The effects of monetary policy through housing and mortgage choices on aggregate demand

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Abstract

Housing and mortgage choices are among the largest financial decisions households make and they substantially impact households' liquidity. This paper explores how monetary policy affects aggregate demand by influencing these portfolio choices. To quantify this channel, I build a heterogeneous-agent life-cycle model with long-term mortgages and endogenous house prices. I find that, although only a small fraction of households adjust their housing and mortgage holdings in response to an expansionary monetary policy shock, these households account for 50 percent of the increase in aggregate demand. Mortgage refinancing explains approximately two thirds of the contribution, whereas adjusted housing choices account for one third—uncovering a new transmission channel. I also show that the different pass-through of the policy rate to short and long mortgage rates drives the difference in the aggregate demand response between economies with predominantly adjustable-rate mortgages and economies with fixed-rate mortgages.

Keywords: Monetary policy, household finance, housing, mortgages, life cycle
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1 Introduction

In this paper I build a quantitative heterogeneous-agent model to explore the relevance of the interactions between monetary policy and the housing market for aggregate demand. Two broad observations motivate my study.

First, in the U.S. over 40 percent of households have a mortgage and the outstanding mortgage debt surpassed USD 15.5 trillion in 2019, which corresponds to about 70 percent of GDP. Hence, changes in mortgage interest rates can substantially impact many households' finances. Moreover, the prevailing mortgage interest rate is an important input when households decide on what houses (if any) they can afford, which in turn affects house prices. With housing being the largest asset on most American households' balance sheets, this channel is potentially an important transmission mechanism of monetary policy into the real economy and aggregate demand, via the pass-through of the central bank's policy rate to mortgage interest rates. Indeed, since the Great Recession, there has been an increased focus on mortgage and housing markets among policy makers. Central banks in many countries are concerned with the extent to which monetary policy affects house prices and household debt, and ultimately how these effects impact consumption demand.

Second, we know that the liquidity positions of households are important for the transmission of monetary policy. Households that are liquidity constrained tend to have strong demand responses to changes in their cash flows, as emphasized in the Heterogeneous Agent New Keynesian (HANK) literature (see Kaplan et al. (2018)). Importantly, both mortgage and housing choices tend to involve substantial cash flows and significantly alter households' liquidity. Hence, if liquidity-constrained households adjust these choices in response to changes in interest rates it can have real and direct implications for aggregate demand.

In my quantitative heterogeneous-agent life-cycle model I analyze these forces. I investigate the role that choices in the housing and mortgage market play for the aggregate demand response of monetary policy.[1] By constructing a model that captures the frictions in these markets, I study how different households' mortgage and housing choices influence their spending, when interest rates change. Furthermore, by including endogenous house prices, I quantify the importance of house-price changes for these portfolio choices. To analyze the effects of monetary policy, I feed in an exogenous real interest rate path, which corresponds to an empirically estimated response from an expansionary monetary policy shock. I find that although only a small share of households make extensive-margin adjustments of their portfolio of housing and mortgages in response to the shock, this group

[1] My focus is on changes in consumption demand, and I use the terms aggregate demand, aggregate consumption demand, and aggregate spending, interchangeably.

accounts for approximately 50 percent of the increase in aggregate spending. Specifically, I document a new channel of monetary transmission, namely, households who update their housing choice. These households account for about 16 percent of the increase in aggregate spending. Together with households who refinance their mortgage, they are the main contributors to the increase in demand. I also show that the aggregate consumption response is highly dependent on the pass-through of the policy rate to mortgage interest rates and the effect on house prices. In fact, the different pass-through to short and long mortgage rates can explain the difference in the aggregate spending response in economies with primarily adjustable-rate as compared to fixed-rate mortgages.

To explore these mechanisms it is important to model the mortgage and housing markets in sufficient detail. In the model, households choose how much to consume, whether to rent or own a house, their house size, mortgage financing, and savings in risk-free liquid bonds. Importantly, owned housing is illiquid and markets are incomplete as households cannot fully insure against idiosyncratic earnings risks. There are two features of the housing market that create the illiquid nature of housing equity. First, households pay transaction costs to buy or sell a house. Second, if a homeowner wants to access its housing equity by taking up a larger mortgage, it incurs refinancing costs. Additional features of the housing market include down-payment and payment-to-income requirements that have to be fulfilled when purchasing a home or refinancing a mortgage.

Since households cannot perfectly insure against earnings risks, there are households who are constrained due to poor earnings realizations. Furthermore, since housing wealth is illiquid, there are also some relatively wealthy households that are constrained in their spending. In particular, many young homeowners use large mortgages to finance their house purchase and save mainly for precautionary reasons as they expect higher earnings in the future. These homeowners are therefore relatively liquidity constrained and have high exposures to changes in interest rates. Notably, in this model, households may endogenously generate substantial changes in their cash flows in response to monetary policy. When the mortgage interest rate changes, some households find it optimal to adjust their mortgage and housing holdings, with large implications for their liquidity. Hence, unlike in standard models, where cash-flow effects of a monetary policy shock only occur over time in the form of changes in the return on savings and through general-equilibrium effects on earnings, in this model some households instantly realize sizeable changes in their cash flows.

The calibrated model matches salient life-cycle and cross-sectional features of the U.S. data, relating to housing, mortgage debt, net worth, and liquid savings. Importantly, the model replicates the share of liquidity-constrained homeowners in the data. Thus, by including housing as an illiquid asset, with frictions measured in the data, the model is able to match the prevalence of wealthy, liquidity-constrained households.

To then study how households respond to monetary policy shocks, I use shocks to the real interest rate that are empirically estimated. In the main analysis, I consider a -100 basis points (bp) shock to the nominal interest rate, which affects the economy through its impact on the real interest rates on bonds and mortgages.

Results on aggregate responses and portfolio choice

In response to the expansionary monetary policy shock, I find that house prices rise by 2.0 percent and aggregate consumption demand increases by 0.7 percent. Moreover, I find that households' discrete portfolio adjustments of whether to rent, buy, move, or stay in a house, and the use of mortgage refinancing, substantially impact the effect on aggregate demand. Specifically, if restricting households to make the same extensive-margin portfolio choices as they had done without the shock, the aggregate demand response is 50 percent lower, even though this constraint only affects 6 percent of households.[2] Furthermore, I find that both the pass-through of the monetary policy shock to mortgage interest rates as well as the response in house prices are important for the response in aggregate consumption. In fact, if the monetary policy shock solely impacts the return on bonds, hardly any households make extensive-margin portfolio adjustments, and the increase in aggregate demand is reduced by over 90 percent.

The decline in the mortgage interest rate causes almost all of the increase in house prices. Most households who buy a house finance the purchase with a mortgage. By purchasing a house, a household can immediately transform the negative income effect from the lower return on savings into a benefit of lower interest payments on debt. As a result, the demand for housing increases, and there is a rise in the equilibrium house price.

When mortgage interest rates decrease and house prices rise, many households would like to take up a larger mortgage and reoptimize their choice of housing. However, due to frictions and adjustment costs in these markets, only a small share of households find it worthwhile to make such discrete reallocations. Importantly, the liquidity-constrained homeowners are among those who benefit the most from adjusting, since by doing so they can access their illiquid housing wealth. With higher liquid savings they are able to improve their consumption smoothing by directly increasing spending. Specifically, I find that homeowners who use cash-out refinancing in response to the expansionary monetary policy shock account for 36 percent of the increase in aggregate demand, a channel emphasized in previous literature. However, liquidity-constrained homeowners have two viable options to access their illiquid housing wealth: sell the house and move to a new owner-occupied house or move to rental housing. Since the lower mortgage

[2] In this exercise, I force households to choose the same house size and the same discrete mortgage and tenure choice (rent, buy a house, refinance, move, or stay in a house) as if the shock had not occurred.

interest rate causes house prices to rise, it is a particularly good alternative to sell a house. The higher house prices also cause some renters to delay the purchase of a house. Being relieved from the required down payment and transaction costs of buying, these households also consume more in response to the shock. Overall, households who adjust their housing choice due to the interest rate shock account for 16 percent of the increase in aggregate demand. Hence, I document and quantify an additional important channel, that can explain a large share of the increase in aggregate spending.

Mortgage contracts and the pass-through to mortgage interest rates
Recent findings show that households who have mortgages with adjustable rate tend to respond strongly to monetary policy, since their cash flows are directly affected by changes in mortgage interest rates (Di Maggio et al. (2017) and Flodén et al. (2020)). On the other hand, following an expansionary monetary policy shock, the incentives to refinance a mortgage and withdraw equity are potentially larger when mortgages have fixed rate. To investigate the importance of mortgage contract specifications for the transmission of monetary policy, I compare my results from the setting where the available mortgage is a fixed-rate 30-year contract, to an economy where mortgages have variable rate.

With adjustable-rate mortgages (ARMs), the consumption response is significantly larger, following the temporary decline in the interest rate. The fact that all mortgagors experience lower mortgage interest payments with ARMs contributes to a stronger increase in demand among households who do not make extensive-margin portfolio adjustments in response to the shock. Moreover, discrete portfolio updates continue to play an important role. Marginal house buyers benefit more from the less persistent but larger decrease of the mortgage interest rates of ARMs. As a result, house prices increase more, which actually makes it beneficial for a larger number of homeowners to use cash-out refinancing to increase spending, relative to the setting with fixed-rate mortgages (FRMs).

I proceed by examining how the pass-through rate of the monetary policy shock to long interest rates influences the aggregate spending response under FRMs. First, I find that the higher the pass-through, the stronger is the house-price response. Second, if long rates respond equally strong as short rates to the monetary policy shock, the aggregate demand response is remarkably similar in economies with FRMs and ARMs. The benefit that all existing mortgagors are affected by the lower mortgage interest rate under ARMs is roughly as important for aggregate demand as the benefit of persistently low rates of new mortgages under FRMs.

