The Role of Mortgage Interest Fixation Periods for Macro-Prudential & Monetary Policies

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[PRELIMINARY DRAFT – PLEASE DO NOT SHARE WITHOUT THE PERMISSION OF THE AUTHORS]

Abstract: In many countries the most common mortgage contract neither has a fixed nor a fully adjustable rate. The typical interest fixation period varies between two to ten years. This paper offers a structural analysis of how the interest rate fixation period affects the transmission of monetary policy and how it interacts with borrower-based macro-prudential limits. Using a general equilibrium model with long-term mortgage debt and calibrated to the United Kingdom, we find that: *(i)* the interest fixation period and the tightness of credit conditions do not matter if monetary policy shocks are transitory, *(ii)* looser credit limits and shorter fixation periods amplify the redistributive effects of inflation target shocks that increase nominal rates persistently, and *(iii)* LTV limits act as a backstop to the high sensitivity of PTI limits to monetary policy, especially when the interest fixation period is short.

Keywords: Monetary Policy Transmission, Housing, Mortgage Interest Fixation Periods, Credit Limits, Loan-to-Value, Payment-to-Income

JEL classification: E21, E52, G51

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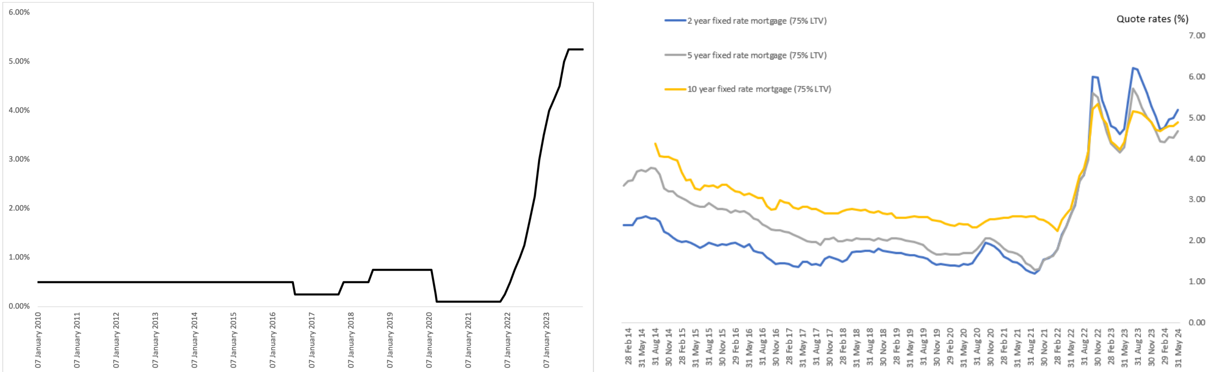
1. Introduction

The relevance of household's balance sheets for the transmission of monetary policy dates back to the net worth channel of Bernanke and Gertler (1995). After the Great Recession, it has gained even more popularity as housing was not only the main driver of the boom and bust, but also was at the center of the transmission of monetary policy into household's consumption. Note that housing is the largest asset in most households' portfolios, and importantly, it is also typically associated to a mortgage as its value often exceeds households' net worth (Campbell and Cocco 2003, Piazzesi and Schneider 2016). Moreover, it is well-known that outright owners' consumption is affected by changes in house prices, either via the housing wealth channel (Iacoviello 2011, Aladangady 2017) or the housing collateral channel (Cloyne, Huber, Ilzetzki, and Kleven 2019); while mortgagors' consumption is in addition affected by changes in their mortgage interest payments (Di Maggio, Kermani, Keys, Piskorski, Ramcharan, Seru, and Yao 2017). As a result, housing tenure status is a key determinant of the strength of the transmission mechanism from interest rates into consumption (Cloyne, Ferreira, and Surico 2020). The strength of these effects also depend substantially on the interest rate schedule associated to the life cycle of the mortgage loan as well as on the credit limits imposed on newly issued mortgage debt. After the Great Recession, policymakers also started to design and implement borrower-based macro-prudential polices to prevent or smooth the impact of future shocks through the housing market, however, little is known about how these limits interact with the persistence of monetary policy shocks as well as with the interest rate schedule of the typical mortgage.

In this paper, we try to fill this gap and offer a structural equilibrium approach to answer the following questions: *how does the strength of monetary policy depend on the mortgage interest fixation period? And how it is affected by credit conditions?* After documenting that in the United Kingdom the typical interest fixation period is either two or five years and that similar fixation periods also predominate in many other countries, we build a general equilibrium model based on Greenwald (2018) in which we compare the transmission of monetary policy into consumption under three different mortgage contracts: fixed rate mortgages (FRM), adjustable rate mortgages (ARM) and hybrid rate mortgages (HRM). The latter are the main theoretical innovation in this paper and allow mortgage payments to switch from fixed to adjustable rates at different times in the life-cycle of the mortgage. Similarly to Garriga, Kydland, and Šustek (2021), we use these counterfactual economies to understand how temporary and persistent



A. Bank Rate B. Mortgage Rates

FIGURE 1. Evolution of Bank & Mortgage Rates

NOTE. Panel A of this figure shows the policy rate chosen by the Bank of England during the period from 2010 to 2023. On the other hand, panel B shows the evolution of mortgage rates for various interest fixation periods and a 75% loan-to-value (LTV) limit.

monetary policy shocks propagate into the real economy. Differently from their paper, we also test the sensitivity of monetary policy transmission to housing tools. First, we investigate how having Payment-to-Income (PTI) limits on top of Loan-to-Value (LTV) limits may dampen or amplify the responses to these shocks. Note that PTI limits are directly affected by changes in interest rates, while LTV limits only change indirectly through the effect of interest rates on house prices. And second, we test how different LTV and PTI calibrations may impact the effects of monetary policy on house prices and the real economy. Moreover, we also focus on interest rate hikes rather than drops as most Central Banks (CBs) have raised their interest rates in the past couple of years. For example, the Bank of England (BoE) raised their interest rate from 0.1% to 5.25% between December 2021 and August 2023, which in turn translated into an increase of 300 basis points in mortgage rates – see Figure 1.

Our findings can be summarized in two sets of results. First, relative to the length of the interest fixation period and its impact on the monetary policy transmission, we find that: *(i)* the response of consumption, output and inflation to a *transitory monetary policy shock* is independent of the mortgage interest fixation period as the standard New-Keynesian channel dominates, leading to increased savings and reduced investment after an increase in the risk-free rate; and *(ii)* a shock to the inflation target that leads to *persistently higher nominal interest rates*, but otherwise, has no significant changes in the real economy, has important redistributive effects from borrowers to savers which are stronger in the *ARM economy* as mortgage rates react one-to-one with the policy rate, leading to a larger increase in mortgage payments. For the *FRM economy* such an increase is gradual, while it is delayed until the end of the interest fixation period for the *HRM economy*. Consequently, it is less costly for the borrower in these two economies to insure against the higher mortgage payments.

The second set of results speak about the interaction with macro-prudential tools. In particular, we find that: *(i)* a shock that leads to persistently higher nominal interest rates is more powerful under looser credit conditions, and in particular, under loose LTVs, which amplify the redistributive effects of the shock, independently of the interest fixation period; and *(ii)* the tightness of credit limits is irrelevant when monetary policy shocks are transitory. These two findings do not imply that we should not care about the interest fixation period when analyzing the interaction between monetary and macro-prudential policies as these results rely heavily on the split between LTV- and PTI-constrained borrowers. In fact, in a *PTI only economy,* the response of mortgage debt issuance to a temporary shock is twice as large in the *ARM economy* relative to the *FRM economy*. House prices also fall approximately 2 percentage points more. On the other hand, these differences are not present in a *LTV only economy*. In other words, the presence of LTV limits smooths out the effects associated with the very sensitive PTI limits to interest rate changes to the extent that the different pass-through associated to different interest fixation periods is deemed to be irrelevant.

Related Literature. This paper is closely related to theoretical papers that analyze the role of household mortgage debt in the transmission of monetary policy, e.g. see Iacoviello (2005), Garriga, Kydland, and Šustek (2017), Greenwald (2018), Auclert (2019), Wong (2019), Beraja, Fuster, Hurst, and Vavra (2019), Garriga, Kydland, and Šustek (2021), Berger, Milbradt, Tourre, and Vavra (2021), or Eichenbaum, Rebelo, and Wong (2022). In several such papers, there is a comparison between ARMs and FRMs given the different pass-through of the policy rate. Recall that in ARM contracts the mortgage rate is linked to the short term nominal interest rate, while in FRM contracts there is a constant rate set at origination. As a result, changes in the policy rate affect mortgage payments almost immediately under ARMs, while it only has an effect on newly issued loans under FRMs. Garriga, Kydland, and Šustek (2021) explore this distinction through the lens of a New Keynesian model with long-term mortgage debt. They show that if monetary policy shocks are transitory, then firms' output responses dominate other channels and consequently the mortgage contract plays a minor role in shaping the responses of macroeconomic aggregates. On the other hand, if monetary shocks are persistent, then firms react through prices rather than output, which in turn affects real mortgage payments and generates redistributive effects, especially under ARMs. Our paper complements their work by analyzing other interest fixation periods beyond the two extremes, FRM and ARM, as well as by considering the interaction with housing tools, which we show that matter for the transmission of persistent shocks. Greenwald (2018) also studies the responses of aggregate variables to transitory and near-permanent shocks to mortgage rates through a similar general equilibrium model with New Keynesian features and mortgage debt. He introduces a couple of important improvements: *(i)* newly issued mortgage debt is subject to *both* loan-to-value (LTV) and payment-to-income (PTI) constraints, and *(ii)* households have the option to pre-pay their mortgages. These two features amplify the transmission from nominal rates to debt, house prices and output via the constraint switching and front-loading effects, and in addition, even when the shock is transitory, create some different aggregate dynamics depending on the prevailing mortgage contract. In fact, when mortgage rates fall temporarily, borrowers rush to lock in lower rates and take larger loans in the FRM economy, resulting in a larger response of output, debt and house prices. The key to understanding the difference in the response to temporary shocks between these two papers is to recognize that the temporary shock in Greenwald (2018) moves the long end of the yield curve (e.g. via unconventional monetary policies), while the temporary shock in Garriga, Kydland, and Šustek (2021) is a traditional policy rate shock that leaves the long end unchanged and shifts the short end. In fact, our work, which relies heavily on these two papers, shows that in a model similar to Greenwald's (2018) there are no differences between FRM and ARM economies after a temporary monetary policy shock like the one in Garriga, Kydland, and Šustek (2021). In any case, our paper differs from these two papers in several aspects: *(i)* our focus is on interest rate hikes rather than drops, *(ii)* in addition to FRM and ARM economies, we also allow for HRM economies given the empirical cross country evidence on the typical interest fixation periods, and *(iii)* we analyze the interactions between monetary policy transmission and credit limits under different mortgage contract structures.

There are several papers that have empirically documented the average interest fixation period for mortgages across different economies. A prominent example is Badarinza, Campbell, and Ramadorai (2018) who show that there is a vast heterogeneity across countries in the relative popularity of adjustable rate and fixed rate mortgages, and in particular, that the United Kingdom has a low share of FRM relative to other countries, like the United States or Germany. In fact, the mortgage rate fixation period in the United Kingdom is typically two or five years as shown in Section 2. We also show that the most popular mortgage contract in many other countries is neither fixed nor fully adjustable but has an interest fixation period similar to that in the United Kingdom. Several papers, such as Calza, Monacelli, and Stracca (2013), Di Maggio et al. (2017) or Cloyne, Ferreira, and Surico (2020), have also highlighted the importance of the mortgage interest fixation period for the transmission of monetary policy into consumption. Hence, we introduce this type of contractural arrangement into Greenwald's (2018) model and study the monetary policy transmission mechanism when all mortgages are assumed to be hybrid. In addition, refinancing costs for these type of mortgages are extremely expensive and, for example, in the United Kingdom, vary between 5% and 10% of the outstanding loan amount (Best, Cloyne, Ilzetzki, and Kleven 2020). Thus, we switch off the endogenous refinancing channel and assume an exogenous refinancing rate which we calibrate using UK data.

There are also several structural papers that study the aggregate implications of different mortgage contracts beyond conventional FRMs and ARMs. For example, Campbell and Cocco (2003) analyze inflation indexed FRMs from a risk management standpoint; Greenwald, Landvoigt, and Van Nieuwerburgh (2021) study shared appreciation mortgages (SAMs) and show that indexing payments to aggregate house prices generates losses for financial intermediaries that are quantitatively larger than the benefits obtained by borrowers; Guren, Krishnamurthy, and Mcquade (2021) look at a menu of different contracts to analyze which one is better designed to reduce consumption volatility and default; while Eberly and Krishnamurthy (2014) propose a mortgage contract that allows for a one-time costless conversion from FRM to ARM. The latter is the most similar to the mortgage type that we consider, with the distinction that we do not allow for a conversion choice as these fees are prohibitively expensive. Overall, we are not aware of any other paper that has studied how monetary policy transmits to the real economy through the lens of a structural general equilibrium model that features hybrid rate mortgages and different credit limits.

Finally, our paper is also related to the recent literature that analyzes the interactions between monetary policy and mortgage debt limits. For example, Ferrero, Harrison, and Nelson (2023) look at the optimal policy mix between monetary and macro-prudential policies, but only focus on loan-to-value (LTV) limits. Millard, Rubio, and Varadi (2024) also examine the interaction between monetary policy and a combination of macro-prudential limits from a positive standpoint. In this sense, our paper is closely related to theirs as we also consider PTI and LTV limits, but we further focus on the potentially different impact of these tools based on the mortgage interest fixation period. In fact, given that in our framework not all borrowers are constrained by the same limit, we are able to show how they complement each other in smoothing the responses of economic variables to monetary policy shocks.

