(\frac{c_t^i}{c_t^j}\right)^{-\gamma} = 1$$

which means that the ratio of consumptions is constant over time and states of the world at:

$$\frac{c_t^i}{c_t^j} = \left(\frac{\lambda_i}{\lambda_j}\right)^{-1/\gamma}$$

Rewrite as:

$$c_t^i = \left(\frac{\lambda_i}{\lambda_j}\right)^{-1/\gamma} c_t^j$$

Integrate both sides with respect to i to get aggregate time t consumption:

$$C_t \equiv \int_0^1 c_t^i di = \lambda_j^{\frac{1}{\gamma}} c_t^j \int_0^1 \lambda_i^{-\frac{1}{\gamma}} di$$

Which implies that a given household's consumption c_t^j is a constant fraction of aggregate consumption C_t:

$$c_t^j = \frac{\lambda_j^{-\frac{1}{\gamma}}}{\int_0^1 \lambda_i^{-\frac{1}{\gamma}} di} C_t$$

The same argument applies to housing, i.e. it can be shown that the planner's optimal allocation of housing to agent j

$$h_{t-1}^j = \frac{\lambda_j^{-\frac{1}{\gamma}}}{\int_0^1 \lambda_i^{-\frac{1}{\gamma}} di} \bar{H}$$

is constant over time.

Since complete markets implement the planner allocation, this means that in a frictionless economy the volatility of the ratio of consumptions is zero. This likewise implies that each agent's consumption grows at the same rate. Formally, take the log:

$$\log c_t^i - \log c_t^j = -\frac{1}{\lambda} (\log \lambda_i - \log \lambda_j)$$

Let $\Delta \log c_t^i$ is defined as $\log c_t^i - \log c_{t-1}^i$. Then the log of the ratio of consumption growth rates is:

$$\begin{aligned} \Delta \log c_t^i - \Delta \log c_t^j &\equiv (\log c_t^i - \log c_{t-1}^i) - (\log c_t^j - \log c_{t-1}^j) \\ &= (\log c_t^i - \log c_t^j) - (\log c_{t-1}^i - \log c_{t-1}^j) \end{aligned}$$

Then in complete markets, it must be true that

$$\mathcal{R}_{ij} = \text{Var}_0 \left[\Delta \log c_t^i - \Delta \log c_t^j \right] = 0$$

We refer to $\mathcal{R}_{ij}$ as a measure of "internal" risk sharing. In an incomplete markets economy, $\mathcal{R}_{ij} \geq 0$ and $\mathcal{R}_{ij}$ serves as a measure of risk sharing between households, with lower values denoting better risk sharing.

III.5.2 Complete Markets Open Economy

The open economy version of the complete markets model is similar to the closed economy version, except that the planner can now trade a risk-free bond with the rest of the world. The

planner's problem is:

$$\max_{\{\{(c_t^i,h_{t-1}^i)\}_{i=0}^1,b_t\}_{t=0}^\infty} \mathrm{E}_0\left[\int_{i=0}^1 \lambda_i \sum_{t=1}^\infty \beta^t \frac{\left((c_t^i)^{1-\theta}(h_{t-1}^i)^\theta\right)^{1-\gamma}-1}{1-\gamma} di\right]$$

such that

$$\int_0^1 c_t^i + \frac{b_t}{1+r_t^d} = Y_t + b_{t-1} \quad \forall t, s^t$$
$$\int_0^1 h_{t-1}^i = \bar{H} \quad \forall t, s^t$$

The derivations above still hold. But now there is an additional choice variable of the planner. Bonds $b_t(s^t)$ show up in the resource constraint for t, s^t and in the resource constraints for all t, s^{t+1} that are reachable from s^t. Denote this set of possible states as $s_{t+1}|s^t$ and the . Then the additional first order condition for the bond is:

$$\frac{\mu_t}{1+r_t^d}\pi(s^t) = \int_{s_{t+1}|s^t} \pi(s^{t+1})\mu_{t+1}$$

Rearranging,

$$1 = (1+r_t^d)\int_{s_{t+1}|s^t} \pi(s_{t+1}|s^t)\frac{\mu_{t+1}}{\mu_t} = (1+r_t^d)\mathrm{E}_t\left[\frac{\mu_{t+1}}{\mu_t}\right]$$

where $\pi(s_{t+1}|s^t)$ denotes the conditional density of s_{t+1} given s^t, and where the second equality stems from the definition of a conditional expectation with $E_t[\cdot]$ denoting $\mathrm{E}[\cdot|s^t]$.

Plug in the FOC for consumption for the multipliers:

$$1 = (1+r_t^d)E_t\left[\left(\frac{c_{t+1}^i}{c_t^i}\right)^{-\gamma(1-\theta)-\theta}\left(\frac{h_t^i}{h_{t-1}^i}\right)^{\theta(1-\gamma)}\right]$$

Recall that for any agent, the optimal housing allocation is constant and the growth rate of consumption is equal to the aggregate consumption growth rate. Then the above equation

simplifies to:

$$1 = (1 + r_t^d) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma(1-\theta)-\theta} \right]$$

The problem admits aggregation, i.e. the planner's optimal choice of bonds is independent of the resource allocation problem.