Overall, my findings show that a key driver of the response in aggregate consumption is the improved consumption smoothing of liquidity-constrained households who update their housing and mortgage choices. The importance of this portfolio channel of monetary policy has implications for a well-known puzzle in the monetary-policy literature: the forward guidance puzzle. A change in interest rates far into the future does little for households who are currently constrained. Thus, the forward-guidance critique does not apply to this channel of monetary policy transmission. I conclude that including housing and mortgages in the analysis of monetary policy has qualitative implications for the transmission channels, and can have quantitatively important consequences for aggregate responses. Thus, a detailed understanding of the housing and mortgage markets is a valuable input in monetary-policy analysis.

The paper is organized as follows. In the remainder of this section I discuss how my findings relate to the literature. Section 2 describes the model. In Section 3, I proceed by calibrating the model to U.S. data, and I compare the model to the data along a range of relevant variables. In Section 4, I present and discuss my results. Section 5 concludes the paper.

1.1 Related literature

There are several empirical studies that suggest that mortgages play an important role in the transmission of monetary policy. In particular, households who experience changes in their mortgage interest payments adjust their consumption to a greater extent than other homeowners (Di Maggio et al., 2017; Flodén et al., 2020). Calza et al. (2013) show that in countries where variable-rate mortgages are more common, house prices and consumption respond more strongly to monetary policy shocks. Cloyne et al. (2019) conclude that the aggregate response to monetary policy is largely driven by mortgagors and households with little liquid wealth. The link between changes in house prices, mortgage debt, and spending is documented in, e.g., Mian et al. (2013) and Mian and Sufi (2014). I use all of these findings as motivating facts that I rationalize in my model. Moreover, I show that approximately half of the effect on aggregate demand comes from households who change their discrete choices. This mechanism is inherently difficult to capture empirically when the counterfactual is not observed. Changes in shares of households of who make different housing and mortgage transactions can be observed, but I show that these mask a rich heterogeneity.

There is an extensive literature that studies the transmission of monetary policy within the framework of dynamic stochastic general equilibrium models. Recently, the importance of incorporating heterogeneous agents with various degrees of liquid and illiquid wealth has been emphasized by Kaplan et al. (2018). In my model, owned housing is an illiquid asset that can be financed with a mortgage, and the costs associated with accessing housing equity are measured in the data. While Kaplan et al. (2018) find that the direct effects of interest rate shocks are small, I show that when including mortgages in the analysis the direct effects can be substantial. The interest rate exposure channel, highlighted in Auclert (2019), is the underlying cause of the heterogeneous income effects of households in my model. However, the focus of my paper is on the subsequent dynamics in the housing and mortgage markets, and how households' choices in these markets influence aggregate spending. The demand effect that I find to be driven by an improved consumption smoothing, is related to the work by McKay and Wieland (2019) on lumpy durable consumption demand. Due to sizeable frictions and transaction costs associated with changing housing and mortgage holdings, changes in housing equity and optimal consumption can be rather lumpy, and monetary policy can affect the timing of adjustments. The severity of the liquidity constraints in the housing market is studied in Boar et al. (2017), who focus on implications for tax rebates and mortgage relief programs. Greenwald (2018) and Hedlund et al. (2021) incorporate housing and mortgages in large structural models and find that endogenous changes in house prices amplify aggregate responses to monetary policy shocks, something that I also find. Furthermore, my results show that extensive-margin portfolio updates among a small group of households are essential for the demand response, a mechanism that requires a rich heterogeneity among households. Specifically, in my model household characteristics are crucial for endogenous portfolio updates, whereas only aggregate states and states of the representative borrower matter in the model in Greenwald (2018). Moreover, by using a life-cycle model and by explicitly modeling the mortgage as a 30-year contract with either fixed or adjustable rate, I am able to realistically capture how constraining mortgage contracts are for different types of households, and ultimately how these households respond differently to interest rate changes.

The main contribution of this paper is to quantify the role of mortgage and housing choices, and the importance of changes in mortgage interest rates and house prices, for the transmission of monetary policy. The literature so far has focused on one such choice, namely, the choice of existing homeowners to take up a new mortgage, i.e., the refinancing channel of monetary policy, and has largely overlooked how housing choices are affected. Chen et al. (2020) document that cash-out refinancing is negatively related to the business cycle and played an important role for the debt and consumption patterns before and during the Great Recession. Beraja et al. (2018) show that the prevalence of mortgage refinancing is linked to house price growth, which in turn affects the spending responses to monetary policy. Eichenbaum et al. (2018) emphasize that the distribution of savings from refinancing is a key determinant of the efficacy of monetary policy. My findings are complementary to these results. I corroborate findings that refinancing plays a central role for the transmission of expansionary monetary policy, but I also show that other transactions in the housing and mortgage markets are of quantitative importance. Concretely, I find that 16 percent of the increase in aggregate demand stems from households who adjust their housing choice. Wong (2019) also highlights the significance of the refinancing channel and examines monetary policy under an FRM versus an ARM regime. I confirm her results that variable-rate mortgages increase the aggregate response of consumption as compared to when FRMs are used, something that also Garriga et al. (2017) and Guren et al. (2021) find. However, by endogenizing the response in house prices, I highlight the asset-price channel. Specifically, I show that the different responses of house prices in these two environments account for approximately 41 percent of the difference in aggregate consumption, a finding that is empirically supported (see Calza et al. (2013)). I also show that the different pass-through of monetary policy to short and long mortgage rates is a key determinant of the difference in the demand response in the two settings.

2 Model

To study the aggregate-demand implications of changes in mortgage and housing choices in response to a monetary policy shock, I use a heterogeneous-agent life-cycle model with a detailed modeling of mortgage contracts and the housing market. The setting represents a small open economy in which the interest rate is exogenous but where house prices and rental rates are equilibrium objects. In a given period, households choose to rent or own a house, the home size, the use of mortgage financing, savings, and consumption. House purchases are subject to transaction costs, and mortgage financing is restricted by down-payment and payment-to-income requirements. Furthermore, refinancing costs reduce the liquidity of housing equity. In the baseline setting, mortgages are modeled as 30-year contracts with fixed interest rate, which is the most commonly used mortgage in the U.S.[3]

2.1 Households

The model is in discrete time. Households enter the economy at age $j = 1$, which represents the first period of working life, and work until age J^{ret}. When each household i is born, it receives an initial endowment of liquid assets $b_{i,1}$, as in Kaplan and Violante (2014), and is allocated a permanent lifetime earnings state. In each period before retirement, the household is endowed with earnings y that depend on the individual lifetime earnings state and that are subject to idiosyncratic permanent and transitory shocks. Following retirement, households receive retirement benefits in a fixed proportion R of the permanent

[3] In Section 4.2, I compare my findings to an economy where adjustable-rate mortgages are used instead.

earnings in the last period of working life, subject to a cap. Households face an age-dependent probability of surviving to the next period $\phi_j \in [0, 1]$, and can live for a maximum of J periods.

There are three assets in the economy: owned housing h, mortgages m, and risk-free bonds b. Households realize utility from consumption c and housing services s, through a CRRA utility function with a Cobb-Douglas aggregator over consumption and housing services

$$U_j(c, s) = e_j \frac{(c^\alpha s^{1-\alpha})^{1-\sigma}}{1-\sigma}. \tag{1}$$

The age-dependent parameter e_j is a utility shifter that accounts for changes in household size over the life cycle (see, e.g., Kaplan et al., 2020). Housing services can be rented at a unit price p_r or attained by owning a house that is purchased at a unit price p_h. If a household chooses to own a home of size h, there is a linear transformation of owned housing into housing services such that $s = h$.

Households derive warm-glow utility from bequests, similar to in De Nardi (2004).

$$U^B(q) = \upsilon \frac{(q + \bar{q})^{1-\sigma}}{1-\sigma}, \tag{2}$$

where υ denotes the weight that is attached to the utility from bequests, and $\bar{q}$ is a positive parameter that determines to what degree bequests are a luxury good. The amount of bequests q is given by the net worth of a household.

The illiquid nature of owned housing is characterized by transaction costs for both buying and selling a house, ς^b and ς^s, respectively. These are modeled as constant shares of the house value. Further, a homeowner needs to pay a periodic maintenance cost δ^h, also proportional to the house value. All homeowners have access to long-term non-defaultable mortgages. The mortgage contract is modeled to represent the most commonly used mortgage in the U.S., i.e., a fixed-payment contract, where the mortgage is paid off over 30 years. It is possible to refinance a mortgage, but it is subject to refinancing costs. The length of the available mortgage contract is indicated by l (which is set to 30 when I parameterize the model). The number of periods left on a mortgage is then given by $N = \min(J - j, l - ma)$, where ma is the mortgage age. I thus assume that mortgages have to be repaid in l years or the number of years left until certain death, whichever is smaller.[4] The minimum required mortgage payment is an age and mortgage-age dependent

[4] This modeling choice is motivated by the fact that retirees tend to hold little debt and the terms of long-term mortgage contracts that are offered to retirees are often less favorable than those offered to working-age households.

fraction $\chi_{j,ma}$ of the current mortgage balance m

$$\chi_{j,ma}\, m = \frac{r^m(1+r^m)^N}{(1+r^m)^N - 1} m, \qquad \text{for } r^m > 0. \tag{3}$$