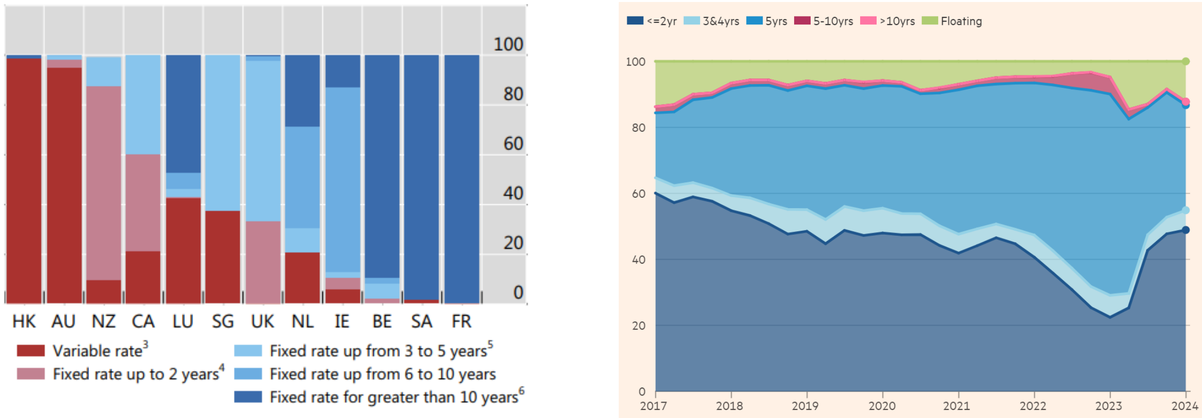
Outline. The rest of the paper is structured as follows. In Section 2 we present some motivating evidence on mortgage interest fixation periods and show that the vast majority of countries have mortgages with fixation periods that do not exceed ten years. We present a general equilibrium model that takes into account such a mortgage interest rate structure in Section 3. Section 4 calibrates the model, which is then used as a laboratory to study the effects of monetary policy shocks on consumption in Section 5.1, and its interactions with housing tools in Section 5.2. Finally, Section 6 concludes.

2. Mortgage Structure: Is the UK Market that Different?

The structure of mortgage contracts is highly variable across countries and over time. One of its most important aspects is the interest rate schedule applicable over the life of a mortgage loan as these differences influence monetary policy transmission. Most theoretical and empirical studies distinguish between two groups: *(i) fixed rate mortgages (FRM)* in which a nominal interest rate is fixed throughout the life of the mortgage, and *(ii) adjustable rate mortgages (ARM)* in which the mortgage rate varies over the life of the contract according to market conditions. Although some countries mainly rely on one of these two types of contracts, there is a vast heterogeneity in the interest fixation period.

Data from the BIS (2023) shows that indeed some countries such as France or the United States rely exclusively on mortgages with interest fixation periods greater than ten years or on fully variable rates as in the case of Australia or Hong Kong. Nonetheless, these are not the predominant mortgage contracts in many other countries. For example, in Canada, Ireland, the Netherlands, and New Zealand there is a considerable share of mortgages with a fixed-term shorter than five years. These contracts, referred to as *hybrid rate mortgages (HRM)*, start with a fixed rate and switch automatically to the standard variable rate at the end of the fixed-term portion of the contract, unless the borrower chooses to refinance onto a new mortgage contract instead.

The United Kingdom is also characterized by this type of contracts. As of 2023, the majority of new mortgage lending in the United Kingdom was on a fixed-term either



A. Borrowers' exposure to interest rate risk

B. Outstanding loans by rate type and fix period in the United Kingdom

FIGURE 2. Interest Fixation Period in Mortgage Loans

NOTE: Panel A shows the share of mortgages broken down by the interest rate fixation period for several countries in the year 2023. Panel B focuses instead on the United Kingdom over the period 2017 to 2024.

for a period of less than two years or for a period of less than five years. The two- and the five-year contracts have also been the most common over time despite some time variation (Figure 2, panel B). Regardless of the downward trend from 2017 until 2022, the majority of loans were extended as two-year fixed-term contracts. After 2022, and coinciding with the policy tightening cycle that begun in the United Kingdom in December 2021, there has been a reversal and more five-year fixed term contracts have been issued. In any case, the prevalence of short-term fixed-rate mortgage contracts makes UK households particularly exposed to the risk of unexpected changes in interest rates relative to households in countries with a predominant share of FRM. In what follows, we will embed hybrid rate mortgages into a New-Keynesian model with long term mortgage debt to study the transmission of monetary policy to households.

In addition, the prevalence of shorter-term mortgage contracts also interacts with financial policies and with lenders' own risk assessment practices. For instance, the FCA's Mortgage Conduct of Business (MCOB) includes a requirement that for mortgages where the interest rate may vary within five years, lenders must verify whether the borrower could still afford payments if interest rates were to rise by a minimum of 100 basis points. This requirement is similar to a payment-to-income constraint and hence we explore how these limits interact with monetary policy under different mortgage contracts.

3. The Model Economy

This section presents a general equilibrium model of the housing market that builds extensively on Greenwald (2018). That is, the model features two type of households, borrowers and savers, that trade mortgages between each other. Borrowers also make decisions about consumption, labor supply, and the size of newly purchased houses; while savers can also make bond purchases to further insure themselves against aggregate shocks, but have a fixed housing stock. The production side of the economy has the standard New Keynesian features and monetary policy follows a Taylor rule.

We assume in our model that the refinancing rate is exogenous and constant, unlike Greenwald (2018). While endogenous refinancing has proven to be important in the United States – see for example Wong (2019), Beraja et al. (2019) or Eichenbaum, Rebelo, and Wong (2022) – this is not a structural feature of the United Kingdom and many other countries in which HRMs dominate and refinancing before the contract is due implies a substantial cost. Moreover, the refinancing channel in the United States, and probably in other countries as well, is not important during tightening cycles as the refinancing rate is constant when interest rate gaps are negative (Berger et al. 2021). [1]

Our primary modeling contribution is to incorporate *hybrid rate mortgages (HRM)* into this framework. We modify the law of motion of promised payments to reflect that HRM mechanically switch from fixed to adjustable rates after T periods and study how the transmission of monetary policy interacts with different housing tools in this environment.

3.1. Households

Set-up. There are two types of representative households: *borrowers* and *savers* with measures χ_b and χ_s, respectively. They differ in their preferences. Savers are more patient than borrowers, i.e. $\beta_s > \beta_b$ where β_j is the discount factor of each type of household. They also have different disutility from working η_j to guarantee that they supply the same amount of labor in the steady state. Nonetheless, each agent type maximizes expected lifetime utility over non durable consumption $c_{j,t}$, housing services $h_{j,t}$, and labor supply $n_{j,t}$

[1] The interest rate gap is the difference between the mortgage rate households are paying and the one prevailing in the market at a given point in time.

(1) $$\mathbb{E}_t \sum_{k=0}^{\infty} \beta_j^k u\left(c_{j,t+k}, h_{j,t+k}, n_{j,t+k}\right)$$

where utility takes the separable form

(2) $$u(c,h,n) = \log(c) + \xi \log(h) - \eta_j \frac{n^{1+\varphi}}{1+\varphi}.$$

These two types also differ in the composition of their balance sheets. In addition to labor income, which is subject to a proportional tax τ_y that is rebated in the form of lump-sum transfers T_t, households can get resources from different asset classes. In particular, households can trade *one-period nominal bonds*, whose balances are denoted by b_t and have a real return R_t. These bonds are in zero net supply and are used by the monetary authority as a policy instrument. Moreover, we assume that positions in b_t must be non-negative (i.e., they cannot be used for borrowing) and consequently are only traded by savers in equilibrium.

Both agent types also own *housing*, which produces a service flow each period equal to its stock. Homeowners have to pay maintenance costs, which are a constant fraction δ of the value of the house. The total housing stock is fixed $\bar{H}$, as well as the saver demand $h_{s,t} = \tilde{H}_s$, which ensures that the borrower is the marginal buyer. Only prepaying borrowers can adjust their housing holdings as each mortgage loan is linked to a specific house. Hence, the law of motion for the total start-of-period borrower housing is

(3) $$h_{b,t} = \rho h^*_{b,t} + (1-\rho) h_{b,t-1}$$

where ρ is the exogenous fraction of borrowers pre-paying their loans in a given period. This brings us to the most relevant asset in this economy: *mortgages*. Borrowers can trade long-term mortgage debt with savers in equilibrium and their mortgage balance is denoted by m_t. Mortgage debt is issued in the form of fixed-rate perpetuities with coupons that geometrically decay at a rate ν. These loans are also pre-payable and nominal, and consequently, real balances also decay each period at the rate of inflation π_t. As a result, the law of motion of total start of the period debt balances is

(4) $$m_t = \rho m^*_{i,t} + (1-\rho)(1-\nu)\pi_t^{-1} m_{t-1}$$

where $m^*_{i,t}$ denotes the newly originated loans which are subject to both loan-to-value (LTV) and payment-to-income (PTI) limits at origination

$$m^*_{i,t} \leq \theta^{LTV} p^h_t h^*_{i,t} \tag{5}$$

$$m^*_{i,t} \leq \frac{\theta^{PTI} w_t n_{i,t} e_{i,t}}{q^*_t} \tag{6}$$

where p^h_t is the price of housing, $h^*_{i,t}$ is the borrower's new house size, w_t is the wage, n_t is labor supply, q^*_t is the coupon of the newly issued mortgage, and $e_{i,t}$ is an idiosyncratic labor productivity shock with c.d.f. Γ_e. [2] The parameters θ^{LTV} and θ^{PTI} capture the average LTV and PTI limits.

A mortgage contract carries interest that the borrower has to pay to the saver. All future mortgage payments associated with a given loan are subject to a proportional tax $\Delta_{q,t}$, which follows an AR(1) process. Independently of this tax, how mortgage interests are paid depends on the contract type. For adjustable rate mortgages (ARM) these payments vary every period according to the policy rate; while for fixed rate mortgages (FRM), the coupon is fixed at origination and consequently the interest on the stock q_t differs from that on the flow q^*_t. Despite these being the two most studied mortgage contracts, the typical mortgage in many countries, including the United Kingdom, is a hybrid between the two in which interest payments are fixed during T years before they vary according to the policy rate. Denoting by $x_{b,t-1}$ and $x_{s,t-1}$ the total promised payments on existing debt by borrowers and savers, we can specify the evolution of mortgage payments under these *hybrid rate mortgages (HRM)* as follows:

$$\begin{aligned} x^{HRM}_{b,t} = \sum_{\tau=0}^{T-1} \left[((1-\rho)(1-\nu))^{\tau} \left(\prod_{i=0}^{\tau-1} \pi^{-1}_{t-i} \right) \rho q^*_{t-\tau} m^*_{t-\tau} \right] + \\ + ((1-\rho)(1-\nu))^{T} \left(\prod_{i=0}^{T-1} \pi^{-1}_{t-i} \right) q^*_{t-T} m_{t-T} \end{aligned} \tag{7}$$

$$\begin{aligned} x^{HRM}_{s,t} = \sum_{\tau=0}^{T-1} \left[((1-\rho)(1-\nu))^{\tau} \left(\prod_{i=0}^{\tau-1} \pi^{-1}_{t-i} \right) \rho \left(q^*_{t-\tau} - \Delta_{q,t-\tau} \right) m^*_{t-\tau} \right] + \\ + ((1-\rho)(1-\nu))^{T} \left(\prod_{i=0}^{T-1} \pi^{-1}_{t-i} \right) \left(q^*_{t-T} - \Delta_{q,t-T} \right) m_{t-T} \end{aligned} \tag{8}$$

[2] The labor productivity shock $e_{i,t}$ is used to split borrowers into PTI- and LTV-constrained households. In particular, a fraction $\int^{\bar{e}} e_i d\Gamma_e(e_i)$ is constrained by the PTI limit, while the remaining fraction $1 - \Gamma_e(\bar{e})$ is constrained by the LTV limit.

where the first term corresponds to the fixed part of the contract and the second to the variable rate. That means that borrowers that refinance in period $\tau < T$, and consequently are still on the fixed part of the contract, are paying the rate that was prevailing at the time of refinancing $q^*_{t-\tau}$, while borrowers that has not yet refinance by period T are already in the variable rate.

Borrower's Problem. The borrower chooses consumption $c_{b,t}$, labor supply $n_{b,t}$, the size of newly purchased houses $h^*_{b,t}$, and the face value of newly issued mortgages m^*_t to maximize lifetime utility subject to the borrowing constraints (5) - (6) and the budget constraint

$$
\begin{aligned}
c_{b,t} \leq & (1-\tau_y) w_t n_{b,t} + \rho \left(m^*_t - (1-\nu)\pi_t^{-1} m_{t-1} \right) - \pi_t^{-1} \left((1-\tau_y)\, x_{b,t-1} + \nu m_{t-1} \right) \\
& - \delta\, p^h_t h_{b,t-1} - \rho\, p^h_t \left(h^*_{b,t} - h_{b,t-1} \right) + T_{b,t}
\end{aligned} \tag{9}
$$

where the right hand side is the sum of labor income $(1-\tau_y) w_t n_{b,t}$, net mortgage issuance $\rho \left(m^*_t - (1-\nu)\pi_t^{-1} m_{t-1} \right)$ and transfers $T_{b,t}$ minus interests and principal payments $\pi_t^{-1} \left((1-\tau_y)\, x_{b,t-1} + \nu m_{t-1} \right)$, net housing purchases $\rho\, p^h_t \left(h^*_{b,t} - h_{b,t-1} \right)$ and housing maintenance costs $\delta\, p^h_t h_{b,t-1}$.

Saver's Problem. The saver also choses consumption $c_{s,t}$, labor supply $n_{s,t}$ and the face value of newly issued mortgages m^*_t to maximize lifetime utility subject to the budget constraint

$$
\begin{aligned}
c_{s,t} \leq & \left(1-\tau_y\right) w_t n_{s,t} + \pi_t^{-1} x_{s,t-1} - \rho \left(m^*_t - (1-\nu)\pi_t^{-1} m_{t-1} \right) \\
& - \delta\, p^h_t \tilde{H}_s - \left(R_t^{-1} b_t - \pi_t^{-1} b_{t-1} \right) + \Pi_t + T_{s,t}
\end{aligned} \tag{10}
$$

where the right hand side is the sum of labor income $\left(1-\tau_y\right) w_t n_{s,t}$, mortgage payments $\pi_t^{-1} x_{s,t-1}$, intermediate profits Π_t, and transfers $T_{s,t}$ minus housing maintenance $\delta\, p^h_t \tilde{H}_s$, net bond purchases $\left(R_t^{-1} b_t - \pi_t^{-1} b_{t-1} \right)$ and net mortgage issuance $\rho \left(m^*_t - (1-\nu)\pi_t^{-1} m_{t-1} \right)$.