Take logs

$$0 = \log(1 + r_t^d) + \log E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma(1-\theta)-\theta} \right]$$

and define

$$\mathcal{R}_{agg} = \text{Var}_0 \left[\log(1 + r_t^d) + \log E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\gamma(1-\theta)-\theta} \right] \right] \geq 0$$

as the "external" risk sharing measure. In complete markets, $\mathcal{R}_{agg} = 0$, while in incomplete markets larger values of $\mathcal{R}_{agg}$ indicate worse risk sharing between households in the economy and the rest of the world.

III.5.3 Internal Risk Sharing in our Model

In our model, there are two kinds of households: borrowers with consumption denoted by c_t^i and savers, with consumption denoted by c_t^S and identical across all savers. Let $C_t^B = \int_0^\ell c_t^i$ denote aggregate borrower consumption and $C_t^S = (1 - \ell) c_t^s$ denote aggregate saver consumption.

Borrowers are unconditionally identical, meaning internal risk sharing is summarized fully by two risk-sharing measures $\mathcal{R}_{iB}$ and $\mathcal{R}_{BS}$, where $\mathcal{R}_{iB}$ is the variance of the ratio of consumption growth rates between borrower i and the aggregate borrower, and $\mathcal{R}_{BS}$ is the variance of the ratio of aggregate consumption growth rates between borrowers and savers.

Recall, we can write borrower i's consumption at time t, c_t^i, as the product of borrower consumption per unit of wealth $\hat{c}_t^i$ and borrower wealth at time $t-1$, w_{t-1}^i. Consumption per unit of wealth only depends on the identity of the borrower i through the realizations of iid shocks to $\mathcal{S}_t^i = (\epsilon_t^i, \tau_t^i, \eta_t^i)$.

Write the log growth rate of borrower i's consumption as:

$$\Delta \log c_t^i = \log \hat{c}_t(\mathcal{S}_t^i) - \log \hat{c}_{t-1}(\mathcal{S}_{t-1}^i) + \log \hat{w}_{t-1}(\mathcal{S}_{t-1}^i)$$

where $\hat{w}_{t-1}(\mathcal{S}_{t-1}^i)$ represents the growth rate in wealth $\Delta \log w_{t-1}^i$, which also depends on the identity of the borrower i only through the realiations of iid shocks.

The definition of $\mathcal{R}_{iB}$ is $\text{Var}_0[\Delta \log c_t^i - \Delta \log C_t^B]$. Using the law of total variance,

$$\mathcal{R}_{iB} = \text{Var}_0 \left[\text{E}_t \left[\Delta \log c_t^i - \Delta \log C_t^B \right] \right] + \text{E}_0 \left[\text{Var}_t \left[\Delta \log c_t^i - \Delta \log C_t^B \right] \right]$$

where the conditional moments Var_t and E_t are taken cross-sectionally with respect to realizations of idiosyncratic shocks. Simplifying,

$$\mathcal{R}_{iB} = \text{Var}_0 \left[\text{E}_t \left[\Delta \log c_t^i \right] - \Delta \log C_t^B \right] + \text{E}_0 \left[\text{Var}_t \left[\Delta \log c_t^i \right] \right]$$

Finally, $\mathcal{R}_{BS}$ is defined as $\text{Var}_0[\Delta \log C_t^B - \Delta \log C_t^S]$.

IV Calibration Details

IV.1 Mortgage Payments and Duration

Recall, a fixed rate mortgage issued at time 0 pays $\iota_f + \delta \bar{q}^m$ in the first period, $(1-\delta)(\iota_f + \delta \bar{q}^m)$ in the second period, and so on.

Define a mortgage yield to maturity ytm as the discount rate which discounts mortgage cash flows to the mortgage price.

It is easy to see that

$$q^m(ytm) = \sum_{t=1}^{\infty} (1-\delta)^{t-1} \frac{\iota_f + \delta \bar{q}^m}{(1+ytm)^t} = \frac{\iota_f + \delta \bar{q}^m}{ytm + \delta}$$

and that therefore the mortgage is priced to par when $ytm = \iota_f$. We calibrate the model by setting ι_f to the steady state equilibrium ytm, thus ensuring that $\bar{q}^m = 1$.

Define duration of the fixed rate mortgage as the negative semi-elasticity of the mortgage price with respect to the yield to maturity. We have:

$$-\left.\frac{\partial q^m/q^m}{\partial ytm}\right|_{\iota_f} = \frac{1}{\iota_f + \delta}$$

An adjustable rate mortgage makes fixed rate payments $\iota_\tau + \delta\bar{q}^m$, $(1-\delta)(\iota_\tau + \delta\bar{q}^m)$, etc. until (stochastic) reset time τ and pays adjustable payments $(1-\delta)^{\tau-1}\left(r^f_\tau + \iota_a + \delta\bar{q}^m\right)$, $(1-\delta)^{\tau}\left(r^f_{\tau+1} + \iota_a + \delta\bar{q}^m\right)$, etc. after.