In steady state, the mortgage interest rate r^m is given by the risk free rate r plus an exogenous credit spread κ, i.e., $r^m = r + \kappa$. How the mortgage interest rate is affected by monetary policy depends on the pass-through of the policy rate and if the mortgage contracts have fixed or adjustable rates, which will be discussed in more detail in Section 4. New mortgage financing is restricted by a loan-to-value (LTV) requirement as well as a payment-to-income (PTI) cap. The LTV constraint is given by

$$m' \leq (1-\theta) p_h h', \tag{4}$$

where θ specifies the required down-payment share of the house value $p_h h'$, and where prime indicates the current period choice of a state variable. The PTI requirement is modeled as

$$\frac{\chi_{j+1,ma} m' + (\tau^h + \varsigma^I) p_h h'}{n} \leq \psi, \tag{5}$$

where τ^h and ς^I represent property tax and home insurance payments, respectively, and n is permanent income.[5] Thus, ψ sets the maximum share of current permanent income that can be allocated to housing-related payments. These constraints need to be obeyed whenever a house is purchased or if a household chooses to refinance. In the latter case, the household has to pay a fixed refinancing cost ς^r, and a refinancing cost ς^r_p proportional to the mortgage size. A homeowner who does not refinance its mortgage needs to adhere to the minimum payment schedule

$$m' \leq (1+r^m)m - \chi_{j,ma}\, m. \tag{6}$$

In a given period, the state variable cash-on-hand x of a household is defined as follows,

$$x \equiv \begin{cases} y + (1+r)b - (1+r^m)m + (1-\varsigma^s)p_h h - \delta^h p_h h - \Gamma & \text{if } j > 1 \\ y - \Gamma + b & \text{if } j = 1. \end{cases} \tag{7}$$

It consists of labor income or social security benefits y, any savings from liquid bonds less

[5] When banks evaluate the payment capabilities of prospective mortgage holders, three main components include mortgage payments, property taxes, and home insurance costs. Home insurance costs are only included for calibration purposes of the PTI requirement, see Section 3.1, and are not included in the households' budget constraint.

the mortgage balance including interest, the value of the house net of transaction costs, less maintenance costs and total tax payments Γ.[6]

The total tax payments are made up by five different taxes

$$\Gamma \equiv \tau^l y + \mathbb{I}^w \tau^{ss} y + \tau^c r b + \tau^h p_h h + T(\tilde{y}). \tag{8}$$

A household pays local taxes on earnings given by the proportional tax rate τ^l.[7] All working-age households, as indicated by $\mathbb{I}^w$, also pay a social security tax τ^{ss}, proportional to earnings. Furthermore, there is a capital income tax τ^c that applies to all earned interest, and the property tax τ^h is paid by homeowners as a share of their house value. Finally, $T(\tilde{y})$ captures the progressive federal labor income tax, where T is a non-linear function that takes taxable labor income after deductions $\tilde{y}$ as its argument. A household may deduct its mortgage interest payments, property taxes, and local labor income taxes. The federal income tax system is described in more detail in Section 2.3.

Let R, B, Ref, S denote the mutually exclusive and exhaustive cases where a household rents, buys a house, is a homeowner who refinances its mortgage, or is a homeowner who stays in their house and fulfills the minimum mortgage payment requirement, respectively. The dynamic household problem is described by the following Bellman equation where households discount future periods exponentially, with a discount factor β. Let $\mathbf{z} \equiv (h, m, ma, n, x)$, then for each $k \in \{R, B, Ref, S\}$,

$$V_j^k(\mathbf{z}) = \max_{c,s,h',m',b'} U_j(c,s) + (1-\phi_j)U^B(q') + \beta\phi_j \mathbb{E}_j\left[V_{j+1}(\mathbf{z}')\right]$$

subject to

$$c + b' + \mathbb{I}^R p_r s + \mathbb{I}^B(1+\varsigma^b)p_h h' + \mathbb{I}^{Ref,S}(1-\varsigma^s)p_h h + \mathbb{I}^{Ref}(\varsigma^r + \varsigma_p^r m') \leq x + m' \tag{9}$$

$$q' = b' + p_h h' - m' \tag{10}$$

$$s = h' \qquad \text{if } h' > 0 \tag{11}$$

$$m' \geq 0 \qquad \text{if } h' > 0 \tag{12}$$

$$m' = 0 \qquad \text{if } h' = 0 \tag{13}$$

$$c > 0, s \in S, h' \in H, b' \geq 0,$$

where $\mathbb{I}^k$ are indicator variables that take the value of one for the relevant case and zero

[6]The definition of cash-on-hand includes the net revenue from selling a house. This is only included for computational simplicity, and a household that stays in its house does not incur a transaction cost.

[7]Local labor income taxes are deductible, and are included in the model to ensure that high-earning households benefit more from using itemized deductions.

otherwise.[8] Equation (9) specifies the household's budget constraint, and equation (10) defines the bequests. The last four rows state a set of constraints including that a homeowner may not be a landlord and mortgages may only be used to finance owned housing. A household that buys a house or refinances its mortgage also needs to fulfill the LTV and PTI requirements specified in equations (4) and (5), and a homeowner that stays in the same house but does not refinance its mortgage needs to fulfill the minimum mortgage payment requirement in equation (6). Additionally, rented housing services are only available in discrete sizes contained in the ordered set $S = \{\underline{s}, s_2, s_3, ..., \overline{s}\}$. Owned housing is limited to a set H, which is a proper subset of S. Specifically, the smallest size $\underline{h}$ in H is larger than the smallest size in S, and above and including $\underline{h}$ the two sets are identical.[9] The solution to the household problem is given by

$$V_j(\mathbf{z}) = \max_k V_j^k(\mathbf{z}) \tag{14}$$

for $k \in \{R, B, Ref, S\}$, with the corresponding set of policy functions

$$\left\{c_j(\mathbf{z}), s_j(\mathbf{z}), h'_j(\mathbf{z}), m'_j(\mathbf{z}), b'_j(\mathbf{z})\right\}.$$

2.2 Rental market

The rental market consists of a unit mass of homogeneous rental firms f that provide rental housing to households. Firms operate in a competitive market and are owned by foreign investors. The required rate of return of the investors equals the after-tax return on bonds. In steady state, the house price is constant, i.e., $p_h = p'_h$, and the equilibrium rental rate p_r^{ss} per unit of housing is given by the following user-cost formula,

$$p_r^{ss} = \left[1 - \beta_f + \beta_f \left(\delta^r + \tau^h\right)\right] p_h, \tag{15}$$

where $\beta_f = \frac{1}{1+(1-\tau^c)r}$ is the investors' discount factor. Thus, the rental rate is such that, after paying maintenance costs and property taxes, rental firms earn their required rate of return. Both the maintenance cost and the property taxes are given by constant shares of the rental property value in the next period. The maintenance cost covers the depreciation of rental property $\delta^r p_h$, where $\delta^r > \delta^h$.[10]

[8] To ensure that bequests cannot be negative, the utility from bequests is not discounted, but the parameters of the bequest function are calibrated to match moments in the data.

[9] It is common in the literature to restrict the minimum house size available for owning, e.g., see Cho and Francis (2011), Floetotto et al. (2016), Gervais (2002), and Sommer and Sullivan (2018).

[10] The assumption that the depreciation rate is higher for rental property than for owned housing is common in the literature (see, e.g., Piazzesi and Schneider, 2016), and is supported by the potential moral hazard problem in rental housing markets.

Motivated by the finding that rental rates often adjust slowly to changes in house prices, I assume that owners of rental firms have a long-term investment horizon.[11] Rental firms own the steady-state stock of rental housing and in any period where the demand for rental housing deviates from the steady-state demand, rental firms transact in the housing market such that their rental stock equals demand. In steady state, the per-period present value of profits of the rental firms consist of the rental revenue less the discounted costs in the next period,

$$\pi_f^{ss} = p_r^{ss}\bar{S} - \beta_f \left(\delta^r + \tau^h\right) p_h \bar{S},$$

where $\bar{S}$ is the steady-state rental stock. Let S denote the demand for rental housing in any given period. The present value of profits in a period with rental demand S is then given by

$$\pi_f^{tr} = p_r S - \beta_f(\delta^r + \tau^h)p_h' S + p_h(\bar{S} - S) - \beta_f p_h'(\bar{S} - S),$$

where p_r is the rental rate, p_h is the house price in the current period, p_h' is the house price in the next period, and the stock $\bar{S} - S$ of housing is transacted in the market. The last two terms in the equation capture that the rental firms do not mark-to-market the entire rental housing stock, but only the part of the stock that is actually transacted. Given the assumption of competitive markets, with free entry and exit, the rental firms earn the same return on their investments in any given period as they do in steady state, i.e., $\pi_f^{tr} = \pi_f^{ss}$. The rental rate p_r is then provided by

$$p_r = (1 - \beta_f)p_h + \beta_f(\delta_r + \tau_h)p_h' + \beta_f \Delta p_h' \frac{S - \bar{S}}{S}, \tag{16}$$

where $\Delta p_h' \equiv p_h - p_h'$. Thus, the rental rate is such that the investors earn their required rate of return, after paying maintenance cost and property taxes, and after accounting for realized gains and losses on the share of the rental stock that is transacted in the market.[12]

[11] See, e.g., Blackley and Follain (1996) who show that rents adjust slowly to changes in the user cost of housing. There are a number of frictions in rental markets that I do not model explicitly, such as rent control and consumer protection in contracts, which contribute to the slow adjustment of rental rates to house-price changes.

[12] Note, in a fully flexible rental market, which is a common assumption in the housing literature, the fraction in the last term of equation (16) would be equal to one, and house-price changes would have a greater pass-through to rental rates.

2.3 Government

The government in the model has two main tasks: providing retirement benefits to households and taxing the agents in a manner that reflects the U.S. tax code. Overall, the government runs a surplus, which it spends wastefully, or on matters that do not affect the agents in the model. Rental firms pay two taxes, property taxes in proportion to the value of the rental stock and capital income taxes on their profits. As discussed in Section 2.1, households pay five different taxes. Working-age households pay social security taxes, and all households pay local and federal labor income taxes. Additionally, there is a tax on earned interest on savings, and homeowners pay a property tax.

To capture the level of progressivity in the U.S. federal income tax schedule, I use a continuous and convex tax function as in Heathcote et al. (2017), where the argument is taxable earnings net of deductions $\tilde{y}$. The function is given by

$$T(\tilde{y}) = \tilde{y} - \lambda \tilde{y}^{1-\tau^p}, \tag{17}$$

where parameters λ and τ^p control the level and the degree of progressivity in the tax system.