3.2. Production

The production side of the economy has the standard New Keynesian ingredients. A perfectly competitive final good producer that, using intermediate goods $y_t(i)$ as inputs, produces output Y_t. That is, the final good producer solves the static problem

$$\max_{y_t(i)} P_t \left[\int_0^1 y_t(i)^{\frac{\lambda-1}{\lambda}} di \right]^{\frac{\lambda}{\lambda-1}} - \int_0^1 P_t(i)\, y_t(i) di \tag{11}$$

where P_t is the price of the final good and $P_t(i)$ is the price of each intermediate input $y_t(i)$. The first order condition of this problem gives a demand function for good i

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\lambda} Y_t \ . \tag{12}$$

To meet this final good producer's demand, the producer of intermediate good i operates a linear production function

$$y_t(i) = a_t n_t(i) \tag{13}$$

where $n_t(i)$ is labor hours and a_t is total factor factor productivity (TFP) that evolves according to

$$\log a_t = (1 - \phi_a)\mu_a + \phi_a \log a_{t-1} + \varepsilon_{a,t} \tag{14}$$

where $\varepsilon_{a,t}$ is a white noise process. Cost minimization by firm i determines how much labor to hire each period. In particular, a firm i hires workers until the point where wage equals the marginal cost times the marginal product of labor

$$W_t = MC_t(i) a_t \ . \tag{15}$$

Since these producers have some market power, they also set prices. However, they cannot freely adjust them and are subject to price stickiness of the Calvo-Yun form with indexation, which stipulates that each period a fraction $1 - \zeta$ of firms adjust their price to their optimal (flexible) price and the remaining fraction ζ update their price according to the steady state inflation rate.

3.3. Monetary authority

Monetary policy is characterized by a Taylor-type rule of the form

$$\log R_t = \log \bar{\pi}_t + \phi_r (\log R_{t-1} - \log \bar{\pi}_{t-1}) + \\ + (1 - \phi_r) \left[(\log R_{ss} - \log \pi_{ss}) + \varphi_\pi (\log \pi_t - \log \bar{\pi}_t) \right] + \log \eta_t \tag{16}$$

where ϕ_r controls the degree of interest rate smoothing, the subscripts "*ss*" refer to steady state values, $\bar{\pi}_t$ is a time-varying inflation target and η_t is a temporary interest rate shock. $\bar{\pi}_t$ and η_t are defined by

$$\log \bar{\pi}_t = (1 - \phi_{\bar{\pi}}) \log \pi_{ss} + \phi_{\bar{\pi}} \log \bar{\pi}_{t-1} + \varepsilon_{\bar{\pi},t} \tag{17}$$

$$\log \eta_t = \phi_\eta \log \eta_{t-1} + \varepsilon_{\eta,t} \tag{18}$$

where $\varepsilon_{\bar{\pi},t}$ and $\varepsilon_{\eta,t}$ are white noise processes which are orthogonal to each other and that we refer to as an *inflation target shock* and an *interest rate shock*, respectively. We include these two types of policy shocks to be able to distinguish between near-permanent and transitory shocks because it has been shown by Garriga, Kydland, and Šustek (2021) the distinction between the two matters when analyzing the responses under different mortgage contracts.

3.4. Key equilibrium conditions

The mortgage contract type affects how borrowers pay back savers. We have shown above how one can specify the low of motion of total promised payments on existing mortgage debt such that one is able to capture the typical UK mortgage payment structure. In this section, we present how it affects equilibrium conditions and what it entails for mortgage pricing. We use the ARM and FRM economies as benchmark to simplify the exposition.

The influence of the low of motion of promised payments appears in the borrower's and saver's optimality conditions with respect to the face value of newly issued mortgages. The borrower's optimality of new debt requires

$$1 = \Omega^m_{b,t} + \Omega^x_{b,t} q^*_t + \mu_t \tag{19}$$

where μ_t is the multiplier on borrower's aggregate credit limit, and $\Omega^m_{b,t}$ and $\Omega^x_{b,t}$ are the marginal continuation *costs* of taking on an additional unit of debt and of promising an additional dollar of initial payments, respectively. These two marginal continuation values differ based on how interest is paid. In an economy with just FRM contracts, these values are defined as

$$\Omega_{b,t}^{m,FRM} = \mathbb{E}_t \left[\Lambda_{t,t+1}^{b} \pi_{t+1}^{-1} \left(\nu + (1-\nu)\,\rho + (1-\nu)(1-\rho)\Omega_{b,t+1}^{m,FRM} \right) \right] \tag{20}$$

$$\Omega_{b,t}^{x,FRM} = \mathbb{E}_t \left[\Lambda_{t,t+1}^{b} \pi_{t+1}^{-1} \left((1-\tau_y) + (1-\nu)(1-\rho)\Omega_{b,t+1}^{x,FRM} \right) \right] \ . \tag{21}$$

while in an economy with ARM contracts, for which promised payments are no longer an endogenous state variable as they change every period, $(\Omega_{b,t}^{m} + \Omega_{b,t}^{x} q_t^*)$ can be combined into a single term $\Omega_{b,t}^{ARM}$ that represents the total continuation cost of an additional unit of debt and it is given by

$$\Omega_{b,t}^{ARM} = \mathbb{E}_t \left[\Lambda_{t,t+1}^{b} \pi_{t+1}^{-1} \left((1-\tau_y)\, q_t^* + \nu + (1-\nu)\,\rho + (1-\nu)\,(1-\rho)\,\Omega_{b,t+1}^{ARM} \right) \right] \ . \tag{22}$$

Finally, turning to the hybrid rate mortgage (HRM) economy, we see how these marginal continuation values have some similarities with those from the FRM and ARM economies. In fact, the marginal continuation cost of taking an additional unit of debt under HRM is identical to than under FRM, i.e.

$$\Omega_{b,t}^{m} = \Omega_{b,t}^{m,FRM} = \Omega_{b,t}^{m,HRM} \ . \tag{23}$$

Moreover, the marginal cost of promising an additional dollar of initial payments is identical to that of the FRM up to period T, when the contract mechanically switches to adjustable rates. After period T, it is equal to 0 as for ARM contracts. This is reflected by the finite sum that characterizes this marginal cost in the HRM economy

$$\Omega_{b,t}^{x,HRM} = \sum_{\tau=1}^{T} (1-\rho)^{\tau-1}\,(1-\nu)^{\tau-1}\,\mathbb{E}_t \left[\left(\prod_{j=0}^{\tau-1} \Lambda_{t+j,t+j+1}^{b} \pi_{t+j+1}^{-1} \right) (1-\tau_y) \right] \tag{24}$$

The saver's optimality condition with respect to newly issued mortgage debt is also affected by the low of motion of promised payments. In general, it requires that

$$1 = \Omega_{s,t}^{m} + \Omega_{s,t}^{x} \left(q_t^* - \Delta_{q,t} \right) \tag{25}$$

where $\Omega_{s,t}^{m}$ and $\Omega_{s,t}^{x}$ are the marginal continuation *benefits* of an additional unit of debt and of an additional dollar of initial payments, respectively. Similarly to the borrower's marginal costs, these marginal benefits under HRM contracts have some similarities with their counterparts under FRM and ARM contracts. In fact, it is also the case that the marginal benefit of an additional unit of debt is identical under FRM and HRM contracts. That is,

$$\Omega^{m}_{s,t} = \Omega^{m,FRM}_{s,t} = \Omega^{m,HRM}_{s,t} = \mathbb{E}_t\left[\Lambda^{s}_{t,t+1}\pi^{-1}_{t+1}\left(\rho\,(1-\nu) + (1-\rho)(1-\nu)\Omega^{m}_{s,t+1}\right)\right] . \tag{26}$$

Moreover, the marginal benefit of an additional dollar of initial payments under HRM is also equal to its FRM counterpart up to period T when the contract switches to adjustable rates and it is zero afterwards as in the ARM case as shown below:

$$\Omega^{x,HRM}_{s,t} = \sum_{\tau=1}^{T}(1-\rho)^{\tau-1}(1-\nu)^{\tau-1}\,\mathbb{E}_t\left[\left(\prod_{j=0}^{\tau-1}\Lambda^{s}_{t+j+1,t+j}\pi^{-1}_{t+j+1}\right)\right] . \tag{27}$$

The marginal continuation benefits of an additional dollar of initial payments in the FRM economy as well as the marginal continuation benefit of an additional unit of debt in the ARM economy are reproduced in Appendix A.1.

4. Calibration

This section describes the calibration procedure and shows how the model is able to fit the data along several dimensions. The calibration strategy follows the common recipe of setting some parameters externally, while others are chosen jointly with the objective of minimizing the distance between a collection of data and model moments.

We choose the HRM economy with 2 year fixes as the benchmark for calibration. As noted above in Figure 2, these are the most common contracts in the United Kingdom and are representative of about 50% of the mortgage loan market. Nonetheless, we also show how steady state moments for a given calibrated parameter vector would change if we were to assume that all mortgage contracts are either on the fixed or the adjustable rate.

4.1. Externally calibrated parameters

Demographics & preferences. The fraction of borrowers χ_b is set to match the share of mortgagors whose savings are less than 20% of their total income which is equivalent to 27.74%. This fraction is recovered by combining data from the 2019 English Housing

Survey and Money Dashboard.[3] As households have a measure of one, savers represent 72.26% of households in our model economy. Their discount factor β_s is chosen to pin down a ten-year UK gilt yield of 2.5% as they are the only agents that can save in government bonds in our model economy. This results in a value of $\beta_s = 0.998$. Preferences across types also differ in their labor disutility parameters, η_b and η_s, which are chosen to guarantee that borrowers and savers supply the same amount of labor in steady state, $n_{b,ss} = n_{s,ss} = 1/3$. This requires that $\eta_b = 7.518$ and $\eta_s = 5.775$.

The remaining preference parameters that are not internally calibrated are set to standard values in the literature. In particular, the housing utility weight is set to $\xi = 0.25$, while the inverse of the Frisch elasticity is set to $\varphi = 1.0$.

Income process. For the income shock distribution Γ_e, we follow Greenwald (2018) and choose a log-normal specification $\log e_{i,t} \sim \mathcal{N}(-\sigma_e/2, \sigma_e^2)$ which implies that

$$\int_{\bar{e}_t} e_i d\Gamma_e(e_i) = \Phi\left(\frac{\log \bar{e}_t - \sigma_e^2/2}{\sigma_e}\right)$$

where Φ is the CDF of the standard normal distribution. To capture the dispersion in which constraint is binding we set σ_e match the standard deviation of $\log(PTI_{i,t}) - \log(LTV_{i,t})$ in the data. This term is the difference of individual borrowers' log PTI and LTV ratios at origination, which equals $\log e_{i,t}$ in the model. Using the debt service ratio (DSR) as a proxy for the PTI, we find that the UK average of this series is 0.53. Hence, we set σ_e to that value. Labor income is taxed at the rate $\tau_y = 0.212$ which corresponds to the national average prior to interest mortgage deductions in the United Kingdom.

Housing & mortgages. For the debt limit parameters, we set $\theta^{PTI} = 0.36$ and $\theta^{LTV} = 0.85$ which is consistent with the UK empirical distribution of these limits as most mortgagors bunch around those ratios. The amortization parameter is set to the average weighted amortization as a fraction of the loan amount, which in the United Kingdom amounts to 0.57% monthly. Hence, $\nu = 1.71\%$ as one model period corresponds to a quarter. The exogenous refinancing rate is calibrated such that the average duration on a house is ten years, consistently with the UK average. The log housing stock $\log \bar{H}$ is calibrated so

[3] The English Housing Survey is used to get homeownership rates for outright owners and mortgagors, while Money Dashboard (MDB) data is useful to compute how many of those have savings below some threshold, consistent with the model assumption about borrowers being constrained by one of the two credit limits.

TABLE 1. Parameter values

Parameter	Interpretation	Value	Internal / Jointly
Demographics & preferences			
χ_b	Fraction of borrowers	27.74%	N
β_b	Borr. discount factor	0.957	YY
β_s	Saver discount factor	0.998	Y
ξ	Housing utility weight	0.25	N
η_b	Borr. labor disutility	7.518	Y
η_s	Saver labor disutility	5.775	Y
φ	Inv. Frisch elasticity	1.0	N
Income process			
σ_e	Income dispersion	0.53	N
τ_y	Income tax rate	0.212	N
Housing & mortgages			
θ^{PTI}	Max PTI ratio	0.36	N
θ^{LTV}	Max LTV ratio	0.85	N
ν	Mortgage amortization	1.71%	N
ρ_b	Refinancing rate	0.10	N
δ_h	Housing depreciation	0.005	N
$\log \bar{H}$	Log housing stock	2.256	Y
$\log \bar{H}_s$	Log saver housing stock	1.678	YY
μ_q	Term premium (mean)	0.36%	YY
ϕ_q	Term premium (pers.)	0.852	N
Productive technology			
μ_a	Mean (TFP shock)	1.015	Y
ϕ_a	Persistence (TFP shock)	0.9	N
σ_a	Standard deviation (TFP shock)	0.05	N
λ	Variety elasticity	6.0	N
ζ	Price stickiness	0.75	N
Monetary authority			
ϕ_r	Interest rate smoothing	0.8336	N
φ_π	Taylor rule weight on inflation	1.497	N
π_{ss}	Steady state inflation	1.005	Y
$\phi_{\bar{\pi}}$	Persistence (infl. target shock)	0.994	N
ϕ_η	Persistence (interest rate shock)	0.3	N

NOTE. The model is calibrated at quarterly frequency. Parameters denoted "Y" in the "Internal / Jointly" column are chosen implicitly to match a particular moment at steady state, while those denoted "YY" are chosen jointly to minimize the distance between data and model moments.

that the price of housing is unity at steady state, $p^h_{ss} = 1$. The depreciation rate of the housing stock is set to a standard 0.5% per quarter. Finally, the persistence of the term premium shock is set to the value used by Greenwald (2018).

Productive technology. The persistence and the standard deviation of the TFP shock are taken from COMPASS, the workhorse DSGE model used at the Bank of England for policy analysis and forecasting (Burgess, Fernandez-Corugedo, Groth, Harrison, Monti, Theodoridis, and Waldron 2013). We take their median estimates and set $\rho_a = 0.9$ and $\sigma_a = 0.05$. The mean of the TFP process is chosen such that output in steady state equals one, $y_{ss} = 1$. This results in a value of $\mu_a = 1.015$.

The price-setting parameters take on conventional values: the fraction of firms updating their price ζ is set to 0.75 so that the average price duration is 4 quarters, while the elasticity of substitution λ among varieties is set to 6.0 such that the steady state mark-up $\lambda/(\lambda - 1)$ is 1.2.