In the baseline calibration, we set $\iota_\tau = \iota_f$ and $\iota_a = \iota_f - \bar{r}$. Then the per-remaining-balance portion of the ARM payment can be written as $\iota_f + (r^f_t - \bar{r})$.

Let $\mathbb{1}^{\text{fixed}}_{1,\ldots,t}$ be a random indicator variable equal to 1 if the mortgage is still in the fixed/teaser stage at time t. So the expected ARM cash flow at time t is then given by:

$$\mathrm{E}_0\left[(1-\delta)^{t-1}\left[\mathbb{1}^{\text{fixed}}_{1,\ldots,t}(\iota_f + \delta\bar{q}^m) + \left(1 - \mathbb{1}^{\text{fixed}}_{1,\ldots,t}\right)\left(\iota_f + r^f_t - \bar{r} + \delta\bar{q}^m\right)\right]\right]$$

Collecting terms,

$$(1-\delta)^{t-1}\left((\iota_f + \delta\bar{q}^m) + \mathrm{E}_0\left[\left(1 - \mathbb{1}^{\text{fixed}}_{1,\ldots,t}\right)\left(r^f_t - \bar{r}\right)\right]\right)$$

Let $\mathbb{1}^{\text{adj}}_s$ be an indicator equal to 1 if a mortgage that resets from fixed to floating at time s. Then

$$\mathbb{1}^{\text{fixed}}_{1,\ldots,t} = \prod_{s=1}^{t}\left(1 - \mathbb{1}^{\text{adj}}_s\right)$$

The realization of morgage resets $\mathbb{1}^{\text{adj}}_s$ are independent of each other, and also independent from the realizaton of future indexation rates r^f_t. Every period, the probability that a mortgage still in the teaser stage resets to the adjustable stage, i.e. $\mathrm{E}_0[\mathbb{1}^{\text{adj}}_s]$ is π_τ. So the expected ARM cash flow at time t can be written as:

$$(1-\delta)^{t-1}\left((\iota_f + \delta\bar{q}^m) + \left(1 - (1-\pi_\tau)^t\right)\left(\mathrm{E}_0[r^f_t] - \bar{r}\right)\right)$$

Define yield to maturity ytm for an adjustable rate mortgage as the (risk-neutral) discount rate that discounts expected ARM cash flows to the mortgage price. We have:

$$\begin{aligned} q^m(ytm) &= \sum_{t=1}^{\infty}(1-\delta)^{t-1}\frac{\iota_f+\delta\bar{q}^m}{(1+ytm)^t} + \sum_{t=1}^{\infty}(1-\delta)^{t-1}\left(1-(1-\pi_\tau)^t\right)\frac{\mathrm{E}_0[r_t^f]-\bar{r}}{(1+ytm)^t} \\ &= \frac{\iota_f+\delta\bar{q}^m}{ytm+\delta} + \left(\mathrm{E}_0[r_t^f]-\bar{r}\right)\left(\frac{1}{ytm+\delta} - \frac{1-\pi_\tau}{1+ytm-(1-\delta)(1-\pi_\tau)}\right) \end{aligned}$$

The first term is the price of the FRM. The second term is equal to zero because $\mathrm{E}_0[r_t^f]=\bar{r}$ in equilibrium. In steady state, risk neutral and physical measures coincide because there are no risk premia, so $ytm=\iota_f$ prices the mortgage to par ($\bar{q}^m=1$) just as before.

To define the duration of the adjustable mortgage, write the price of the mortgage as a function of ytm and future rate r:

$$q^m(ytm,r) = \frac{\iota_f+\delta}{ytm+\delta} + (r-\bar{r})\left(\frac{1}{ytm+\delta} - \frac{1-\pi_\tau}{ytm-(1-\delta)(1-\pi_\tau)}\right)$$

Then, consider the change in mortgage price due to a *parallel* shift in all interest rates, i.e. when $\frac{\partial r}{\partial ytm}=1$. Formally, duration is given by $-\frac{\partial q^m(ytm,r(ytm))/q^m(ytm,r(ytm))}{\partial ytm}$ evaluated at $ytm=\iota_f$ and r such that $q^m(\iota_f,r)=0$, which means $r=\bar{r}$. Taking derivatives,

$$\begin{aligned} \frac{\partial q^m(ytm,r(ytm))}{\partial ytm} = &-\frac{1}{ytm+\delta} + (r-\bar{r})\frac{\partial}{\partial ytm}\left(\frac{1}{ytm+\delta} - \frac{1-\pi_\tau}{1+ytm-(1-\delta)(1-\pi_\tau)}\right) \\ &+ \frac{\partial r}{\partial ytm}\left(\frac{1}{ytm+\delta} - \frac{1-\pi_\tau}{1+ytm-(1-\delta)(1-\pi_\tau)}\right) \end{aligned}$$

Imposing $r=\bar{r}$ leads the second term to drop out. Imposing $ytm=\iota_f$ and $\frac{\partial r}{\partial ytm}=1$, we get:

$$-\frac{\partial q^m(ytm,r(ytm))}{\partial ytm}\frac{1}{q^m(ytm,r(ytm))}\bigg|_{ytm=\iota_f,r=\bar{r}} = \frac{1-\pi_\tau}{1+\iota_f-(1-\delta)(1-\pi_\tau)}$$

which is the steady-state contractual duration of the ARM with a reset probability of π_τ.