Taxable earnings are determined by labor income or retirement benefits less any deductions. Working-age households can choose to use an itemized deduction, a standard deduction, or not deduct anything, while retired households may only choose between the latter two. If a household chooses to use itemized deductions, it can deduct mortgage interest payments, property taxes, and local labor income taxes. The most favorable type of deduction depends on a household's earnings and the size of any payments that are deductible under the itemized specification. Specifically, a household chooses the type of deduction that minimizes $T(\tilde{y})$, subject to

$$\tilde{y} \in \begin{cases} \{\max(y - ID, 0), \max(y - SD, 0), y\} & \text{if } j \leq J_{ret} \text{ and } ID > SD \\ \{\max(y - SD, 0), y\} & \text{otherwise} \end{cases} \tag{18}$$

$$\text{where } ID = r^m m + \tau^h p_h h + \tau^l y.$$

ID denotes the deductible amount if a household uses itemized deductions, and SD is the tax subsidy available to households that opt for the standard deduction.

To summarize, the main components of the U.S. tax system relating to housing and mortgages are included in the model, i.e., imputed rents are not taxed, property taxes and mortgage interest payments are deductible, both itemized and standard deductions are available to households, and the earnings tax is progressive. By including these features, the model captures the heterogeneous benefits of owned housing and mortgages intrinsic to the U.S. tax system.

2.4 Equilibrium house prices

The dynamic programming problem is solved recursively. The steady state of the baseline economy is solved for by computing the value and policy functions, and simulating an economy where households behave according to the solved for decision rules. The equilibrium house price in steady state is set exogenously, and the rental rate is then given by equation (15). The steady-state total demand for housing, both rental and owned housing, provides the total supply of housing, which is held constant throughout the rest of the analysis.[13]

To analyze the effects of an interest rate shock, I solve for a transitional equilibrium from an unexpected shock to the real interest rate. Given the exogenous path of the real interest rate on bonds, I compute transition paths of the mortgage interest rate and aggregate earnings (see Section 4.1). For the analysis where mortgages have adjustable rate, the mortgage interest rate at any point in time is given by the periodic risk-free interest rate plus the credit spread κ. With adjustable-rate mortgages, the repayment plans update for all new and outstanding mortgages, to capture the change in the mortgage interest rate. For fixed-payment mortgages, on the other hand, only the repayment plans of households who take up a new mortgage, i.e., those who take up a mortgage when buying a new house or when refinancing, adjust to the change in the mortgage interest rate. In the main analysis, I assume a 60 percent pass-through of the real interest rate shock to the long mortgage rate of new fixed-payment mortgages, and in Section 4.2, I consider alternative pass-through rates.

For the transitional equilibrium, a vector of house prices and a vector of total rental housing supply are solved for, such that in each period of the transition, the total demand for housing, both rental and owned housing, equals the total supply, and the demand for rental housing equals the rental supply, given the rental rate in equation (16). I assume that households have perfect foresight of the transition paths of interest rates, earnings, and house and rental prices. The equilibrium definitions are stated in Appendix A, and a more detailed description of the solution method, and the discretization of the state space and the transitory earnings shocks, is provided in Appendix B.

[13] Since the paper analyzes effects of transitory shocks to the interest rate, the assumption of fixed housing supply is arguably reasonable.

3 Calibration

The model is parameterized to the U.S. economy in 1989 to 2013. I choose to use average data moments across many years in an attempt to avoid cyclicalities and to capture a steady state of the economy. Most of the parameter values are taken from data or other studies. The remaining parameters are calibrated jointly by minimizing the distance between several relevant equilibrium moments in the model and their data counterparts.

3.1 External model parameters

A summary of the independently calibrated parameters are found in Table 10 of Appendix C. A model period corresponds to one year.

Demographics

Households enter the economy at age 23 and work until age 65. The probability of dying at any age $(1 - \phi_j)$ is set to match the observed and projected mortality rates for males born in 1950, in the Life Tables for the U.S., social security area 1900-2100 (see Bell and Miller (2005)). The maximum age J in the model is 83 years. The age-dependent equivalence scale parameters e_j are determined from the Panel Study of Income Dynamics (PSID). The parameter values are set to the square root of the predicted values from a regression of family size on a third-order polynomial of age.

Preferences and interest rates

The parameter governing households' relative risk aversion σ is set to 2, which gives an intertemporal elasticity of substitution of 0.5. The real interest rate on risk-free bonds r is set to 0.03. This is consistent with the average yield on 30-year constant maturity nominal Treasury securities, deflated by the yearly headline Consumer Price Index (CPI). Between 1997 and 2013, this average real rate was 0.034 (Federal Reserve Statistics Release, H15, and the Bureau of Labor Statistics, Databases & Tables, Inflation & Prices). The mortgage spread κ is set to 0.014. This is given by the average yearly difference between the rate on 30-year fixed-rate conventional home mortgage commitments and the above nominal Treasuries, from 1997 to 2013. Thus, the steady-state mortgage interest rate is 0.044.

Taxes

The local labor income tax rate is determined by the average state and local labor income tax rate for households that itemize deductions, which was 5 percent in 2011 (Lowry, 2014). The tax rate on capital income is chosen to be the maximum rate that applies to long-term capital income for most taxpayers, which is 15 percent. The social security tax paid by the working age population, i.e., the payroll tax, is set to 15.3 percent of earnings. This rate captures the payroll taxes that are paid by both employees and employers (Harris, 2005). The property tax varies significantly across U.S. states. I choose a property tax rate of 1 percent, which is approximately the median rate in the American Housing Survey (AHS) for the 2009, 2011, and 2013 survey years.

Housing and mortgage markets

Mortgages have to be repaid over the course of 30 years, which is the most commonly used mortgage length in the U.S. Hence, l is set to 30. The minimum down-payment requirement θ in the model is 0.20. Below this threshold, mortgage lenders often require an extra insurance. Between 1978 and 1992, the average down payment of first-time buyers in the U.S. ranged from 11.4 to 20.5 percent of the house value (U.S. Bureau of the Census, Statistical Abstract of the United States (GPO), 1987, 1988, and 1994). The payment-to-income requirement ψ is set to 0.28, as in Greenwald (2018).

The depreciation rate on owner-occupied housing δ^h is taken from Harding et al. (2007) and is set to 0.03. This value is the estimated median depreciation rate, gross of maintenance. The home insurance rate ς^I is equal to 0.005 of the house value. This figure is taken from the AHS, where the median property insurance payments correspond to approximately half of the median property tax payments.

The transaction costs for buying and selling a house, ς^b and ς^s, are set to 2.5 and 7 percent, respectively. These numbers are taken from Gruber and Martin (2003) who use median transaction costs in CES data to estimate the transaction costs in proportion to the house value. The refinancing cost that is proportional to the mortgage size ς_p^r is set to 0.01, as in Boar et al. (2017).

Assets of newborns

In order to capture the positive relationship between wealth and earnings among young households, newborn households in the model are endowed with initial liquid assets $b_{i,1}$ conditional on earnings. The allocation is based on the method in Kaplan and Violante (2014). In the Survey of Consumer Finances (SCF), households of age 23-25 are divided into 21 groups based on earnings. Within each group, the share of households with asset holdings above 1,000 2013 dollars is calculated, along with their median asset values. The median asset holdings are then scaled by the median earnings of households aged 23-64. Within each of the comparable 21 groups in the model, ranked on initial earnings, the shares found in the SCF divide the households into low-earners who do not receive any initial assets, and high-earners who are allocated the median asset value consistent with that group, and rescaled by the median earnings of working-age households in the model.

Labor income and social security

In each period, households are endowed with exogenous earnings. The estimation of the earnings process follows Cocco et al. (2005). There is a deterministic life-cycle component of labor income, and in each period during working age, households' earnings are subject to idiosyncratic permanent and transitory shocks. For household i, of age $j \leq J^{ret}$, the log of labor income is given by

$$\log(y_{ij}) = \alpha_i + g(j) + \eta_{ij} + \nu_{ij} \quad \text{for } j \leq J_{ret}, \tag{19}$$

where α_i is a household fixed effect with the distribution $N(-\frac{\sigma_\alpha^2}{2}, \sigma_\alpha^2)$. The function $g(j)$ captures the deterministic life-cycle component of earnings, while η_{ij} and ν_{ij} are the permanent and transitory components, respectively. The transitory earnings shock ν_{ij} is i.i.d., with the distribution $N(-\frac{\sigma_\nu^2}{2}, \sigma_\nu^2)$. The permanent earnings risk is modeled as a random walk, where there are i.i.d. shocks ζ_{ij} with the distribution $N(-\frac{\sigma_\zeta^2}{2}, \sigma_\zeta^2)$, such that

$$\eta_{ij} = \eta_{i,j-1} + \zeta_{ij} \quad \text{for } j \leq J_{ret}. \tag{20}$$

In the model, the permanent earnings state n_{ij} consists of the three permanent components of labor income, i.e., $\log(n_{ij}) = \alpha_i + g(j) + \eta_{ij}$. In retirement, households receive a constant fraction R of permanent earnings in the last period of working life, subject to a cap B^{max}. Thus, there is no labor-income uncertainty in retirement.

$$\log(y_{ij}) = \min\left(\log(R) + \log(n_{i,J_{ret}}),\ \log(B^{max})\right) \quad \text{for } j \in]J_{ret}, J] \tag{21}$$

The labor income process is estimated using PSID data from 1970 to 1992. See Karlman et al. (2021) for a more detailed description of the data. A linear fixed-effect regression of the log of households' earnings on dummies for age, marital status, family composition, and education, is run to estimate the deterministic life-cycle profile. The components $g(j)$ are given by fitting a third-order polynomial to the mean predicted earnings by age from the regression. To estimate the variances of the permanent and transitory earnings shocks, I use a similar method as in Carroll and Samwick (1997). The variance of the fixed-effect shock is found by computing the residual variance of earnings that is left after accounting for the life-cycle component and the estimated variances of the permanent and transitory shocks, for households of age 23 to 25. The estimated variances are presented in Table 1.