Monetary authority. In the Taylor rule, the interest rate smoothing term and the weight on inflation are taken from COMPASS. Using their median estimates we set $\phi_r = 0.8336$ and $\varphi_\pi = 1.497$. The mean of the inflation target shock is calibrated to target a 2% inflation rate in the steady state, which results in $\pi_{ss} = 1.005$.

To calibrate the inflation target shock and the interest rate shock processes, we follow Garriga, Kydland, and Šustek (2021) by setting the persistence of the inflation target shock and the transitory interest rate shock to $\varphi_{\bar{\pi}} = 0.994$ and $\varphi_\eta = 0.3$, respectively.[4]

4.2. Internally calibrated parameters, targets, and model fit

The remaining three parameters: the borrower discount factor, β_b, the log saver housing stock, $\log \bar{H}_s$, and the mean of the term premium shock, μ_q, are jointly chosen to match three moments in the data: the borrower's house value to income which equals 5.0, the saver's house value to income which is slightly higher and equal to 6.4 and the annualized mortgage rate which is assumed to have a one percentage point spread over the government bond yield.

Table 2 shows how the model with HRM and two-year fixes is able to match these moments (top block), as well as to match the steady state targets mentioned in the previous section, after setting $\beta_b = 0.957$, $\log \bar{H}_s = 1.678$ and $\mu_q = 0.36\%$. Moreover, we also

[4] Using the same parameters for these two shock process helps relating our findings to theirs.

TABLE 2. Targets and model fit

Moment	**HRM (T=8)**	**Target / Data**	**FRM**	**ARM**
Targeted jointly				
House value to income (borr.)	5.08	5.0	4.995	4.945
House value to income (saver)	6.36	6.4	6.388	6.410
Mortgage Rate	3.03%	3.5%	5.33%	5.33%
Steady state targets				
10 Year Gilt Yield	2.5%	2.5%	2.5%	2.5%
Inflation	2.08%	2%	2.08%	2.08%
Output	1.0	$y_{ss} = 1$	1.00	1.00
House price	1.132	$p^h_{ss} = 1$	1.368	1.358
Hours worked (borr.)	0.325	$n_{b,ss} = 1/3$	0.331	0.334
Hours worked (saver)	0.332	$n_{b,ss} = 1/3$	0.330	0.329

NOTE. This table shows the model's ability to capture certain features of the UK economy when calibrated using HRM with 2 years in the fixation period. For comparability, these moments are also shown in the counterfactual economies with FRM or ARM at the same parameter values.

show in the last two columns of Table 2 how these steady state moments change when mortgages are assumed to be either fixed or adjustable rate mortgages. Interestingly, the house price and mortgage rate are higher in the FRM and ARM economies.

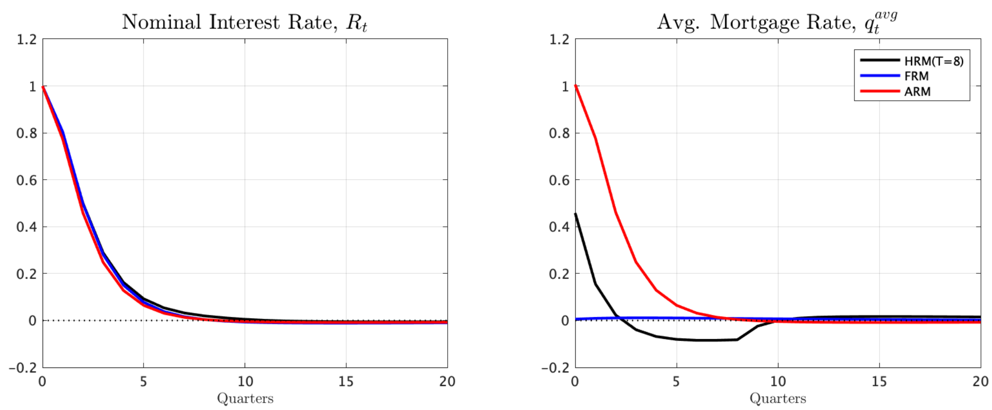
5. Results

5.1. Monetary policy pass-through and its effects on consumption

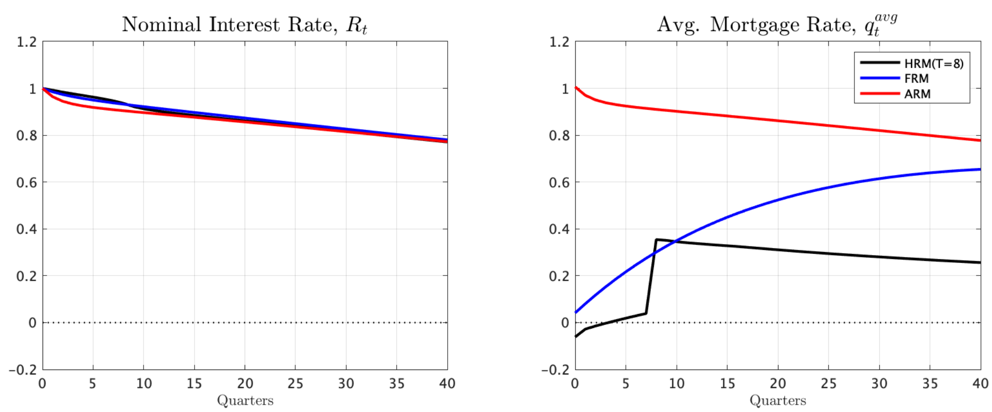
We study the effects of monetary policy shocks on consumption across the three mortgage contract economies. In doing so we distinguish between temporary and persistent shocks as in Garriga, Kydland, and Šustek (2021). These shocks have been calibrated such that they die out after the same number of quarters as in their paper.

Independently of the persistence of the shock, a first step to understand how unexpected movements in the policy rate R_t affect consumption through the housing market is to analyse the monetary policy pass-through to mortgage rates. Figure 3 shows how a 1% increase in R_t translates into changes in the average mortgage rate in the economy.[5]

[5] Since we model long-term mortgage debt, there are two relevant mortgage rates: *(i)* on newly issued debt, q^*_t, and *(ii)* on existing debt q_t. The impulse response functions in the right panel of Figure 3 shows the average between the two.



A. Temporary Monetary Policy Shock



B. Persistent Inflation Target Shock

FIGURE 3. Monetary Policy Pass-Through

NOTE. Responses are normalized such that R_t increases by 1% upon impact in the HRM, FRM & ARM economies. Mortgage rates are expressed as percentage point (annualized) deviations from steady state.

Turning first to the temporary monetary policy shock (panel A), we see that in a *ARM economy* there is a one-to-one pass through and the average mortgage rate response is identical to that of the nominal interest rate. On the other extreme, the average mortgage rate in the *FRM economy* almost does not respond to the increase in the policy rate. As the refinancing rate is rather low, the increase in the mortgage rate on newly issue debt, which is also smaller than in the *ARM economy*, does not get reflected on the overall rate. Finally, in the *HRM economy*, the average mortgage rate increases upon impact but not as much as the increase in R_t, and therefore, the impact on mortgage payments is weaker than in the *ARM economy* but stronger than in the *FRM economy*. This is shown in the subplot in the first row, third column of Figure 4.

Despite the differential response of nominal mortgage payments across the three economies, the response of consumption is almost identical. This is explained by the

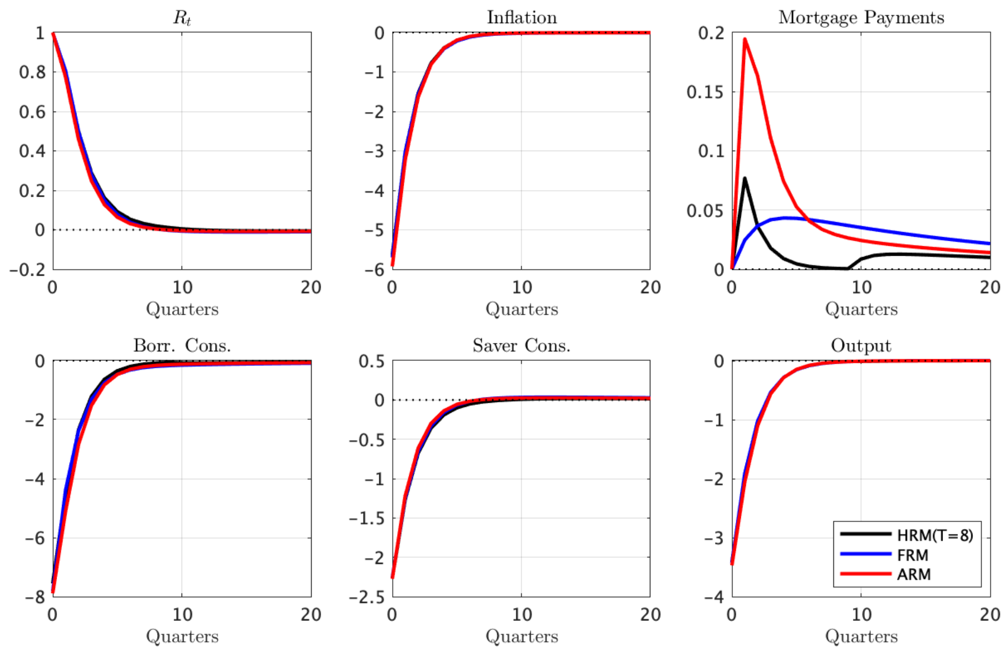


FIGURE 4. Response to a 1% (temporary) monetary policy shock

NOTE. A value of 1 represents a 1% increase relative to the steady state except for mortgage payments, which are measured in percentage points. Output, borrower and saver's consumption are expressed in real terms, and together with inflation and the nominal interest rate are annualized.

larger role of the New Keynesian channel relative to the cash-flow channel when shocks are temporary. Firms respond to the temporarily higher policy rates by decreasing production. This creates downward pressure on prices, but only temporarily as the inflation rate returns to its steady state level within a few quarters. As the inflation rate moves in the opposite direction of the nominal interest rate, the real rate increases even more than the policy rate, and as a result, monetary policy has real effects, as shown by the response of output and consumption that fall substantially in the short run – see bottom panel of Figure 4. The drop in consumption is heterogenous across the two types of agents. In fact, borrower's consumption falls almost four times as much as saver's consumption because the latter can partially smooth out the fall in labor income by investing in more profitable bonds. Given that borrowers do not have this margin of adjustment, they try to compensate for increased real mortgage payments by working more hours. However, they cannot fully compensate the fall in wages by their increase in hours, leading to a large drop in consumption. In any case, it is interesting how the response through hours worked is stronger in the *ARM economy* as real mortgage payments increase more – see Figure A1.

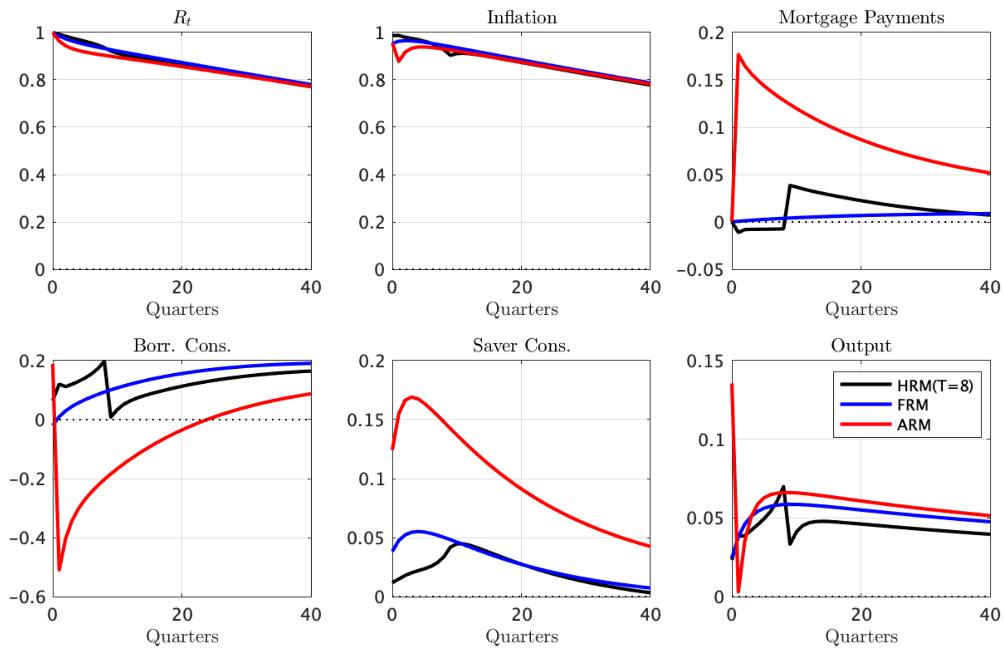


FIGURE 5. Response to a 1% (persistent) inflation target shock

NOTE. A value of 1 represents a 1% increase relative to the steady state except for mortgage payments, which are measured in percentage points. Output, borrower and saver's consumption are expressed in real terms, and together with inflation and the nominal interest rate are annualized.

The persistent monetary policy shock, modeled as an inflation target shock, has similar implications in terms of the pass-though to mortgage rates. As shown in Panel B of Figure 3, the average mortgage rate response in the *ARM economy* is again identical to the evolution of the nominal interest rate. The one-to-one pass through shows up immediately in the response of nominal mortgage payments, which increase persistently and are above their initial steady state value even after ten years – see 1st row, 3rd column of Figure 5. On the other hand, the pass-through to mortgage rates in the *FRM economy* takes longer to materialize. Borrowers exogenously refinance into persistently higher rates making the average mortgage rate in the economy increase only gradually. Finally, the pass-through in the *HRM economy* shares some features with the ARM and FRM economies. The average mortgage rate initially increases gradually up to the 8th quarter, when rates switch to being adjustable, and consequently, the average mortgage rate jumps up and then slowly decays given the persistent nature of the shock. As a result, nominal mortgage payments only jump up after two years which gets reflected in borrowers' consumption response.

Unlike for the temporary shock, the persistent change in the policy rate and consequently in mortgage rates has different effects on consumption depending on the mortgage contract structure. These effects are mostly distributional and wash out in the aggregate because firms adjust via prices rather than output, making the rate of inflation increase one-to-one with the nominal interest rate, which in turn leaves the real interest rate unchanged. As result, output and aggregate consumption are not affected and monetary policy has almost no real effects. Nevertheless, there is a redistribution of consumption from borrowers to savers as the persistent nature of the shock makes the increase in mortgage payments more costly to offset. This is particularly important in the *ARM economy* as the increase in mortgage rate is more pronounced and hence the drop in borrower's consumption and the increase in saver's consumption are larger than in the FRM and HRM economies. In other words, the redistributive effects of the shock are amplified when interest fixation periods are shorter.