Note that at $\pi_\tau=0$, the expression simplifies to $1/(\iota_f+\delta)$, which is the FRM duration. At $\pi_\tau=1$, i.e. a reset occuring with probability at the time of the first cash flow (one year after issuance), the duration is 0.

V Two-Period Model

In this section, we illustrate the main differences in the allocation of risk between fixed-rate mortgage (FRM) and adjustable-rate mortgage (ARM) regimes using a two-period model with time indexed by $t = 0, 1$.

V.1 Borrowers

A continuum of borrowers indexed by i is endowed with equal initial wealth w_0 and have preferences over $t = 1$ consumption, residual $t = 1$ wealth, and housing.

Borrowers allocate their initial wealth to deposits d_i, mortgages m_i, houses h_i, and Lucas trees s_i to maximize $E[u(c_{1,i}, w_{1,i}, h_i)]$, the expectation of their $t = 1$ utility kernel given by:

$$U(c, w, h) = (1 - \beta) \log c + \beta \log w + \beta\theta \log h \tag{IA.22}$$

subject to the $t = 0$ budget constraint:

$$w_0 = p_0^h h_i + p_0^s s_i + q d_i - q_0^m m_i$$

Because ex-ante borrowers are identical in terms of their wealth and distributions of $t = 1$ shocks, they will make identical portfolio decisions, and so we will drop i subscripts on h, s, d, and m.

$t = 1$ consists of two subperiods. In the first subperiod ("morning"), borrowers are exposed to an *idiosyncratic* income shock $\epsilon_i \in \{\epsilon_L, \epsilon_H\}$ to the yield of their Lucas tree y_i, such that $y_i = 1 + \epsilon_i$.

Borrowers use their liquid assets – income and deposits – to make mortgage payments and consume. Any excess liquid assets can be carried over into the second subperiod ("afternoon") and constitute remaining borrower wealth along with the value of their housing, trees, and

mortgages.

Crucially, borrowers cannot trade these illiquid assets until the afternoon, meaning they cannot obtain additional liquidity in the morning to finance their mortgage payments and consumption. Their only way to increase liquid assets at $t = 1$ is to default on the mortgage payment. To characterize the borrowers' default decision, consider the two branches of their decision tree.

If borrowers do not default, they solve a simple consumption-savings problem:

$$\max_{a_i \geq 0} (1 - \beta) \log(\ell_i - a_i) + \beta \log(\omega_i + a_i)$$

where

$$\ell_i = y_i s + d - xm$$

is their stock of liquid assets after making the mortgage payment xm_i, and

$$\omega = p_1^s s + p_1^h h - q_1^m (1 - \delta) m$$

is their illiquid wealth, consisting of Lucas trees, houses, and remaining fraction $1 - \delta$ of their mortgage balance, all at $t = 1$ prices.

The borrowers per-unit mortgage payment x is given by $\iota + \delta$, where ι represents the interest payment and δ represents the principal payment. In an FRM regime, ι is fixed, while in an ARM regime, $\iota = r + \iota_a$ is a fixed spread over the prevailing short rate r. Therefore, shocks to r constitute the second, *aggregate*, source of risk in the economy.

The optimal unconstrained choice of intraperiod savings equates the marginal utility of consumption $(1 - \beta)/c_i$ with the marginal utility of wealth β/w_i, yielding the following expression for intraperiod savings:

$$a_i^* = \max\{0, \beta\ell_i - (1-\beta)\omega\}$$

is increasing in liquid assets and decreasing in illiquid wealth, such that when liquid assets are low – either because of a bad income realization or because ARM mortgage payments increase due to a rate hike – the borrower is constrained. She would like to borrow from her illiquid wealth to finance additional consumption at the expense of future wealth, but she cannot do so directly. The only way to accomplish this is to default, gaining liquid assets xm at the expense of losing housing wealth p_1^h and a fraction of non-housing wealth $\lambda p_1^s s$, as well as extinguishing the remaining principal $(1-\delta)q_i^m m$. A positive value of λ represents pecuniary costs of default in addition to foreclosure, e.g. partial recourse, costs of being locked out of the financial market for some amount of time, etc.