Parameter	Description	Value
σ_α^2	Fixed effect	0.156
σ_ζ^2	Permanent	0.012
σ_ν^2	Transitory	0.061

Table 1: Estimated variances

Note: The estimated variances for: the fixed-effect earnings shock that households are exposed to when they enter the economy, and the permanent and transitory earnings shocks that households are subject to before retirement. Estimated using PSID data.

The replacement rate R for retirees is chosen to be 50 percent of permanent earnings in the last period of working life, which is taken from Díaz and Luengo-Prado (2008). The maximum-benefit limit B^{max} is computed from Social Security Administration (SSA) data, and is equal to 0.61 in the model. This number can be evaluated relative to the mean of expected annual earnings during working life that is normalized to one.

3.2 Endogenously calibrated parameters

The parameters that I calibrate endogenously by targeting relevant moments in the data are listed in Table 2. The parameters are calibrated simultaneously, but the most relevant target moments for the respective parameters are listed in the table along with their values in the data and in the model.

Parameter	Description	Value	Target moment	Data	Model
α	Consumption weight	0.75	Median house value-to-earnings	2.30	2.30
β	Discount factor	0.92	Median LTV	0.35	0.35
δ^r	Depreciation rate, rentals	0.055	Homeownership rate, age < 35	0.44	0.40
$\underline{h}$	Min. owned house value	0.35	Homeownership rate	0.70	0.73
ς^r	Fixed refinancing cost	0.12	Refinance rate	0.08	0.08
$\bar{q}$	Luxury of bequests	6.8	Net worth p75/p25, age 68-76	5.37	5.26
υ	Utility shifter of bequests	190	Mean net worth/mean earnings	1.38	1.40
SD	Standard deduction	0.081	Itemization rate	0.53	0.53
λ	Level, tax function	0.975	Average marginal tax rates	0.13	0.13
τ^p	Progressivity, tax function	0.17	Distr. of marginal tax rates	See text	

Table 2: Endogenously calibrated parameters

Note: The parameter values are shown in column three. Column five displays the relevant target moment value in the data, while column six shows the comparable moment value in the model when the listed parameter values are used. The values are annual when relevant. The minimum owned house size $\underline{h}$, the fixed refinancing cost, the luxury parameter in the utility function for bequests, and the standard deduction SD, can be assessed by comparing to the mean of expected annual earnings during working life that is normalized to one.

Unless otherwise stated, the data moments are computed from the SCF, using pooled data over the 1989 to 2013 waves. The parameter α in the utility function controls the share of expenses that is allocated to consumption as opposed to housing services. The target moment that is used to discipline this parameter is the median house value-to-earnings, conditional on owning, which is an indicator of the relative importance of housing costs compared to other expenses. The discount factor β affects borrowing and savings decisions, and is therefore calibrated by targeting the median LTV in the economy. The benefit of buying a house instead of renting is in the model affected by the preferential tax treatment of owned housing as well as the difference between the depreciation rate of owned and rental housing. To calibrate the depreciation rate of rental housing δ^r, I use the homeownership rate among households younger than 35 as a target moment. The overall homeownership rate is used to discipline the size of the smallest housing unit available to own $\underline{h}$. To account for the frictions in the mortgage market, I calibrate the fixed refinancing cost ς^r. In the steady state, the interest rate is constant and thus there is no reason to refinance to capture changes in the mortgage interest rate. The fixed refinancing cost is therefore calibrated by targeting the share of households that refinance while also extracting equity from the house. This data moment value is taken from Boar et al. (2017).

The two parameters of the utility function of bequests are disciplined by two target moments relating to savings. First, the parameter that captures the extent to which bequests are a luxury good $\bar{q}$ is calibrated by targeting the fraction of net worth in the 75th over the 25th percentile, for households aged 68 to 76. Second, the parameter that determines the weight that is assigned to the utility from bequests υ is calibrated to match the mean net worth over mean earnings. Finally, I calibrate three parameters relating to the tax system. The level of the standard deduction SD impacts to what extent households use the itemized deduction, which in turn influences how households are differently affected by a change in mortgage interest rates. The standard deduction amount is used to match the itemization rate among the working-age population. The parameter λ that influences the level of the tax and transfer function $T(\tilde{y})$ is calibrated to match the average marginal tax rate in the economy; while the progressivity parameter τ^p is calibrated to approximate the distribution of households across statutory federal labor income tax brackets. The latter is done by computing the shares of households that are exposed to the different tax brackets. In the model, where the federal labor income tax rate is continuous, households are allocated to their nearest statutory bracket. I solve for the τ^p that minimizes the sum of the absolute values of the difference in shares in the model versus in the data. The data on the shares and the average marginal tax rate are taken from the Congressional Budget Office in 2005 (Harris, 2005), and the tax rates for the brackets correspond to the tax code from 2003 to 2012 (The Tax Foundation, 2013).

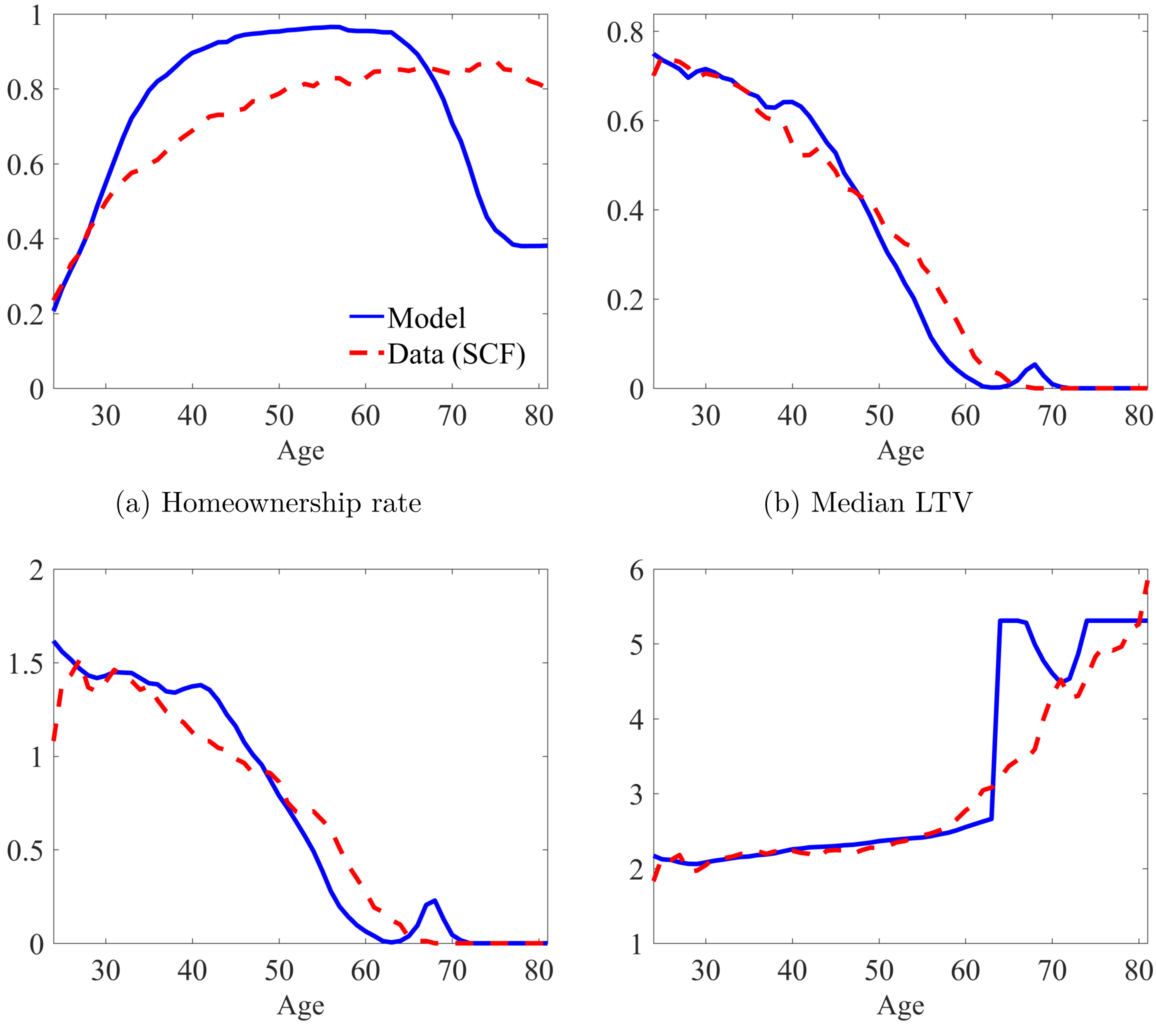
3.3 Model versus data

To evaluate how well the model reflects the data along dimensions that are not targeted in the estimation, I present a comparison between the model and the data for moments that are particularly important for how households respond to interest-rate changes. The effects of a change in the mortgage interest rate depend on the types of households that are homeowners and mortgagors, and how large mortgages different households use. In Figure 1, the life-cycle profiles of homeownership, median LTV, and median mortgage and housing relative to earnings are presented. The life-cycle patterns are clear: young homeowners are the most in debt and have the largest mortgage balances relative to earnings. The model successfully matches the life-cycle profiles computed from the SCF, with the exception of homeownership, where too many middle-aged households and too few old households are homeowners.