5.1.1. The length of the fixation period and its impact on consumption

Until now we have focused on the consumption responses to temporary and persistent monetary policy shocks under the assumption that borrowers spend two years (8 quarters) under a fixed rate before automatically switching to an adjustable rate. This is the typical duration in the United Kingdom, however, the average duration varies across countries as shown in Section 2. It is important to recognize that in reality borrowers also have different number of periods left in the fixed part of their mortgage contract when the shock hits. Unfortunately, we cannot speak about the distribution of mortgage interest durations in the cross section as there is no heterogeneity on that front in our model economy. Nonetheless, as a first approximation to the problem we show in Figure 6 the response of borrower's and saver's consumption to an inflation target shock in HRM economies with different durations on the fixed part of the mortgage. In particular, the responses are depicted for the ARM, FRM and HRM economies with $T = \{1, \ldots, 8\}$. A clear message arises from this figure: the lower T is (lighter lines), the larger is the redistribution from borrower's consumption to saver's consumption since these responses are more and more similar to those in an economy with only ARMs.

The response of borrower's and saver's consumption to the temporary monetary policy shock for different HRM economies is not shown here because the cash-flow channel is unimportant when the shock is transitory and therefore consumption responses are independent of the mortgage contract structure, and consequently, of the duration in the fixed part of the contract for HRMs.

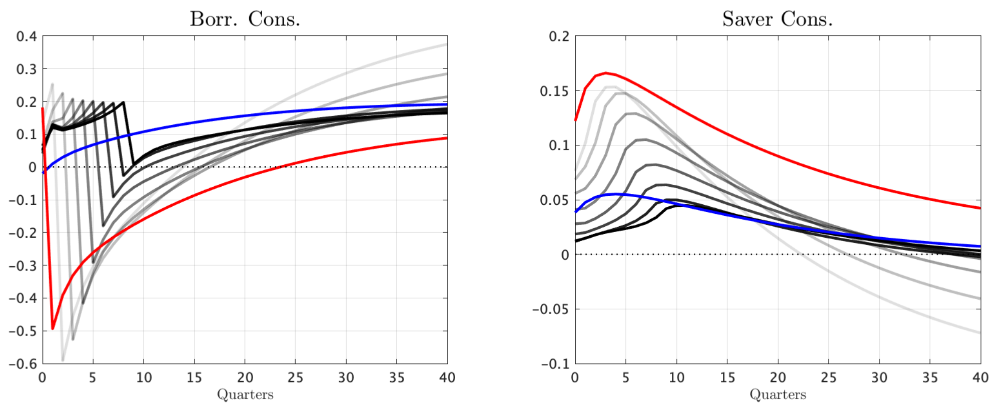


FIGURE 6. Consumption response to a 1% (persistent) inflation target shock under different contract durations

NOTE. A value of 1 represents a 1% increase relative to the steady state. The blue and the red lines corresponds to the FRM and the ARM economies. The different shades of black lines represent the response in a HRM economy, with T=8 being the darker line and T=1 corresponding to the lighter line.

5.2. Credit limits and the monetary policy transmission

In this section we focus on the interaction between monetary policy and credit limits. We carry out two types of exercises: *(i)* we analyze the responses to temporary and persistent shocks under different calibrations for the PTI and LTV limits, and *(ii)* we explore how the split between LTV- and PTI-constrained borrowers affects the strength of the transmission of monetary policy and its interaction with credit limits. For simplicity, we focus on ARM and FRM economies as the two extremes of HRM contracts and leave out other interest fixation periods from this analysis.

5.2.1. Alternative LTV and PTI limits: loose vs. tight credit

To understand the effects of different PTI and LTV calibrations on the transmission of monetary policy into the real economy, we compare the benchmark economy for which the population average credit limits are $\theta_{LTV} = 0.85$ and $\theta_{PTI} = 0.36$, with three counterfactual economies: *(i)* the *Loose LTV* economy that has a 20% looser maximum LTV limit, i.e. $\theta_{LTV} \approx 1.0$, *(ii)* the *Loose PTI* economy that has a 20% looser maximum PTI limit, i.e. $\theta_{PTI} \approx 0.43$, and *(iii)* the *Loose Credit* economy in which both PTI and LTV are 20% looser relative to the benchmark economy.

Figure 7 depicts the response to a monetary policy shock that raises the policy rate by 1% upon impact in the *ARM economy* under these four different calibrations. Recall that the interest fixation period was irrelevant in explaining the response to this shock as the

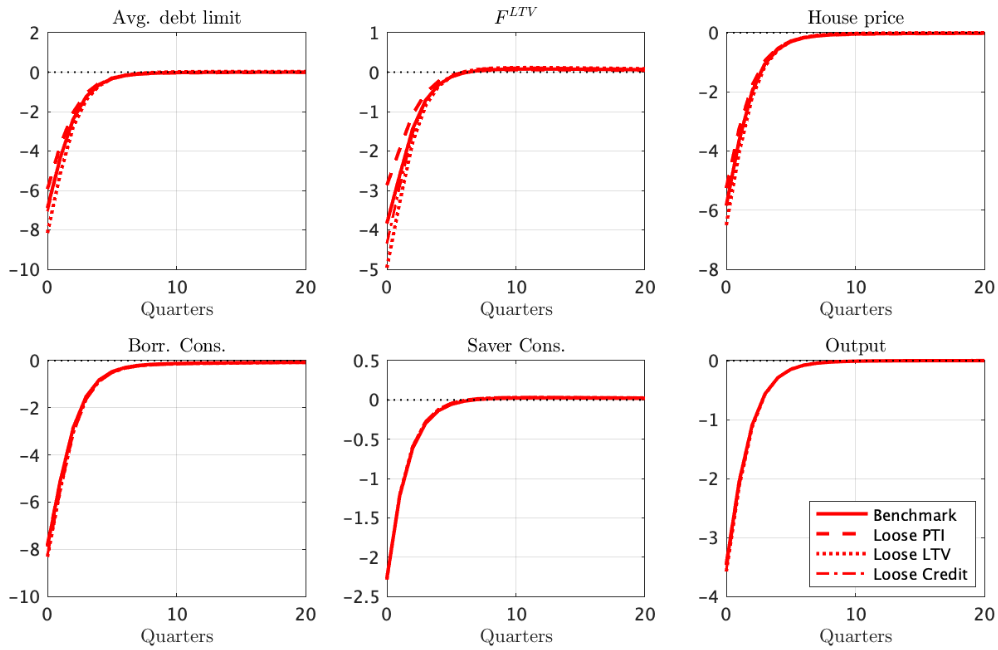


FIGURE 7. Loose Credit Limits & the Temporary Monetary Policy Shock – ARM Economy

NOTE. A value of 1 represents a 1% increase relative to the steady state, except for F^{LTV} and new issuance which are expressed in percentage points. New debt issuance is defined as: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, the house price is p_t^h, and the average debt limit $\bar{m}_t$. Output and consumption are reported in real terms.

New Keynesian channel dominated. Similarly, credit conditions, which are obviously related to the housing market, are also not important for explaining the response to this shock and we get almost identical responses regardless of the average credit limits. Intuitively, this result also holds for the *FRM economy* as shown in Panel A of Figure A3.

On the other hand, this is no longer true when the economy is hit by a shock that moves nominal interest rates persistently. Figure 8 displays the response to a 1% inflation target shock in the *ARM economy* under these four different calibrations. Intuitively, a looser LTV limit implies a lower steady state fraction of LTV-constrained borrowers (86.33% in the benchmark vs. 77.42% in the *Loose LTV* economy). Since the PTI limit is more sensitive to interest rate changes and there are initially more PTI-constrained borrowers, the average debt limit and the stock of debt fall more in the *Loose LTV* economy. Consequently, the lower housing demand pushes down house prices significantly more in this economy relative to the benchmark. In particular, ten years after the shock hits, house prices fall by 1.61% in the *Loose LTV economy*, while they only fall by 1.06% in the benchmark. On the other hand, a looser PTI calibration has the opposite effect: a larger steady state share of LTV-constrained borrowers (91.24%) implies a lower response of

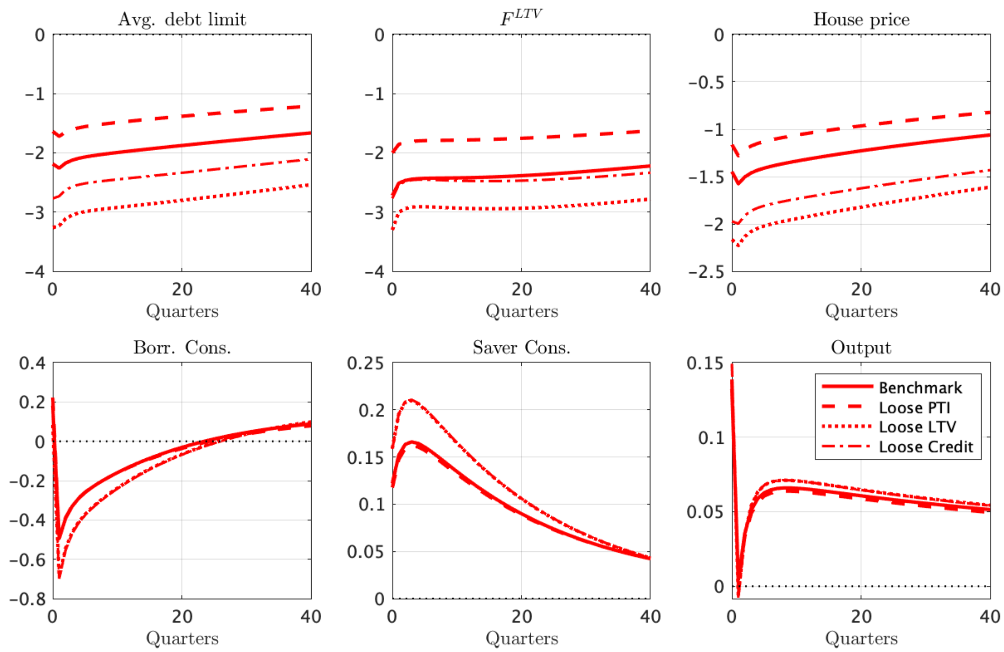


FIGURE 8. Loose Credit Limits & the Inflation Target Shock – ARM Economy

NOTE. A value of 1 represents a 1% increase relative to the steady state, except for F^{LTV} and new issuance which are expressed in percentage points. New debt issuance is defined as: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, the house price is p_t^h, and the average debt limit $\bar{m}_t$. Output and consumption are reported in real terms.

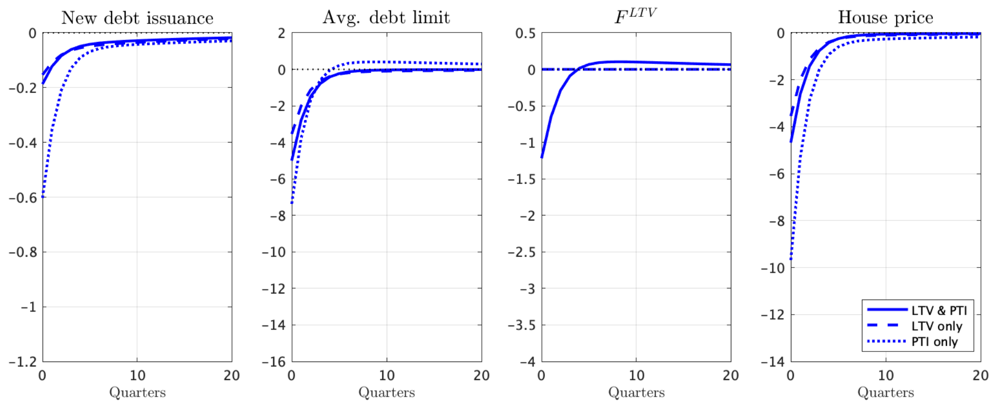
the average debt limit, the stock of debt and house prices despite the increased share of PTI-constrained borrowers associated to higher mortgage rates. Finally, when both credit limits are looser the effects associated with a looser LTV limit dominate as there are fewer steady state LTV-constrained borrowers (82.62%). Hence, the stock of debt, the average debt limit and house prices fall more when both credit limits are loose. In fact, ten years after the shock hits, house prices fall by 1.43% in the *Loose Credit economy*, which is in between the fall in the *Loose LTV* and benchmark economies as the looser PTI limit operates in the opposite direction. These results are consistent with other studies that find that looser credit limits amplify the effects of other shocks when these are permanent (Castellanos, Hannon, and Paz-Pardo 2024). In addition, it is interesting to note that differences in credit conditions also affect the consumption response of borrowers and savers. In particular, these are stronger when LTV limits are looser. In fact, the peak of saver's consumption is 25% larger and the lowest level of borrower consumption is 38% lower when LTVs are loose. On the other hand, looser PTI has only tiny effects on consumption.

In a nutshell, loose LTV limits amplify the effects on house prices and mortgage debt as well as the redistribution of consumption from borrowers to savers associated with persistent movements in the policy rate. Given that PTI limits operate in the opposite direction, coordinating the loosening of LTV limits and PTI limits helps in offsetting the effects of rates on house prices and mortgage debt as the latter act as a backstop. These effects are also present in the *FRM economy*, but they are slightly different quantitatively, as shown in Panel B of Figure A3.

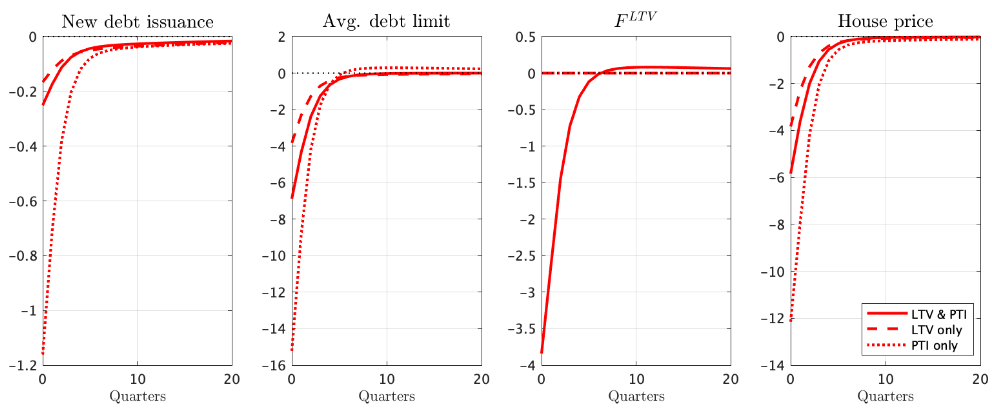
5.2.2. The complementarity between LTV and PTI limits

In the previous section, we have seen that the split between LTV- and PTI-constrained households is a relevant statistic to understand how credit conditions interact with nominal interest rate hikes. Consequently, we explore in this section how these two limits interact with each other. To do so, we consider two counterfactual economies: *(i)* the *LTV only economy* which imposes only the LTV constraint, and *(ii)* the *PTI only economy* which imposes only the PTI constraint. These are just two extremes in which all borrowers are constrained by one of the two limits. In fact, in many other available models, which would serve the same purpose as ours, only one of the two constrains binds (Garriga, Kydland, and Šustek 2021, Millard, Rubio, and Varadi 2024). Nonetheless, we follow Greenwald (2018) in allowing for a split between the two, which not only amplifies the transmission from rates to debt and house prices via the constraint switching effect, but also allow us to show how the initial steady state split between these two affects the transmission of monetary policy and how its strength depends on the interest fixation period.