Additionally, defaulting comes with a non-pecuniary stochastic default penalty $\eta_i \sim F_\eta$, such that a household defaults iff

$$u(c_i^{nd}, w_i^{nd}, h) < u(c_i^d w_i^d, h) + \eta_i$$

where the no-default consumption and wealth are given by

$$\begin{aligned} c_i^{nd} &= y_i s + d - xm - a_i^* \\ w_i^{nd} &= a_i^* + p_1^s s + p_1^h h - q_1^m(1-\delta)m \end{aligned}$$

and the default consumption and wealth are given by

$$\begin{aligned} c_i^d &= y_i s + d \\ w_i^d &= (1-\lambda)p_1^s s \end{aligned}$$

Borrowers optimally default if the realization of η_i is above a threshold value η_i^*, which depends on both idiosyncratic and aggregate shocks and is given by

$$\eta_i^* = (1-\beta)\log\frac{c_i^{nd}}{c_i^d} + \beta\log\frac{w_i^{nd}}{w_i^d}$$

implying a survival probability $F_i = F(\eta_i^*)$.

For a borrower with a large stock of liquid assets s and d, the ratio of no-default to default consumption is close to 1, and so her default decision will be largely strategic, i.e. based on the change in wealth due to default. When λ is low, such a borrower will "send in the keys" to a property underwater.

But when the stock of liquid assets is smaller, the driver of default will be the liquidity borrowers can unlock in high marginal utility states by foregoing the mortgage payment xm, even if this default leads to lower future wealth. Empirical evidence, e.g., Ganong and Noel (2022), suggests that this is the primary reason borrowers default. In our model, a rise in ARM mortgage payments due to interest rate hikes together with interaction effects with drivers of strategic default can lead to significant amplification.

We are now ready to characterize the borrowers' $t = 0$ problem. Denoting the Lagrange multiplier on (shadow value of relaxing) the budget constraint by μ, we can write the Euler equation for deposits as:

$$q\mu = \mathrm{E}\left[(1-F_i)\frac{1-\beta}{c_i^{nd}} + F_i\frac{1-\beta}{c_i^d}\right]$$

The marginal cost of deposits is given by $q\mu$, while the marginal benefit is given by the expected marginal utility of consumption, with the expectation taken over aggregate interest rate shocks, idiosyncratic income shocks, and idiosyncratic default penalty shocks, which enter the problem exclusively through the default probabilities F_i that they imply.

The Euler equation for houses equates the marginal cost of housing $p_0^h\mu$ against the marginal benefit, which consists of the user cost $\beta\theta/h$ and the marginal contribution of housing to wealth, which borrowers receive only if they do not default:

$$p_0^h \mu = \mathrm{E}\left[\frac{\beta\theta}{h} + \beta(1-F_i)\frac{p_1^h}{w_i^{nd}}\right]$$

By obtaining a mortgage, borrowers relax their budget constraint by q_0^m (worth $q_0^m\mu$ to them) at $t=0$. The marginal cost at $t=1$ consists of the two terms. First, mortgage payments enter the marginal utility of consumption. Second, the remaining mortgage balance enters the marginal utility of wealth. Both terms apply only if the borrower does not default:

$$q_0^m \mu = \mathrm{E}\left[(1-F_i)\left(\frac{1-\beta}{c_i^{nd}}x + \frac{\beta}{w_i^{nd}}(1-\delta)q_i^m\right)\right]$$

Finally, Lucas trees have a utility cost of $p_0^s\mu$ and yield marginal benefits of all four types – consumption and wealth in both no-default and default branches:

$$p_0^s \mu = \mathrm{E}\left[(1-F_i)\left(\frac{1-\beta}{c_i^{nd}}y_i + \frac{\beta}{w_i^{nd}}p_1^s\right) + F_i\left(\frac{1-\beta}{c_i^{d}}y_i + \frac{\beta}{w_i^{d}}(1-\lambda)p_1^s\right)\right]$$

To close the borrower side of the model, we assume that houses and Lucas trees are in fixed unit supply $H = \int h di = S = \int s di = 1$.

V.2 Lenders

Lenders are perfectly competitive and risk-neutral financial intermediaries (an assumption we will relax in the fully dynamic model). They raise funds in the form of deposits D^I at price q from borrower households as well as in wholesale markets. They use these funds to make mortgage loans M^I at price q^m to households.

Each performing mortgage yields a $t=1$ cash flow of x to the lender, as well as having a remaining ex-payment value of $(1-\delta)q_1^m$. When borrowers default, lenders foreclose on the house, yielding a per-house value $p_1^h(1-\zeta)$ net of foreclosure costs $\zeta \geq 0$. The remaining mortgage balance is extinguished.

Let $F_I = \int F_i di$ denote the aggregate default rate (taking an expectation over idiosyncratic income realizations of borrowers). Then the total $t = 1$ of the lenders mortgage portfolio is:

$$\mathcal{X} M^I = (1 - \nu) \left[(1 - F_I)(x + (1 - \delta) q_1^m) M^I + F_I p_1^h H (1 - \zeta) \right]$$

where $\nu \geq 0$ denotes the lenders' operating costs as a fraction of the mortgage portfolio. The lender's $t = 0$ problem is to maximize their profit:

$$\max_{D^I, M^I} \mathrm{E}[(1 - \nu)\mathcal{X} M^I - D^I]$$

subject to the budget constraint $q D^I = q_0^m M^I$.