The prevalence of liquidity-constrained households impacts the importance of cash-flow effects of monetary policy. A comparison of the distributions of liquid asset-to-earnings and LTV in the model versus the data is displayed in Figure 2.[14] The figure demonstrates that there are significant shares of households with low liquid savings and with high debt levels, both in the data and in the model. The distribution of liquid asset-to-earnings in the model matches the data remarkably well, given that liquid savings is not targeted in the calibration. If zooming in on the lower part of the distribution one can compare the share of hand-to-mouth households in the data versus the model. In the model, 24 percent of households have a liquid asset-to-earnings ratio of less than 0.5, which is a threshold often used in the literature to approximate hand-to-mouth behavior, whereas this number is 38 percent in the SCF. Importantly, among homeowners, i.e., the relatively wealthy households, this share is approximately 32 percent in the model and 31 percent in the data. Hence, the model does well in terms of matching the prevalence of wealthy households with low liquid savings, but underestimates the share of liquidity-constrained renters.[15]

[14] I define liquid assets as checking, savings, money market, and call accounts, prepaid cards, cash, bonds and bills, less any credit card debt balance.

[15] To match the share of liquidity-constrained renters in the data one could introduce, e.g., discount-factor heterogeneity. However, the purpose of this paper is to analyze the effects of housing and mortgage choices for monetary policy transmission, for which poor renters play a small role.



(a) Homeownership rate

(b) Median LTV

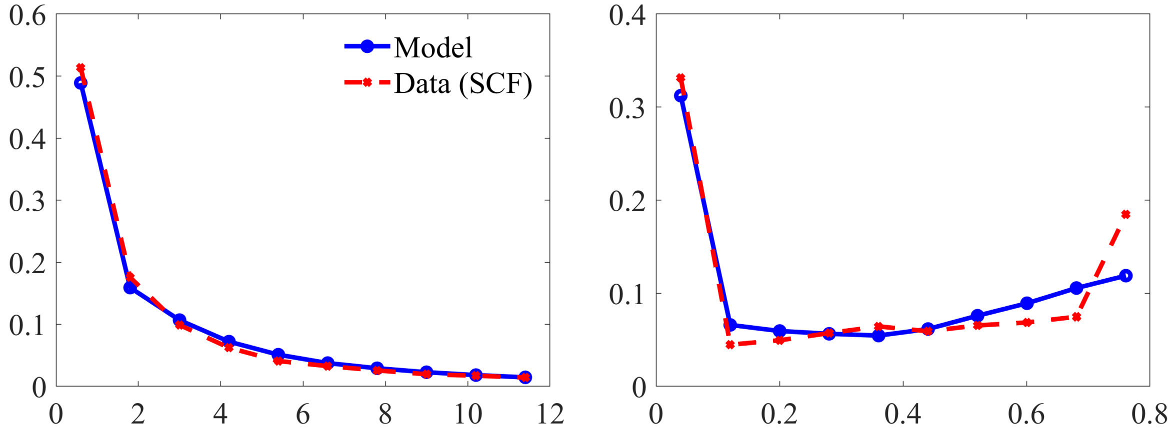
(c) Median mortgage-to-earnings

(d) Median house-to-earnings

Figure 1: Comparison between model and data: non-targeted life-cycle profiles
Note: Data refers to the Survey of Consumer Finances, for the survey years 1989 to 2013.

4 Results

When the central bank changes the interest rate it can affect the optimal portfolio allocation of households. Specifically, when there is a pass-through to mortgage interest rates, monetary policy can impact households' mortgage financing and housing choices. These types of portfolio adjustments often involve large transactions and changes in households' liquidity, that in turn can influence aggregate consumption demand. Moreover, a change in the demand for owned housing leads to potentially important equilibrium effects on house prices. To shed light on the role of mortgage and housing choices for monetary policy transmission, I use the model presented in the previous sections and compute impulse response functions (IRFs) to an exogenous shock to the real interest



(a) Distribution, liquid asset-to-earnings

(b) Distribution, LTV

Figure 2: Comparison between model and data: non-targeted distributions
Note: Data refers to the Survey of Consumer Finances, for the survey years 1989 to 2013.

rate on bonds. I begin in Section 4.1 by quantifying the effects of changes in mortgage interest rates and house prices for aggregate spending, and I proceed by assessing how monetary policy affects aggregate demand through households' housing and mortgage choices. Moreover, I evaluate potential non-linearities and asymmetries in aggregate responses by examining shocks of different sizes and signs. In Section 4.2, I investigate the importance of the mortgage-contract specification by comparing my main findings in the baseline setting with fixed-rate mortgages (FRMs) to a setting where adjustable-rate mortgages (ARMs) are used instead.

4.1 The role of housing and mortgage choices for demand

To disentangle how housing and mortgage choices affect the aggregate demand response to monetary policy, let us first consider the different ways that a change in the interest rate affects households' consumption. In this model, there are three main transmission channels. First, the traditional channel of intertemporal substitution makes households want to consume more today and less tomorrow when the interest rate declines, as the relative price of consumption today compared to tomorrow decreases. Second, a decline in the interest rate affects the lifetime resources of households by affecting the return on savings and the interest cost of mortgages. These income effects impact different households differently. Households without or with a relatively small mortgage compared to savings, experience a negative income effect, whereas households with large mortgages tend to be positively affected by the decrease in the interest rate. Moreover, there are additional income effects resulting from the equilibrium effect of demand on earnings.

Third, a change in the interest rate affects the portfolio allocations of households. As the return on liquid savings and the cost of mortgages change, there are equilibrium implications for house prices, and the optimal portfolio holdings of many households are altered. Along the intensive margin, homeowners may choose to reallocate their savings between liquid bonds and illiquid housing equity by paying off more or less on their mortgage. Importantly, households may also make extensive-margin adjustments, by buying and/or selling a house, and/or by taking up a new mortgage.

For households who are liquidity constrained, consumption responses to monetary policy are not necessarily reflecting their forward-looking Euler equation. For these households, cash-flow effects can lead to significanlty different responses than implied by intertemporal substitution and income effects alone. Although changes in the return on savings and the interest payments on mortgages affect households' future cash flows, these changes in cash flows are for most households relatively small, and arise over time. Similarly, equilibrium effects of changes in demand tend to have a delayed impact on earnings. Much larger cash-flow effects occur instantly for households who adjust their housing and mortgage choices. If these households are constrained in their spending, the cash-flow effects can have real and direct implications for aggregate demand.

Portfolio adjustments endogenously make some households less liquidity constrained and others more constrained in their spending. Some homeowners may in response to the decline in the interest rate choose to access their housing equity by refinancing their mortgage or by moving to a new house. Some renters may choose to delay their house purchase in order to increase consumption today, in particular if house prices are temporary elevated. On the contrary, some renters may advance their house purchase if the mortgage conditions are unusually favorable, straining their liquidity. Thus, to understand how the portfolio channel of monetary policy affects aggregate demand, a quantitative evaluation is necessary.

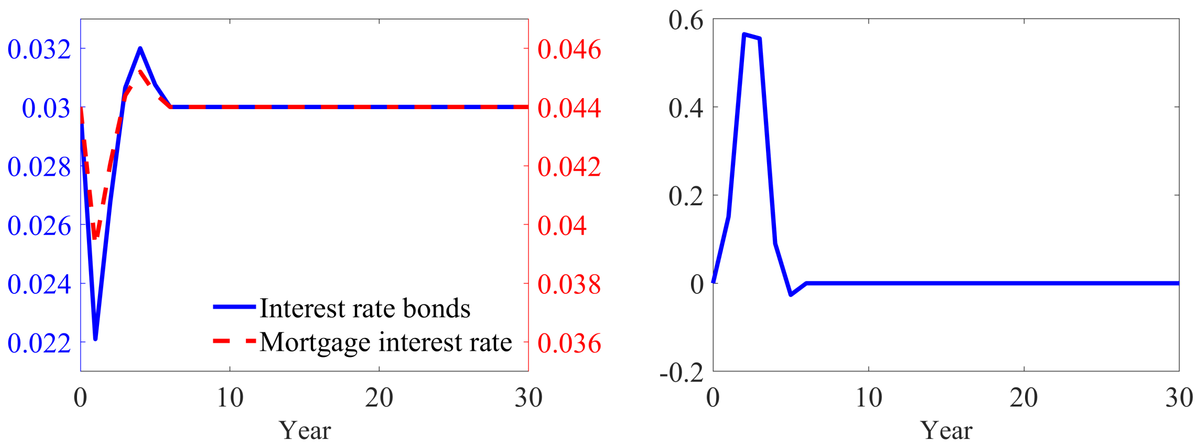
Monetary policy and house prices

To study the effects of an interest rate shock, I use an empirically estimated path of the real interest rate from the identified Romer and Romer (2004) monetary policy shock in Auclert et al. (2020). I begin by considering a -100 basis points (bp) shock to the nominal interest rate. The expansionary shock translates into an immediate reduction of the real interest rate on bonds of approximately 80bp. For the long mortgage interest rate, I assume a 60 percent pass-through, which is in line with empirical findings (Gertler and Karadi (2015), Gilchrist et al. (2015), and Wong (2019)).[16] A household that takes up a new mortgage in the period when the interest rate shock occurs receives a mortgage

[16] In section 4.2, I consider alternative pass-through rates to mortgage interest rates.

interest rate of 3.9 percent for the next 30 years, instead of the steady-state rate of 4.4 percent.

In order to realistically capture how households' housing and mortgage choices are affected by a change in the interest rate, it is crucial that the extent to which homeowners are liquidity constrained in the data, is well represented in the model. Moreover, it is important to include any potential cash-flow effects from monetary policy, since those impact households' liquidity. To incorporate a realistic timing of the equilibrium effect of demand on earnings, and to make the path of earnings consistent with the path of the real interest rate, I impose the empirically estimated path of aggregate income, also from Auclert et al. (2020). Specifically, I let earnings of all working-age households adjust proportionally to the change in aggregate income Y. The paths of the real interest rate on bonds, the real mortgage interest rate, and aggregate income are displayed in Figure 3.