Figure 9 shows the response of new debt issuance, the average debt limit, the fraction of borrowers constrained by the LTV, and the house price to a temporary monetary policy shock in the FRM (panel A) and ARM (panel B) economies with either one or both limits in place. Starting with the *PTI only economy* (dotted lines), we see that the constraint switching effect is switched off as there are no changes in F^{LTV}, however, the initial distribution is such that everyone is PTI-constrained. As PTI limits are more sensitive to interest rate changes and there is a weaker pass-though in the *FRM economy*, the response of new issuance, the average debt limit and the house price is substantially weaker in the *FRM economy*. In fact, in this economy the fall in house prices is 2.36 percentage points lower (9.69% vs. 12.15%), the drop in the average debt limit is 7.84 percentage points lower (7.38% vs. 15.22%) and the fall in debt issuance is half of that in the *ARM economy*. Interestingly, these wide differences are not present in the *LTV only*



A. Fixed Rate Mortgage Economy



B. Adjustable Rate Mortgage Economy

FIGURE 9. Constraint Switching & Temporary Monetary Policy Shocks

NOTE. A value of 1 represents a 1% increase relative to the steady state, except for F^{LTV} and new issuance which are expressed in percentage points. New debt issuance is defined as: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, the average debt limit: $\bar{m}_t$, and the house price: p_t^h.

economy (dashed lines) in which the steady state distribution is such that everyone is LTV-constrained. Intuitively, LTVs are not affected directly by changes in mortgage rates and hence the interest fixation period and its impact on the pass-through to mortgage rates becomes unimportant to explain the response to the shock.

Finally, turning to the benchmark economy with both LTV and PTI limits in place (solid lines), we see that the fraction of households constrained by the LTV decreases in both ARM and FRM economies as the increase in rates tightens the PTI limit. The stronger pass-through in the *ARM economy* and the high sensitivity of the PTI to changes in mortgage rates results into a larger drop in the fraction of LTV-constrained borrowers F^{LTV}, which is almost four times as large than the fall in the FRM economy. Despite this large difference, we only see a 1.17 percentage points larger drop upon impact on house prices (4.67% vs. 5.84%), a 1.88 percentage points larger fall in the average debt limit at time 0 (5.0% vs. 6.88%) and nearly no differences in the initial drop of new debt issuance between the *ARM economy* and *FRM economy*. In a nutshell, this implies that the constraint switching effect is more important when the fixation period is shorter, but it is the steady state distribution of LTV- and PTI-constrained households that matters the most.

6. Conclusion

In this paper, we provide a structural analysis of the impact of mortgage interest fixation periods on the strength of monetary policy and its interaction with borrower-based macro-prudential limits. We base our analysis in a standard housing model with long term debt and New Keynesian features to which we add hybrid rate mortgages to reflect the various interest fixation periods observed in cross country data.

The distinction between temporary and persistent increases in nominal interest rates as well as the inclusion of two types of credit limits, LTVs and PTIs, are crucial to understand our results. We show that a temporary increase in nominal interest rates leads to increased saving and reduced investment as firms react through changes in production rather than prices. As a result, households reduce consumption temporarily. This New Keynesian channel dominates the housing market channel, and consequently, the interest fixation period and credit conditions on borrowers' mortgages play a minor role in shaping the responses to this shock. On the other hand, shocks that lead to persistent increases in nominal interest rates have different impacts depending on both credit conditions and the interest fixation periods. In particular, an inflation target shock that persistently moves nominal interest rates leads to a redistribution from borrowers to savers which is stronger when LTV limits are looser and interest fixation periods are shorter. Moreover, we also find that the split between LTV and PTI constrained households is essential to get to these results. Otherwise, the highly sensitive PTI limits will amplify the effects of monetary policy shocks, even when temporary, and especially for economies dominated by short interest fixation periods.

Our paper highlights the importance of the interest fixation periods for the conduct of monetary and macro-prudential policies. These results open interesting avenues for future research. For instance, we need further understanding on the time variation of interest fixation periods in the data and how they may be affected by macroeconomic conditions. Another interesting line of research would be to disentangle why there are such institutional differences across countries in terms of fixation periods and whether these are related to borrowers' preferences or other factors. This may help explain why monetary policy is more powerful in some economies than others.

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Appendix A. Further Model Details

A.1. Fixed & adjustable rate mortgage economies

Fixed and adjustable rate mortgages have been an object of theoretical comparison for many years given their simplicity and predominance in many countries. Hence, we use them as a benchmark to which compare the HRM analyzed in this paper. This section shows the main equilibrium conditions of the model presented in Section **??** when all mortgages are assumed to be of either type: FRM or ARM.

When considering these economies, the only difference in the model specification concerns the evolution of mortgage payments. As shown in Greenwald (2018), borrower's promised payments in ARM and FRM are defined as

$$x_{b,t}^{ARM} = q_t^* m_t \tag{A1}$$

$$x_{b,t}^{FRM} = \rho q_t^* m_t^* + (1-\rho)(1-\nu)\pi_t^{-1} x_{b,t-1}^{FRM} \tag{A2}$$

respectively. Note that these two equations imply that promised payments is not a state variable in the ARM economy as these change period-by-period, while in the FRM economy it is. In fact, the promised payments in the previous period $x_{b,t-1}^{FRM}$ summarizes the entire history of payments given the recursive definition in (A2). For the saver, these only differ in the mortgage rate which is assumed to be net of taxes, i.e. $\left(q_t^* - \Delta_{q,t}\right)$.

These different specifications of the low of motion of promised payments impact household's optimality conditions as shown in Section 3.4. Here we show how to derive those conditions using the Lagrangian as a representation of the borrower's and saver's optimization problem. Appendix A.2 repeats these derivations in the HRM economy starting from the simplest case with one-period fixes.

A.1.1. FRM economy

Borrower's problem. It can be represented by the following Lagrangian

$$\begin{aligned}
\mathcal{L}_{b,t}^{FRM} = {} & u\left(c_{b,t}, h_{b,t-1}, n_{b,t}\right) + \beta_b \mathbb{E}_t V_b\left(m_t, h_{b,t}, x_{b,t}\right) + \lambda_{b,t}\Big((1-\tau_y) w_t n_{b,t} + \\
& -\pi_t^{-1}\left(\left(1-\tau_y\right) x_{b,t-1}^{FRM} + \nu m_{t-1}\right) + \rho\left(m_t^* - (1-\nu)\pi_t^{-1} m_{t-1}\right) + \\
& -\delta p_t^h h_{b,t-1} - \rho p_t^h\left(h_{b,t}^* - h_{b,t-1}\right) + T_{b,t} - c_{b,t} + \\
& +\mu_t \rho\left(\bar{m}_t^{PTI} \int^{\bar{e}_t} e_i d\Gamma_e(e_i) + \bar{m}_t^{LTV}\left(1-\Gamma_e\left(\bar{e}_t\right)\right) - m_t^*\right)\Big)
\end{aligned} \tag{A3}$$

where $V_b(m_t, h_{b,t}, x_{b,t})$ is the next period borrower's value function and $\lambda_{b,t}$ is the Lagrange multiplier associated to the borrower's budget constraint. Hence, the first order condition with respect to newly issued mortgages, $\frac{\partial \mathcal{L}_{b,t}^{FRM}}{\partial m_t^*} = 0$, implies

$$
\begin{aligned}
&\lambda_{b,t}\rho - \lambda_{b,t}\mu_t\rho = \beta_b \mathbb{E}_t \left[\lambda_{b,t+1}\pi_{t+1}^{-1}\rho \left(\left(1-\tau_y\right) q_t^* + \nu + \rho\left(1-\nu\right)\right)\right] + \\
&\quad + \beta_s^2 \mathbb{E}_{t+1}\left[\lambda_{b,t+2}\pi_{t+1}^{-1}\rho \left(\pi_{t+2}^{-1}\left(1-\rho\right)\left(1-\nu\right)\left(\left(1-\tau_y\right) q_t^* + \nu + \rho(1-\nu)\right)\right)\right] + \dots \\
&\quad + \beta_s^k \mathbb{E}_{t+k}\left[\lambda_{b,t+k+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^k\left(1-\nu\right)^k \left(\prod_{j=1}^{k}\pi_{t+j+1}^{-1}\right)\left(\left(1-\tau_y\right) q_t^* + \nu + \rho(1-\nu)\right)\right] + \dots
\end{aligned} \tag{A4}
$$

which we can write recursively as follows

$$1 = \Omega_{b,t}^{m} + \Omega_{b,t}^{x,FRM} q_t^* + \mu_t \tag{A5}$$

where μ_t is the multiplier on the borrower's aggregate credit limit, and $\Omega_{b,t}^{m}$ and $\Omega_{b,t}^{x,FRM}$ are the marginal costs to the borrower of taking on an additional dollar of face value debt, and of promising an additional dollar of initial payments. These values are defined by

$$\Omega_{b,t}^{m} = \mathbb{E}_t\left[\Lambda_{t,t+1}^{b}\pi_{t+1}^{-1}\left(\nu + \rho\left(1-\nu\right) + (1-\nu)(1-\rho)\Omega_{b,t+1}^{m}\right)\right] \tag{A6}$$

$$\Omega_{b,t}^{x,FRM} = \mathbb{E}_t\left[\Lambda_{t,t+1}^{b}\pi_{t+1}^{-1}\left(\left(1-\tau_y\right) + (1-\nu)(1-\rho)\Omega_{b,t+1}^{x,FRM}\right)\right] \tag{A7}$$

where we have used the definition of the borrower's stochastic discount factor

$$\Lambda_{t,t+1}^{b} \equiv \beta_b \frac{u_{b,t+1}^{c}}{u_{b,t}^{c}} \quad \text{where} \quad u_{b,t}^{c} = \frac{\partial u(c_{b,t}, h_{b,t}, n_{b,t})}{\partial c_{b,t}} . \tag{A8}$$

Saver's problem. It is characterized by the following Lagrangian

$$
\begin{aligned}
\mathcal{L}_{s,t}^{FRM} &= u\left(c_{s,t}, \tilde{H}_s, n_{t,s}\right) + \beta_s \mathbb{E}_t V_s\left(m_t, \tilde{H}_s, x_{s,t}\right) + \lambda_{s,t}\left(\left(1-\tau_y\right) w_t n_{s,t} + \right. \\
&\quad + \pi_t^{-1} x_{s,t-1}^{FRM} - \rho\left(m_t^* - (1-\nu)\pi_t^{-1} m_{t-1}\right) - \delta\, p_t^h \tilde{H}_s + \\
&\quad \left. - \left(R_t^{-1} b_t - b_{t-1}\right) + \Pi_t + T_{s,t} - c_{s,t}\right)
\end{aligned} \tag{A9}
$$

where $V_s(m_t, \tilde{H}_s, x_{s,t})$ is the next period saver's value function and $\lambda_{s,t}$ is the Lagrange multiplier associated to the saver's budget constraint. The first order condition with respect to newly issued mortgages $\frac{\partial \mathcal{L}^{FRM}_{s,t}}{\partial m^*_t} = 0$ is therefore given by

$$
\text{(A10)} \qquad \begin{aligned}
\lambda_{s,t}\rho_t = {} & \beta_s \mathbb{E}_t \left[\lambda_{s,t+1}\pi^{-1}_{t+1}\rho \left(\left(q^*_t - \Delta_{q,t} \right) + \rho \left(1 - \nu \right) \right) \right] + \\
& + \beta^2_s \mathbb{E}_{t+1} \left[\lambda_{s,t+2}\pi^{-1}_{t+1}\rho \left(\pi^{-1}_{t+2} \left(1 - \rho \right) \left(1 - \nu \right) \left(\left(q^*_t - \Delta_{q,t} \right) + \rho(1 - \nu) \right) \right) \right] + \ldots \\
& + \beta^k_s \mathbb{E}_{t+k} \left[\lambda_{b,t+k+1}\pi^{-1}_{t+1}\rho \left(1 - \rho \right)^k \left(1 - \nu \right)^k \left(\prod_{j=1}^{k} \pi^{-1}_{t+j+1} \right) \left(\left(q^*_t - \Delta_{q,t} \right) + \rho(1 - \nu) \right) \right] + \ldots
\end{aligned}
$$

which we can write recursively as follows

$$
\text{(A11)} \qquad 1 = \Omega^m_{s,t} + \Omega^{x,FRM}_{s,t} \left(q^*_t - \Delta_{q,t} \right)
$$

where $\Omega^m_{s,t}$ and $\Omega^{x,FRM}_{s,t}$ are the marginal continuation benefits to the saver of an additional unit of face value and an additional dollar of promised initial payments, respectively. These values are defined by

$$
\text{(A12)} \qquad \Omega^m_{s,t} = \mathbb{E}_t \left[\Lambda^s_{t,t+1}\pi^{-1}_{t+1} \left(\rho \left(1 - \nu \right) + (1 - \rho)(1 - \nu)\Omega^m_{s,t+1} \right) \right]
$$

$$
\text{(A13)} \qquad \Omega^{x,FRM}_{s,t} = \mathbb{E}_t \left[\Lambda^s_{t,t+1}\pi^{-1}_{t+1} \left(1 + \left(1 - \rho \right) \left(1 - \nu \right) \Omega^{x,FRM}_{s,t+1} \right) \right]
$$

where as for the borrower we have used the definition of the saver's stochastic discount factor.