Competition between lenders yields a zero-profit condition:

$$q(1 - \nu)\mathrm{E}[\mathcal{X}] = q_0^m$$

V.3 Equilibrium

To close the model, we assume that outside investors supply short-term funding elastically at exogenous price q. We also assume exogenous $t = 1$ asset prices p_1^h, p_1^s and q_1^m. This allows us to directly vary the sensitivity of these prices to interest rate shocks r and thus to decompose the effects of these rate shocks onto default rates and lender profits into cash flow effects on mortgage payments x and valuation effects through asset prices.

Given these prices and initial endowment w_0, the competitive equilibrium is defined as a set of time 0 portfolio choices s, h, d, m, D^I, M^I, time 0 prices q_0^m, p_0^h, p_0^s, time 1 consumption and intraperiod savings decisions $\{c_i^{nd}, a_i, c_i^d\}$, and time 1 default decisions $\mathbb{1}_i$ for each realization of idiosyncratic and aggregate shocks such that households solve their optimization problems as characterized by the optimality conditions above, lenders satisfy the zero-profit condition and budget constraint, and markets clear: $h = 1$, $s = 1$, $m = M^I$.

To discipline our characterization, we proceed in two steps. First, we solve a "steady state"

of the model, in which we assume constant interest rates, i.e. $\bar{r} = \frac{1}{q} - 1$, and constant prices $q_0^m = q_1^m$, $p_0^h = p_1^h$, $p_0^s = p_1^s$. Second, we solve four different models with interest rate shocks.

1. FRM (Constant Prices): Mortgage payment x is fixed at $\bar{r} + \iota + \delta$, with ι normalized such that time 0 mortgage price $q_0^m = 1$. Since FRMs are a long duration asset, time 1 mortgage prices are inversely proportional to interest rates: $q_1^m = \frac{\bar{r}+\iota+\delta}{r+\iota+\delta}$, with δ governing the duration and hence sensitivitity of mortgage prices to rate shocks. Unlike mortgage prices, house prices p_1^h and Lucas tree price p_1^s remain fixed at p_0^h and p_0^s, respectively, i.e., in this economy we assume no pass-through of rate shocks to real asset prices. With payments and real asset prices remaining fixed, the only effect of interest rate shocks in this economy is on the market value of mortgages.

2. FRM: The mortgage market is the same as in (1). However, we now allow house and Lucas tree prices to vary with interest rates. Both assets can be thought of as perpetuities, and hence a risk-neutral expectation of their cash flows can be written as $p_0^j \bar{r}$ for $j \in \{h, s\}$. After a change in interest rates, the new present value of these cash flows is $p_0^j \frac{\bar{r}}{r^j}$, where $r^j = (1 - \phi_j)\bar{r} + \phi_j r$ is the discount rate appropriate for asset j. Here, the parameter ϕ_j governs the degree of interest rate pass-through to asset j. $\phi_j = 0$ corresponds to the economy described in (1), while $\phi_j > 0$ implies that asset prices fall when interest rates rise. Because asset prices may affect default rates and lender profits, we renormalize the mortgage rate spread ι to ensure that q_0^m remains at 1.

3. ARM (Constant Prices): Mortgage payment x is now a spread over the short rate, $x = r + \iota + \delta$. As in (1), we assume no pass-through of rate shocks to real asset prices. Moreover, because mortgage coupons adjust with rates, the mortgage duration is now 0, so $q_1^m = q_0^m$ for all realizations of r. The only effect of interest rate shocks in this economy is on the mortgage payment. Like in (2), we renormalize ι to ensure $q_0^m = 1$.

4. ARM: The mortgage market is the same as in (3) and real asset prices respond as in (2). As in the other economies, ι is renormalized to ensure $q_0^m = 1$.

V.4 Numerical Example Parametrization

The effect of interest rates on mortgage markets and financial stability depends on the mortgage regime and the degree to which rate shocks are passed through to the prices of real assets. To illustrate this, we consider a numerical example. For most parameters, we choose values consistent with the calibration of the dynamic model in the subsequent section. For other parameters for which the two-period model provides clearer guidance, we provide a rough calibration as follows:

Interest Rates The time 0 interest rate is $\bar{r} = 0.01$, implying a bond price q of approximately 0.99. Time 1 interest rates are normally distributed with a mean of $\bar{r}$ and a standard deviation of 0.01.

Households Household discount factor β is 0.985. Setting it to a value below q implies that absent liquidity constraints, household would not hold deposits. Borrowers value housing services at 10% of their non-housing consumption. A negative income shock leads to a 3/4 drop in income and occurs with probability of 5%. This unlikely but sharp decline in income represents the liquidity consequences of losing a job or, e.g., incurring a large medical expense. In a two-period model with CRRA preferences, initial wealth w_0 is a key determinant of portfolio choices. We set w_0 to produce a mortgage loan-to-value ratio of 80% in the FRM (Fixed Prices) economy, keeping it constant across our experiments so that results can be comparable.