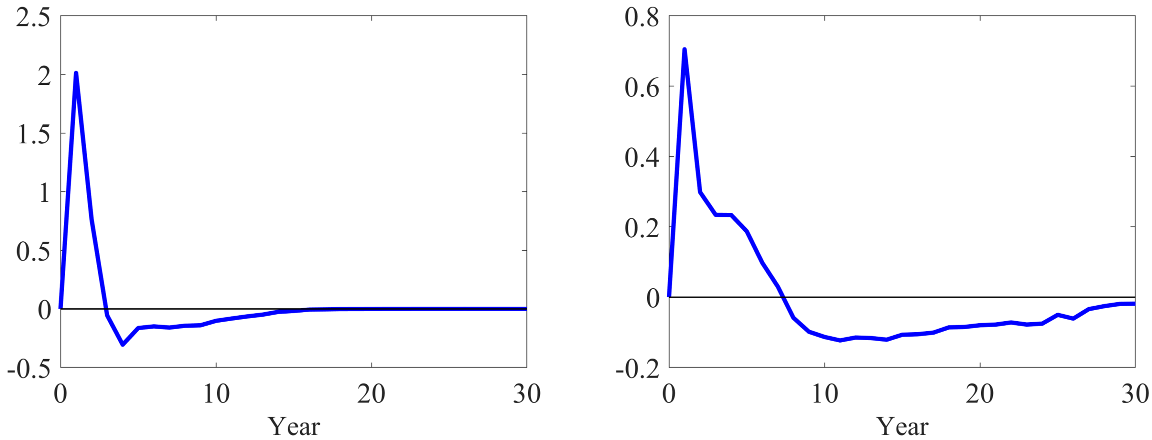
(a) Real interest rates (%)

(b) Aggregate income (%)

Figure 3: The paths of the interest rates on bonds and mortgages and aggregate income
Note: The paths follow an unexpected nominal interest rate shock of -100bp, where the path of the real interest rate on bonds and the path of aggregate income correspond to the estimated impulse response functions in Auclert et al. (2020). The mortgage interest rate reads off the right-hand side y-axis.

To analyze how households respond, I start from the steady state of the model with an invariant distribution of households, and compute the non-linear IRFs to the "MIT shock" of the real interest rates and earnings. Following Boppart et al. (2018), these IRFs can be used to provide a linearized solution to the model with aggregate risk, i.e., only first-order effects of aggregate shocks are considered, as with standard first-order perturbations. The shock occurs just before the households make any decisions, and there is an immediate adjustment of the paths of house prices and rental rates.

The unexpected decrease in the interest rates on bonds and mortgages affects the demand for housing as well as consumption. The equilibrium house-price path that equalizes demand and supply in the housing market in all periods is presented in Figure 4a. By purchasing a house, a household can immediately transform the negative income effect from the lower return on savings into a benefit of lower interest payments on debt. As a result, the demand for housing increases following the expansionary interest rate shock, pushing up house prices. In the period of the shock, house prices increase by 2.0 percent, which is in line with empirical findings in, e.g., Del Negro and Otrok (2007), Iacoviello (2005), and Jarociński and Smets (2008), and more recently Bartscher et al. (2021) and Paul (2020). There is also a substantial increase in aggregate consumption demand, as presented in Figure 4b. In the period of the shock, consumption rises by 0.7 percent.



(a) House prices (%)

(b) Consumption (%)

Figure 4: Impulse response functions for house prices and aggregate consumption
Note: The impulse response functions follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3.

Figure 4 indicates that there is a comovement in house prices and aggregate consumption following the monetary policy shock. To quantify the role of changes in mortgage interest rates, house prices, and earnings, I compare the aggregate demand response in settings with different equilibrium price assumptions. Specifically, I compute consumption responses under the following conditions i) Mortgage interest rates, house prices, and earnings are constant ii) House prices and earnings are constant iii) Earnings are constant iv) All prices adjust. Table 3 presents the aggregate consumption response in the period of the shock under the different assumptions.

Table 3 illustrates that both the lower mortgage interest rate and the higher house prices amplify aggregate demand. When the monetary policy shock only transmits to the interest rate on bonds, but mortgage interest rates, house prices, and earnings are kept constant, demand increases by a modest 0.06 percent. When allowing for mortgage

	$\Delta\ r$	$+\ \Delta\ r^m$	$+\ \Delta\ p_h$	$+\ \Delta\ Y$
Δ aggregate consumption	0.06	0.18	0.29	0.70

Table 3: Consumption responses (%)

Note: Aggregate consumption responses under different equilibrium assumptions for mortgage interest rates, house prices, and earnings. The deviations of consumption, in percent, are computed for the period when the real interest rate shock occurs. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income as displayed in Figure 3, and house prices as presented in Figure 4a, when applicable.

interest rates to also be affected by the shock, the aggregate demand response is three times larger. Moreover, by letting house prices respond endogenously to the shock, the demand response is amplified by an additional 0.11 percentage points. To assess the marginal propensity to consume out of housing wealth, I also consider an exogenous house price shock. For a dollar increase in house values, homeowners increase consumption by 6 cents, which is largely in line with empirical findings in Aladangady (2017) and Mian et al. (2013). Finally, by allowing earnings to increase, the initial response in aggregate demand more than doubles, to 0.70 percent. Worth noting, the initial increase in earnings is relatively small, as seen in Figure 3b. Instead, the expected higher earnings in the future play a key role for the initial demand response, a point discussed further in the next section and Appendix D.1.

The portfolio choice: housing, mortgages, and liquid savings

To understand the mechanisms behind the increase in aggregate demand we need to understand who the households are that respond strongly, and why they do so. I begin by analyzing the importance of households who update their discrete portfolio choices due to the interest rate shock. There are five mutually exclusive discrete choices available to the households: buy a house, refinance a mortgage, move to a different owner-occupied house, stay in a house and follow the amortization plan, and rent housing. To quantify the role of extensive-margin adjustments of households' portfolios, I compute the aggregate consumption response when not allowing households to change their discrete choice due to the interest rate shock. Specifically, households have to choose the same housing services and owned housing as they would have if interest rates and house prices did not change. Similarly, if they were to buy, refinance, move, stay, or rent in steady state, they cannot update these choices in response to the shock. Thus, households may adjust their consumption and savings in bonds and mortgages, but no extensive-margin portfolio adjustments are allowed. The resulting consumption response in the period of the shock is displayed in the third row of Table 4. Moreover, the second row shows the aggregate demand response if households can adjust their housing choices but only those who would have refinanced in steady state can and have to refinance when the shock occurs.

There is a remarkably large difference in aggregate demand, if households are not allowed to make extensive-margin adjustments of their portfolios. In fact, without extensive-margin adjustments over 50 percent of the increase in aggregate spending is wiped out (an increase of 0.34 percent as compared to the equilibrium increase of 0.70 percent). Adjustments of housing choices explain roughly one third of the amplification from discrete-choice updates, whereas refinancing accounts for the rest.

To gain further insights into what types of discrete-choice updates contribute the most to the transmission of monetary policy, I examine consumption responses of households who make each possible update. Table 5 presents the mean consumption response of households who make each discrete portfolio update, as well as the share of households of each type, in parenthesis.[17] The rows indicate the optimal discrete choice if the interest rate shock had not occurred, and the columns specify the optimal choice in the period of the shock. Hence, the main diagonal shows the responses for households who do not make an extensive-margin portfolio adjustment, whereas all the other positions show responses for those who make discrete updates.

Δ C, optimal portfolio choices	0.70
Δ C, steady-state choice to refinance	0.45
Δ C, steady-state discrete choices	0.34

Table 4: Consumption responses (%)

Note: Aggregate consumption responses under different assumptions for extensive-margin portfolio adjustments. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3, and house prices as in Figure 4a.

A first key observation in Table 5 is that less than 6 percent of households make extensive-margin adjustments, although they account for 50 percent of the aggregate consumption response, as seen in Table 4. Let us start by analyzing homeowners who choose to access their housing equity due to the shock. The fourth row of Table 5 shows the consumption responses of households who would have stayed in their home and followed their amortization schedule if the interest rate shock had not occurred. When interest rates decrease and house prices increase some liquidity-constrained homeowners find it optimal to access their housing equity in order to increase consumption. Some of these households are liquidity constrained due to poor earnings realizations. Others are young homeowners who expect higher earnings in the future due to the upwards-sloping

[17] The shares may not add to 100 percent due to rounding.

	Buyers	Refinancers	Movers	Stayers	Renters
Buyers	0.2 (2.4)	-	-	-	7.8 (0.5)
Refinancers	-	1.8 (4.7)	14.4 (0.2)	-10.9 (0.4)	14.1 (0.0)
Movers	-	7.6 (0.1)	1.5 (2.3)	-12.2 (0.3)	0.2 (0.2)
Stayers	-	14.3 (2.0)	6.9 (0.8)	0.1 (59.5)	27.7 (0.4)
Renters	-4.2 (0.3)	-11.9 (0.1)	-3.6 (0.1)	-18.3 (0.3)	0.6 (25.9)

Table 5: Consumption responses and shares (%)

Note: Mean consumption responses of households who make each possible extensive-margin portfolio adjustment. The share of all households who make each portfolio update is in parenthesis, in percent. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The columns indicate the optimal choice to be a buyer, refinancer, mover, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the optimal choice if the interest rate shock had not occurred. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3, and house prices as in Figure 4a.

life-cycle profile of earnings, and therefore save in liquid bonds mainly for precautionary reasons. A homeowner can access their housing equity by either refinancing their mortgage (column 2), or by moving to a new home (column 3) or by becoming a renter (column 5). The consumption responses for all of these households are large and positive, as their extensive-margin portfolio adjustments increase their liquidity and allow for an improved consumption smoothing. Homeowners who choose to refinance their mortgage increase consumption by 14 percent, those who choose to move to a new house increase consumption by 7 percent, and those who become renters find it optimal to hike consumption by 28 percent, on average.