A.1.2. ARM economy

The borrower's and the saver's optimization problems in the ARM economy are characterized by almost identical Lagrangians. Recall that the only difference is in the definition of the low of motion of promised payments. Hence, in this economy the Lagrangian of the borrower is given by equation (A3) after substituting $x^{FRM}_{s,t}$ by $x^{ARM}_{s,t}$. As a result of this change, the first order condition with respect to newly issued mortgages now is given by

$$
\text{(A14)} \qquad \begin{aligned}
\lambda_{b,t}\rho - \lambda_{b,t}\mu_t\rho = {} & \beta_s \mathbb{E}_t \left[\lambda_{b,t+1}\pi^{-1}_{t+1}\rho \left(\left(1 - \tau_y \right) q^*_t + \nu + \rho \left(1 - \nu \right) \right) \right] + \\
& + \beta^2_s \mathbb{E}_{t+1} \left[\lambda_{b,t+2}\pi^{-1}_{t+1}\rho \left(\pi^{-1}_{t+2} \left(1 - \rho \right) \left(1 - \nu \right) \left(\nu + \rho \left(1 - \nu \right) \right) \right) \right] + \ldots \\
& + \beta^k_s \mathbb{E}_{t+k} \left[\lambda_{b,t+k+1}\pi^{-1}_{t+1}\rho \left(1 - \rho \right)^k \left(1 - \nu \right)^k \left(\prod_{j=1}^{k} \pi^{-1}_{t+j+1} \right) \left(\nu + \rho \left(1 - \nu \right) \right) \right] + \ldots
\end{aligned}
$$

which in recursive from can be rewritten as follows

$$\Omega^{ARM}_{b,t} = 1 - \mu_t \tag{A15}$$

where $\Omega^{ARM}_{b,t}$ is the total continuation cost of an additional unit of debt in the ARM economy and is now defined as

$$\Omega^{ARM}_{b,t} = \mathbb{E}_t \left[\Lambda^{b}_{t,t+1} \pi^{-1}_{t+1} \left(\left(1-\tau_y\right) q^*_t + \nu + \rho\left(1-\nu\right) + \left(1-\nu\right)\left(1-\rho\right) \Omega^{ARM}_{b,t+1} \right) \right] . \tag{A16}$$

Similarly, the saver's optimization problem is also characterized by the Lagrangian in (A9) after substituting $x^{FRM}_{s,t}$ by $x^{ARM}_{s,t}$. Consequently, the first order condition with respect to newly issued mortgages is

$$\begin{aligned} \lambda_{s,t}\rho = {} & \beta_s \mathbb{E}_t \left[\lambda_{s,t+1} \pi^{-1}_{t+1} \rho \left(\left(q^*_t - \Delta_{q,t}\right) + \rho\left(1-\nu\right)\right) \right] + \\ & + \beta^2_s \mathbb{E}_{t+1} \left[\lambda_{s,t+2} \pi^{-1}_{t+1} \rho \left(\pi^{-1}_{t+2} \left(1-\rho\right)\left(1-\nu\right)\left(1+\rho(1-\nu)\right)\right) \right] + \ldots \\ & + \beta^k_s \mathbb{E}_{t+k} \left[\lambda_{b,t+k+1} \pi^{-1}_{t+1} \rho \left(1-\rho\right)^k \left(1-\nu\right)^k \left(\prod_{j=1}^{k} \pi^{-1}_{t+j+1} \right) \left(1+\rho(1-\nu)\right) \right] + \ldots \end{aligned} \tag{A17}$$

which can be rewritten in recursive form as

$$\Omega^{ARM}_{s,t} = 1 \tag{A18}$$

where $\Omega^{ARM}_{s,t}$ is again the total continuation benefit of an additional unit of debt in the ARM economy and it is given by

$$\Omega^{ARM}_{s,t} = \mathbb{E}_t \left[\Lambda^{s}_{t,t+1} \pi^{-1}_{t+1} \left(\left(q^*_t - \Delta_{q,t}\right) + \rho\left(1-\nu\right) + (1-\nu)(1-\rho)\Omega^{ARM}_{s,t+1} \right) \right] . \tag{A19}$$

A.2. The hybrid rate mortgage economy

A.2.1. The simplest example: a one-period HRM

Here we show the step-by-step computation of the first order condition of the borrower's and the saver's optimization problem with respect to the newly issued mortgages in an economy with HRM and a fixation period of one year. It helps building the intuition for the more general case with T periods in the fixed part of the contract.

Recall that the only difference between our economies is on the mortgage payment schedule. Hence, it is useful to start writing down the low of motion of promised payments for a HRM economy with one-period in the fixed rate:

(A20) $$x_{b,t}^{HRM(T1)} = \rho q_t^* m_t^* + (1-\rho)(1-\nu)\pi_t^{-1} q_{t-1}^* m_{t-1}$$

where the first summand refers to the payments made when refinancing today and therefore subject to the current mortgage rate, while the second term corresponds payments made when having refinanced the period before and consequently are fixed to the rate prevailing in the previous period.

Borrower's Problem. It be represented by the Lagrangian in (A3) after substituting x_t^{FRM} for $x_t^{HRM(T1)}$. Consequently, the first order condition with respect to newly issued mortgages in this economy is

(A21) $$\begin{aligned}\lambda_{b,t}\rho - \lambda_{b,t}\mu_t\rho = \beta_s \mathbb{E}_t &\left[\lambda_{b,t+1}\pi_{t+1}^{-1}\rho\left(\left(1-\tau_y\right)q_t^* + \nu + \rho\left(1-\nu\right)\right)\right] + \\ + \beta_s^2 \mathbb{E}_{t+1} &\left[\lambda_{b,t+2}\pi_{t+1}^{-1}\rho\left(\pi_{t+2}^{-1}\left(1-\rho\right)\left(1-\nu\right)\left(\left(1-\tau_y\right)q_t^* + \nu + \rho(1-\nu)\right)\right)\right] + \\ + \beta_s^3 \mathbb{E}_{t+2} &\left[\lambda_{b,t+3}\pi_{t+1}^{-1}\rho\left(\pi_{t+2}^{-1}\pi_{t+3}^{-1}\left(1-\rho\right)^2\left(1-\nu\right)^2\right)\left(\nu + \rho(1-\nu)\right)\right] + \ldots \\ + \beta_s^k \mathbb{E}_{t+k} &\left[\lambda_{b,t+k+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^k\left(1-\nu\right)^k\left(\prod_{j=1}^{k}\pi_{t+j+1}^{-1}\right)\left(\nu + \rho(1-\nu)\right)\right] + \ldots\end{aligned}$$

which we can be rewritten as follows

(A22) $$1 = \Omega_{b,t}^m + \Omega_{b,t}^{x,HRM} q_t^* + \mu_t$$

where μ_t is the multiplier on borrower's aggregate credit limit, $\Omega_{b,t}^m$ is the marginal cost to the borrower of taking an additional dollar of face value debt, and $\Omega_{b,t}^{x,HRM}$ is the marginal cost to the borrower of promising an additional dollar of initial payments and it is given by:

(A23) $$\begin{aligned}\Omega_{b,t}^{x,HRM} =& \mathbb{E}_t\left[\Lambda_{t,t+1}^b \pi_{t+1}^{-1}(1-\tau_y)\right] + \\ &+ \mathbb{E}_t\left[\Lambda_{t,t+1}^b \Lambda_{t+1,t+2}^b \pi_{t+1}^{-1}\pi_{t+2}^{-1}(1-\rho)(1-\nu)(1-\tau_y)\right] .\end{aligned}$$

Intuitively, the marginal continuation cost to the borrower of an additional dollar of payments is a finite sum truncated at the end of the fixed period.

Saver's Problem. As for the borrower, the saver's problem is defined by the Lagrangian in (A9) after substituting x_t^{FRM} for $x_t^{HRM(T1)}$. As a result, the first order condition with respect to newly issued mortgages is given by

$$
\begin{aligned}
\lambda_{s,t}\rho = {} & \beta_s \mathbb{E}_t \left[\lambda_{s,t+1}\pi_{t+1}^{-1}\rho\left(\left(q_t^* - \Delta_{q,t}\right) + \rho\left(1-\nu\right)\right)\right] + \\
& + \beta_s^2 \mathbb{E}_{t+1}\left[\lambda_{s,t+2}\pi_{t+1}^{-1}\rho\left(\pi_{t+2}^{-1}\left(1-\rho\right)\left(1-\nu\right)\left(\left(q_t^* - \Delta_{q,t}\right) + \rho(1-\nu)\right)\right)\right] + \\
& + \beta_s^3 \mathbb{E}_{t+1}\left[\lambda_{s,t+3}\pi_{t+1}^{-1}\rho\left(\pi_{t+2}^{-1}\pi_{t+3}^{-1}\left(1-\rho\right)^2\left(1-\nu\right)^2\left(1+\rho(1-\nu)\right)\right)\right] + \ldots \\
& + \beta_s^k \mathbb{E}_{t+k}\left[\lambda_{b,t+k+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^k\left(1-\nu\right)^k\left(\prod_{j=1}^{k}\pi_{t+j+1}^{-1}\right)\left(1+\rho(1-\nu)\right)\right] + \ldots
\end{aligned} \tag{A24}
$$

which can be rewritten in the following form

$$
1 = \Omega_{s,t}^{m} + \Omega_{s,t}^{x,HRM(T1)}\left(q_t^* - \Delta_{q,t}\right) \tag{A25}
$$

where $\Omega_{s,t}^{m}$ is the marginal continuation benefit of an additional unit of face value debt as defined in equation (26) and $\Omega_{s,t}^{x,HRM(T1)}$ is the marginal benefit to the saver of promising an additional dollar of initial payments and it is defined as

$$
\Omega_{s,t}^{x,HRM(T1)} = \mathbb{E}_t\left[\Lambda_{t,t+1}^{s}\pi_{t+1}^{-1}\right] + \mathbb{E}_t\left[\Lambda_{t,t+1}^{s}\Lambda_{t+1,t+2}^{s}\pi_{t+1}^{-1}\pi_{t+2}^{-1}(1-\rho)(1-\nu)\right] . \tag{A26}
$$

A.2.2. A general T-periods HRM

Using the intuition from the simplest case we show the derivations required to obtain the first order conditions shown in Section 3.4 for the general HRM economy. We first start with the first order condition of the borrower's problem with respect to newly issued mortgages

$$
\begin{aligned}
\lambda_{b,t}\rho - \lambda_{b,t}\mu_t\rho = {} & \beta_s \mathbb{E}_t\left[\lambda_{b,t+1}\pi_{t+1}^{-1}\rho\left(\left(1-\tau_y\right)q_t^* + \nu + \rho\left(1-\nu\right)\right)\right] + \ldots \\
& + \beta_s^2 \mathbb{E}_{t+1}\left[\lambda_{b,t+2}\pi_{t+1}^{-1}\rho\left(\pi_{t+2}^{-1}\left(1-\rho\right)\left(1-\nu\right)\left(\left(1-\tau_y\right)q_t^* + \nu + \rho(1-\nu)\right)\right)\right] + \ldots \\
& + \beta_s^T \mathbb{E}_{t+T}\left[\lambda_{b,t+T+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^T\left(1-\nu\right)^T\left(\prod_{j=1}^{T}\pi_{t+j+1}^{-1}\right)\left(\left(1-\tau_y\right)q_t^* + \nu + \rho(1-\nu)\right)\right] + \ldots \\
& + \beta_s^k \mathbb{E}_{t+k}\left[\lambda_{b,t+k+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^k\left(1-\nu\right)^k\left(\prod_{j=1}^{k}\pi_{t+j+1}^{-1}\right)\left(\nu + \rho(1-\nu)\right)\right] + \ldots
\end{aligned} \tag{A27}
$$

where here $T < k$. This condition can be rearranged and rewritten as equation (24). Note that, intuitively, the term $\left(1-\tau_y\right)q_t^*$ only shows up until period T as the history of payments only matter for the marginal continuation value unit then. In contrast, this term only shows up for the first summand in the ARM economy, while it always shows up for the FRM economy.

Similarly, the first order condition of the saver's optimization problem with respect to newly issued mortgages is given by

$$
\begin{aligned}
\lambda_{s,t}\rho = {} & \beta_s \mathbb{E}_t \left[\lambda_{s,t+1}\pi_{t+1}^{-1}\rho\left(\left(q_t^* - \Delta_{q,t}\right) + \rho\left(1-\nu\right)\right)\right] + \\
& + \beta_s^2 \mathbb{E}_{t+1}\left[\lambda_{s,t+2}\pi_{t+1}^{-1}\rho\left(\pi_{t+2}^{-1}\left(1-\rho\right)\left(1-\nu\right)\left(\left(q_t^* - \Delta_{q,t}\right) + \rho(1-\nu)\right)\right)\right] + \\
& + \beta_s^T \mathbb{E}_{t+T}\left[\lambda_{b,t+T+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^T\left(1-\nu\right)^T\left(\prod_{j=1}^{T}\pi_{t+j+1}^{-1}\right)\left(\left(q_t^* - \Delta_{q,t}\right) + \rho(1-\nu)\right)\right] + \ldots \\
& + \beta_s^k \mathbb{E}_{t+k}\left[\lambda_{b,t+k+1}\pi_{t+1}^{-1}\rho\left(1-\rho\right)^k\left(1-\nu\right)^k\left(\prod_{j=1}^{k}\pi_{t+j+1}^{-1}\right)\left(1+\rho(1-\nu)\right)\right] + \ldots
\end{aligned} \tag{A28}
$$

where $T < k$ and again can be rearranged and rewritten as equation (27).