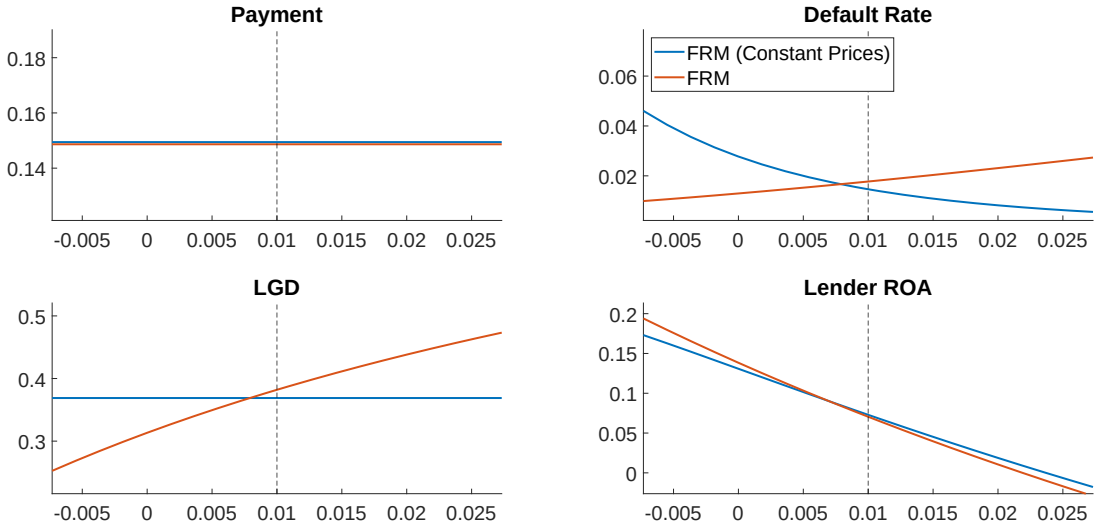
Default The pecuniary penalty of default λ is 0.1, meaning that households' future income declines by 10% as a result of default. Utility costs of default are normally distributed with mean 0 and standard deviation of 0.2125. Together, these parameters imply default rates of 1.6%-2.2% in line with recent empirical estimates.

Lenders Lenders' operating costs ν are set to 0.06, and foreclosure costs ζ are 0.5. These parameters directly effect mortgage rates and losses given default. The mortgage duration δ is set to 0.07. At mortgage rates implied by ν, this value of δ yields a FRM mortgage duration of approximately 7 years, consistent with the effective duration of mortgages in the US.

V.5 Two-Period Model Results

Figures IA.11 and IA.12 highlight the key intuition from the model, by showing how selected outcome variables in $t = 1$ respond to interest rate shocks. Figure IA.11 plots the responses for the two FRM economies (1) with constant asset prices and (2) with asset prices responding to rate shocks, while Figure IA.12 shows the results for the two ARM economies (3) and (4).

Figure IA.11: One-Period Outcomes in Response to Interest Rate Shock: FRM



Notes: This figure shows the $t = 1$ responses to a range of interest rate realizations, for mortgage payments ("Payment"), losses given default ("LGD"), mortgage default rates ("Default Rate"), and lender return on assets ("Lender ROA"). The vertical dashed line represents the mean interest rate $\bar{r}$.

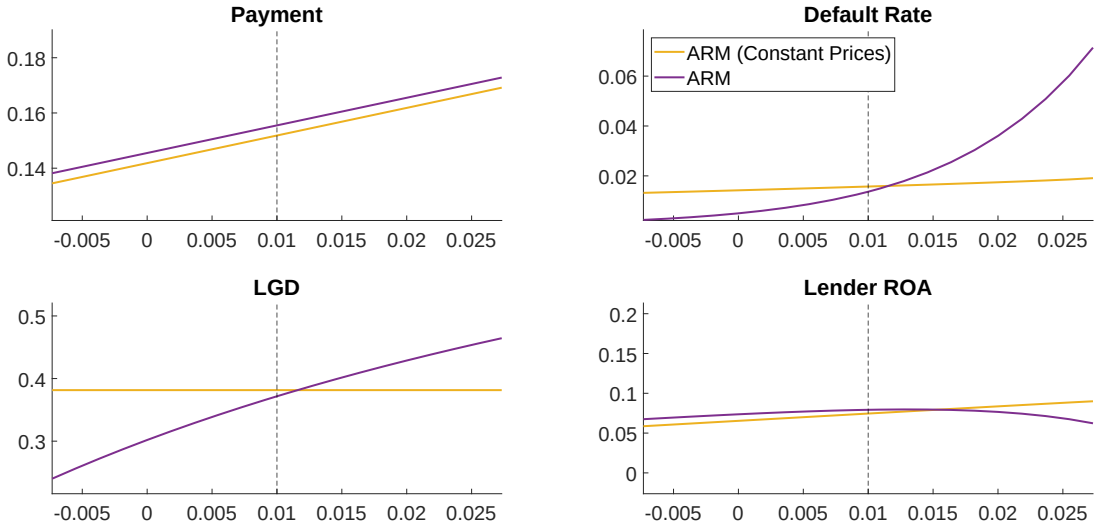
First, consider the FRM economies in Figure IA.11. Intuitively, payments do not respond to rate shocks as a key feature of fixed-rate mortgage contracts, and so borrowers' liquidity is unaffected. Default rates respond to interest rate shocks only to the extent the borrower's strategic incentives are altered. A drop in the mortgage price due to higher rates makes default less attractive — prevailing mortgage rates are higher, making the borrower's existing mortgage with a lower fixed-rate more valuable, which the borrower would have to give up in case of default. In the FRM economy with constant house and Lucas tree prices, this leads to lower default rates as interest rates rise. Loss given default (LGD) remains unchanged, leading to lower credit losses for lenders. Fixed-rate mortgages are a long-duration asset, and so the value of surviving mortgages decreases with interest rates. The increase in discount rates offsets the increase in cash flows coming from slightly lower defaults, leading to a lower return on