Appendix B. Additional Figures

B.1. Temporary monetary policy shock

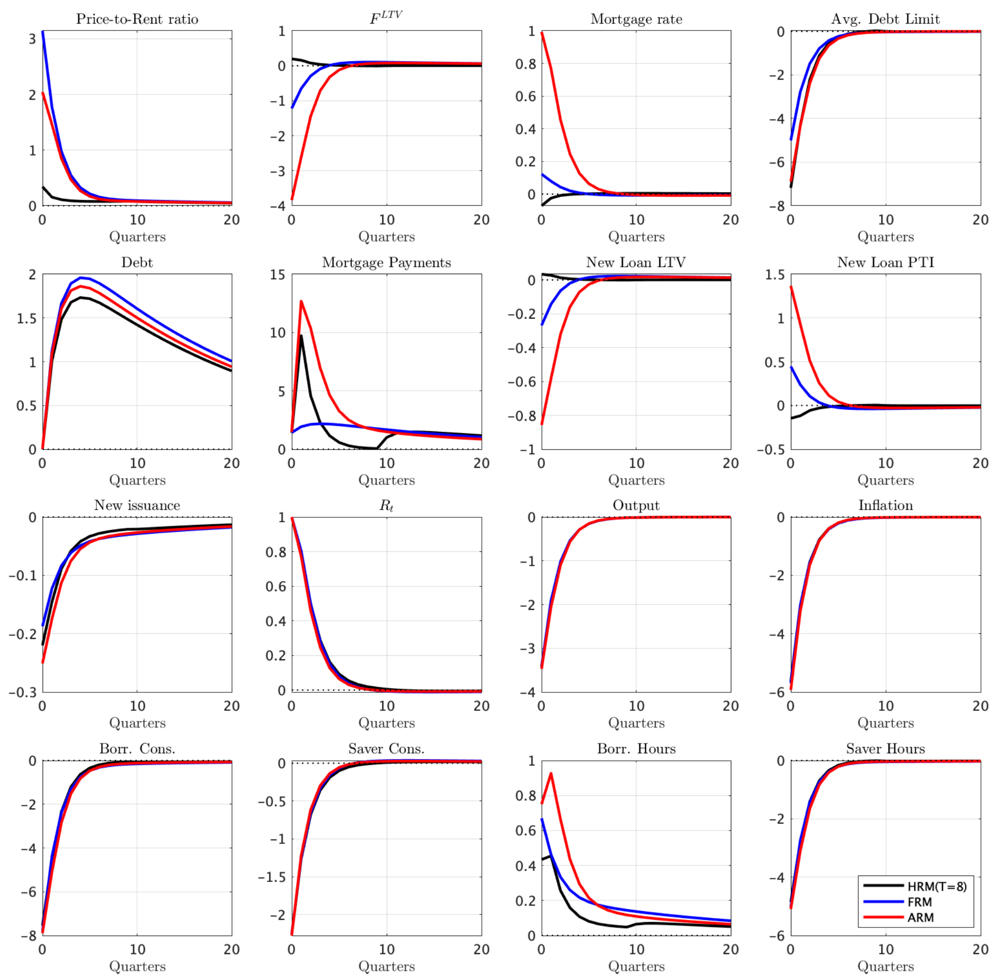


FIGURE A1. Response to a 1% (temporary) monetary policy shock

NOTE. Responses are normalized such that R_t increases by 1% upon impact in the HRM, FRM & ARM economies. A value of 1 represents a 1% increase relative to the steady state except for F^{LTV}, New Loan LTV, and New Loan PTI, which are measured in percentage points, and New Issuance, which is measured as a fraction of steady state output. Variable definitions are as follows. Price-to-Rent Ratio: $p_t^h/(u_t^h/u_t^c)$, Mortgage Rate: $q_t^* - \nu$, Avg. Debt Limit: $\bar{m}_t$, Debt: m_t, Mortgage payments: $\pi_t^{-1}x_{t-1}$, New Issuance: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, New Loan LTV: $m_t^*/p_t^h h_{b,t}^*$, New Loan PTI: $q_t^* m_t^*/w_t n_{b,t}$. Avg. Debt Limit, Debt, Output, Borr. Cons. and Saver Cons. are reported in real terms. Mortgage Rate, R_t, Output and Inflation are annualized.

B.2. Persistent inflation target shock

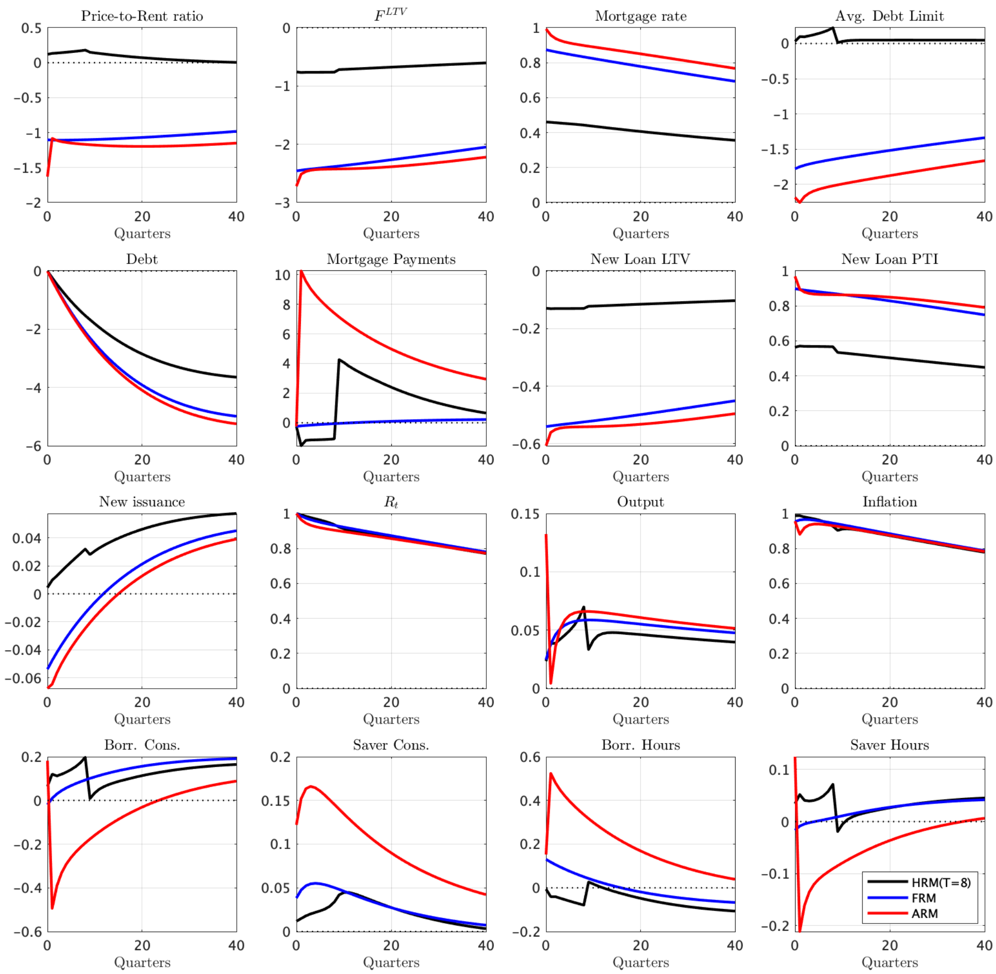
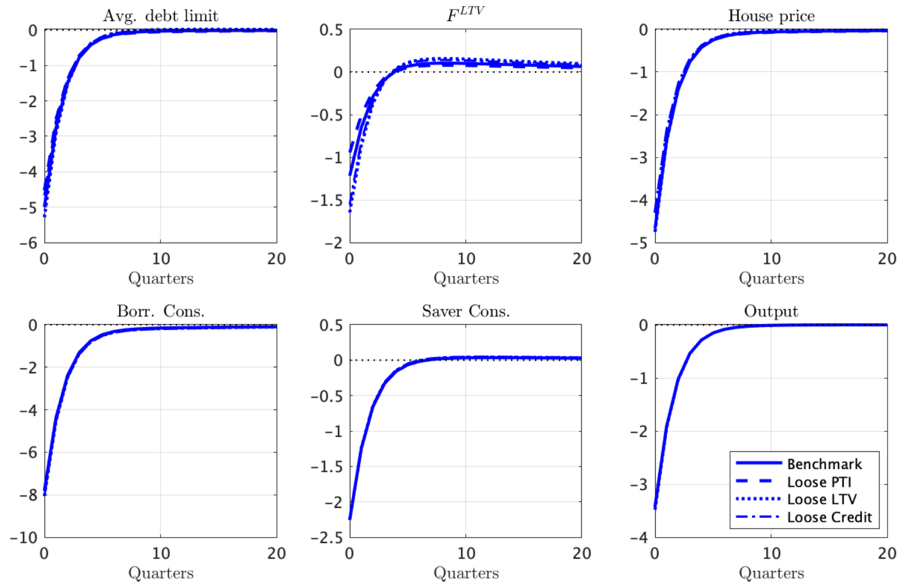


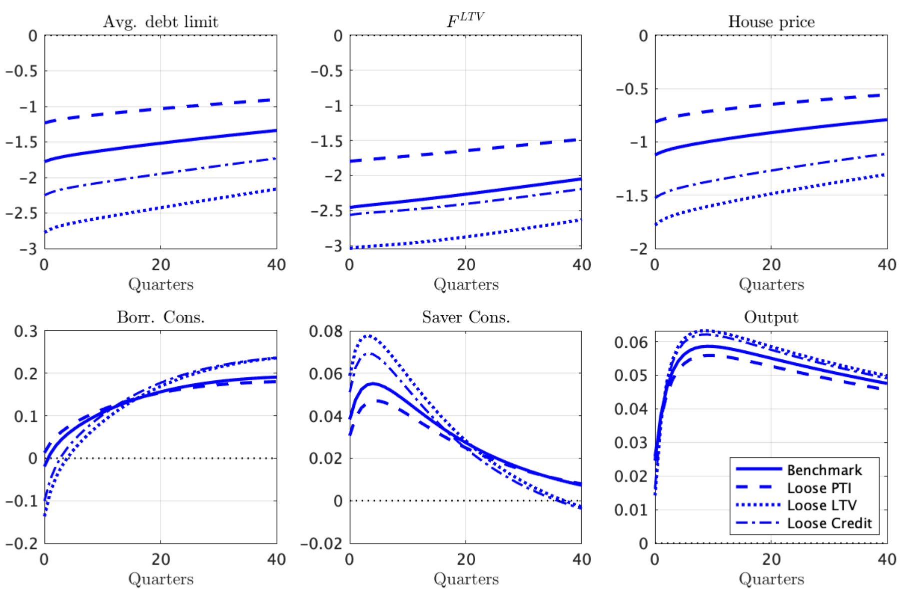
FIGURE A2. Response to a 1% (persistent) inflation target shock

NOTE. Responses are normalized such that R_t increases by 1% upon impact in the HRM, FRM & ARM economies. A value of 1 represents a 1% increase relative to the steady state except for F^{LTV}, New Loan LTV, and New Loan PTI, which are measured in percentage points, and New Issuance, whic is measured as a fraction of steady state output. Variable definitions are as follows. Price-to-Rent Ratio: $p_t^h/(u_t^h/u_t^c)$, Mortgage Rate: $q_t^* - \nu$, Avg. Debt Limit: $\bar{m}_t$, Debt: m_t, Mortgage payments: $\pi_t^{-1}x_{t-1}$, New Issuance: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, New Loan LTV: $m_t^*/p_t^h h_{b,t}^*$, New Loan PTI: $q_t^* m_t^*/w_t n_{b,t}$. Avg. Debt Limit, Debt, Output, Borr. Cons. and Saver Cons. are reported in real terms. Mortgage Rate, R_t, Output and Inflation are annualized.

B.3. Alternative PTI & LTV calibrations



A. Temporary Monetary Policy Shock

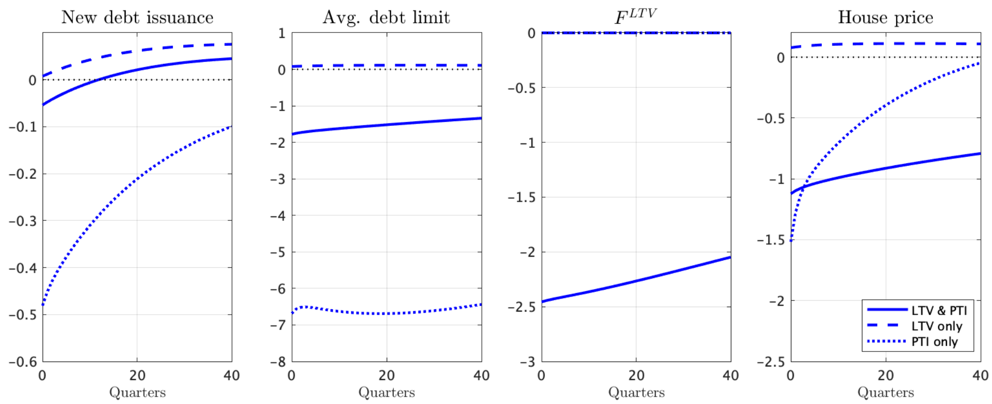


B. Inflation Target Shock

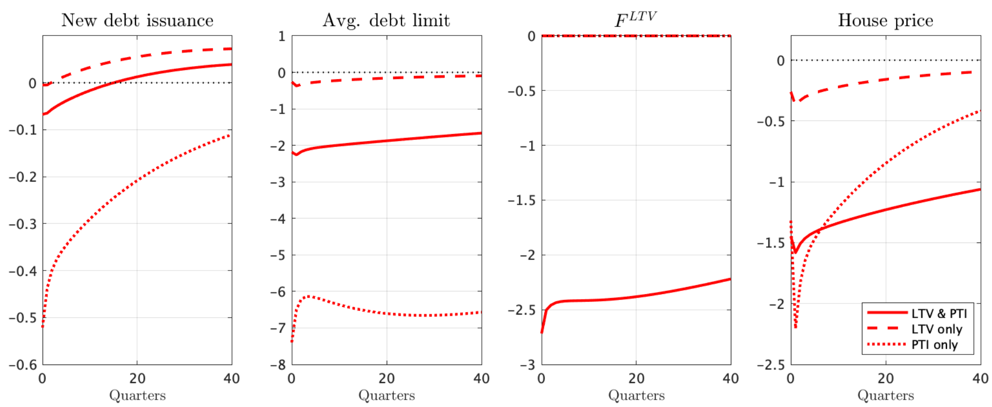
FIGURE A3. Loose Credit Limits & the Fixed Rate Mortgage Economy

NOTE. A value of 1 represents a 1% increase relative to the steady state, except for F^{LTV} and new issuance which are expressed in percentage points. New debt issuance is defined as: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, the house price is p_t^h, and the average debt limit $\bar{m}_t$. Output and consumption are reported in real terms.

B.4. Constraint Switching Effect



A. Fixed Rate Mortgage Economy



B. Adjustable Rate Mortgage Economy

FIGURE A4. Constraint Switching & Persistent Inflation Target Shocks

NOTE. A value of 1 represents a 1% increase relative to the steady state, except for F^{LTV} and new issuance which are expressed in percentage points. New debt issuance is defined as: $\rho(m_t^* - (1-\nu)\pi_t^{-1}m_{t-1})$, the average debt limit: $\bar{m}_t$, and the house price: p_t^h.