the lender's mortgage portfolio when rates increase. The reverse is true based on the same mechanisms in the case of a rate cut.

In the FRM economy where asset prices are flexible, house and Lucas tree prices fall when rates rise. Thus there are two forces affecting default incentives. A rise in morgage rates still makes it valuable to hold on to a below-market-rate mortgage. But now, higher discount rates mean that the price of assets lost in default — the house, and a fraction of future income — are lower, making default more attractive. The two forces largely offset each other. In our numerical example, on net, the latter force prevails, leading to a small increase in default rates due to rate hikes.

What does this mean for lenders? Consider losses given default. With fixed prices, LGD is unchanged by rate shocks. When prices are flexible, rate hikes lower the value of collateral and thus increase losses given default. Rather than hedging interest rate risk in long-duration FRMs, credit risk now amplifies it, leading to a steeper relationship between interest rate risk and lenders ROA.

Figure IA.12: One-Period Outcomes in Response to Interest Rate Shock: ARM



Notes: This figure shows the $t = 1$ responses to a range of interest rate realizations, for mortgage payments ("Payment"), losses given default ("LGD"), mortgage default rates ("Default Rate"), and lender return on assets ("Lender ROA"). The vertical dashed line represents the mean interest rate $\bar{r}$.

The economies with ARMs look considerably different in Figure IA.12. Even if asset prices stay fixed at t=1, the rate hike-driven increase in mortgage payments causes an increase in defaults as a larger fraction of households cannot afford the higher payments. In contrast, from

the lender's perspective, the value of now short-duration surviving mortgages remains constant, as does LGD, since prices are fixed. Their total return responds to rates entirely through cash flows. Higher payments collected on performing loans outweigh the increase in defaults, and returns increase in rates.

Comparing FRMs with ARMs holding prices fixed conveys the traditional FRM vs. ARM intuition. Under the FRM regime, rate hikes benefit households who are protected from rate rises, at the expense of lenders, while this is reversed in the ARM economy.

However, this simple intuition becomes more nuanced when we allow prices to adjust in the economy. In the ARM economy where prices respond to shocks, in response to a rate hike, not only do borrower payments go up, but the cost of default also goes down in present value terms. Moreover, there is no offsetting mortgage rate value channel, i.e. unlike with fixed-rate mortgages, existing borrowers do not benefit from holding a low-rate mortgage in a high-rate environment. As a result, default rates increase substantially, as do losses-given default.

While the lender still benefits from higher payments collected on performing loans, the increase in losses due to higher default rates and LGD leads to a lower net return if the rate hike is large enough. However, the source of these losses is markedly different: while FRM lenders experience losses stemming from interest rate risk, ARM lenders experience losses primarily stemming from credit risk induced by rate rises. The magnitude of these losses depend both on the size of the interest rate shock but also on the level of household debt. An alternative parametrization in which the $t = 0$ LTVs are closer to 100% than to 80% can generate loss-driven low returns on mortgages of the same magnitude as the rate-driven low returns in the FRM economy. In work going forward, we will quantitatively evaluate under what conditions one force dominates the other from a financial stability perspective.

The discussion above also abstracts away from lenders' funding costs. The change in ROA is an upper bound on their unlevered return on equity (ROE) because it represents the case where funding costs are unchanged (e.g., because lenders have a high degree of market power in deposits). The increase in interest income collected by ARM lenders gives them a negative exposure to interest rate risk, i.e. negative duration. Were their funding costs to increase one for one with rates, the asset and liability effects would offset each other, and their portfolio would be immunized, leaving borrowers to bear all the interest rate risk. However, the last

set of results makes it clear that even as ARMs immunize lenders from interest rate risk, they increase their exposure to credit risk.

The quantitative model we develop in the paper allows us to explore these trade-offs in a more realistic setting, where lenders face funding costs and households face a broader set of risks. We will also be able to evaluate the implications of these trade-offs for optimal monetary policy.