There are also homeowners who would have accessed their housing equity also without the interest rate shock, but who choose to do so in a different way, due to the shock. For these households the consumption responses vary more, as they are already accessing their illiquid savings regardless of the shock. Some households would have refinanced their mortgage if the shock had not happened, but when the shock occurs they choose to also update their housing choice and move to a new house, or move to a rental house. The average consumption of both of these groups increase by 14 percent, as seen in the second row of Table 5. Other homeowners would have moved to a new house had the interest rate shock not occurred, but now choose to stay in the current house and refinance their mortgage to access their housing equity. This group of households increase consumption by almost 8 percent. Finally, homeowners who would have become renters if it was not for the interest rate shock, but who now choose to stay in their house and refinance their mortgage or move to a different owner-occupied house, lower consumption by 12 and 4 percent, respectively.

Other homeowners choose to no longer access their housing equity, due to the shock.

The consumption responses of these households are displayed in the fourth column of Table 5 (rows 2, 3, and 5). In general, these households endogenously become more liquidity constrained, due to their portfolio choice, and decrease their consumption significantly. The higher earnings, and the lower mortgage interest rate and higher house prices improve the current and future cash flows of these households to the extent that they no longer find it optimal to pay the refinancing and transaction costs to access their housing equity.

When it comes to renters, there are two potential extensive-margin portfolio adjustments: some renters delay and others advance their house purchase. On the one hand, some renters would have bought a house if it was not for the interest rate shock, but when house prices increase they choose to no longer do so. When these households do not have to finance the down payment and the transaction costs associated with buying a house, their liquid savings are substantially larger, and their average consumption increases by 8 percent. On the other hand, some renters value highly the favorable mortgage conditions after the interest rate shock, and take the opportunity to buy a house when mortgage rates are low. As the down-payment requirement strains these households' liquidity, they respond by decreasing consumption by 4 percent.

As mortgage and housing choices are associated with substantial changes in households' liquidity, this imply that a change in liquidity rather than liquidity per se is a key determinant of consumption responses. Figure 5 presents the mean consumption responses over deciles of liquid asset-to-earnings as compared to deciles of changes in liquid asset-to-earnings. The figure highlights that households with large liquid savings can also respond strongly to monetary policy shocks. In fact, liquid asset-to-earnings is a poor predictor of demand responses, since it is a poor predictor of extensive-margin portfolio adjustments. Changes in liquid asset-to-earnings, on the other hand, capture the strong demand effects of households who adjust their mortgage and housing choices in response to the interest rate shock.[18]

To quantitatively assess the importance of the different types of extensive-margin portfolio adjustments, Table 6 presents the relative contribution of each type for the overall demand response. Households who choose to refinance their mortgage due to the shock contribute the most to the increase in aggregate spending (45 percent, the sum of rows 3, 4, and 5, column 2). This is also evident in the second row of Table 4, which shows that the aggregate demand response is reduced from 0.70 percent to 0.45 percent, if the steady-state choices to refinance are imposed. However, it is also clear that updated housing choices play an important role for the transmission of monetary policy. Households who had been homeowners if it was not for the interest rate shock, but who

[18]The groups in Table 5 whose liquid savings increase (decrease) due to extensive-margin portfolio adjustments are also the groups who increase (decrease) consumption (see Table 11 in Appendix D).

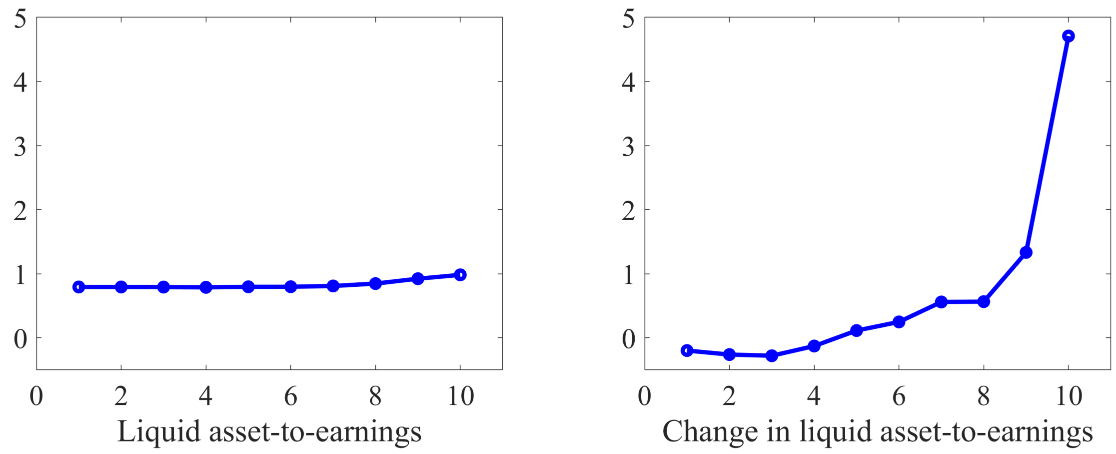


Figure 5: Consumption responses (%)

Note: Mean consumption responses over deciles of liquid asset-to-earnings and change in liquid asset-to-earnings. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3, and house prices as in Figure 4a.

are now renting, contribute substantially to the aggregate demand response (12 percent in total, the sum of rows 1 and 4, column 5). In addition, households who move to a new house due to the shock account for 9 percent of the consumption response (the sum of rows 2 and 4, column 3). On the flip side, homeowners who decide to no longer access their housing equity due to the more favorable mortgage conditions and higher earnings contribute with negative 12 percent to the aggregate spending increase (the sum of rows 2, 3, and 5, column 4).

Extensive-margin portfolio adjustments do not only contribute to stronger demand effects in the short run, but as seen in Figure 4b, there is a negative effect on aggregate consumption over time. This follows from the improved consumption smoothing that the portfolio updates allow for. The higher consumption today is financed by a lower consumption in future periods, when these households expect to have more liquidity at hand. Figure 11 in Appendix D also reveals that many of the portfolio updates are advances or postponements of mortgage and housing choices. The figure shows that the initial increase in the shares of refinancers and movers is followed by declines. After approximately ten years, the shares have returned to their steady-state levels. Thus, the portfolio channel partly works by affecting the timing of portfolio adjustments. This mechanism is similar to the transmission through timing adjustments of durable goods demand, as discussed in McKay and Wieland (2019).

Taking stock, the portfolio channel plays a significant role in the transmission of monetary policy. Specifically, a small group of households find it optimal to adjust their housing and mortgage choices, and these households account for half of the initial response in aggregate demand. Households who refinance their mortgage to access their illiquid wealth are particularly important, a channel that has been emphasized in previous literature. However, refinancing is not the only way through which homeowners can access their housing equity to increase consumption. Out of the contribution from discrete-choice updates, refinancing accounts for approximately two thirds, whereas housing choices make up one third (see Table 4). Hence, it is not only the frictions in the mortgage market that are important for the effectiveness of monetary policy, but the flexibility of the housing market proves crucial as well. The combination of down-payment requirements, transaction costs when buying and selling a house, in addition to refinancing costs and amortization requirements, impact the transmission of monetary policy.

	Buyers	Refinancers	Movers	Stayers	Renters
Buyers	0.01	-	-	-	0.04
Refinancers	-	0.16	0.03	-0.05	0.00
Movers	-	0.01	0.04	-0.03	0.00
Stayers	-	0.45	0.06	0.13	0.08
Renters	-0.01	-0.01	-0.00	-0.04	0.15

Table 6: Contributions to the direct response in aggregate demand

Note: Contributions to the aggregate consumption response, of households who make each possible extensive-margin portfolio adjustment, for the period when the interest rate shock occurs. The columns indicate the optimal choice to be a buyer, refinancer, mover, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the optimal choice if the interest rate shock had not occurred. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3, and house prices as in Figure 4a.

Let us also discuss the consumption responses of households who do not make extensive-margin portfolio adjustments, as are shown in the main diagonals in Table 5 and 6. The absolute magnitudes of the consumption responses of these groups are smaller than for those who make discrete portfolio adjustments, but they constitute a majority of households. First, households who choose to buy a house regardless of the interest rate shock have an average increase in consumption of 0.2 percent. 2.4 percent of all households make up this group, and they contribute with 1 percent to the overall increase in demand. These households are negatively affected by the increase in house prices, but positively affected by the lower mortgage interest rate. Although there is an increase in consumption for this group on average, there is some heterogeneity in the responses among the different households, where a significant share reduce consumption. Households in this group can adjust their liquidity along two margins: by updating the house size that they buy and by adjusting the size of a mortgage, which contributes to the heterogeneous responses in consumption within the group.

Homeowners who refinance their mortgage irrespective of the interest rate shock, increase consumption by 1.8 percent due to the shock. This group comprises 4.7 percent of all households and contributes with 16 percent to the overall increase in demand. Refinancers benefit from both the lower mortgage interest rate and the higher house prices. As previously discussed, these households are intrinsically liquidity constrained. As their future mortgage interest payments decline, they can choose to save less for precautionary reasons. Furthermore, given the LTV requirement, the higher house prices allow them to take on more debt, making them less constrained in their spending.

Households who move to a new house regardless of the interest rate shock increase consumption by 1.5 percent on average and make up 2.3 percent of all households. These households benefit from the lower mortgage interest rate but are differently affected by the house-price change depending on if they upsize or downsize. Overall, they contribute with 4 percent to the aggregate spending response.

The households who choose to stay in their house and comply with their amortization schedule, irrespective of the interest rate shock, are relatively unconstrained and their behavior is well described by their Euler equation. Hence, intertemporal substitution and income effects drive the consumption responses of most of these households. There is a large heterogeneity within this group, where some households have large mortgages and others have already paid off their mortgage in full. This heterogeneity translates into different consumption responses within the group, with some households increasing consumption and others cutting down, although the average response is an increases by 0.1 percent. The group makes up 59.5 percent of all households and contributes with 13 percent to the increase in aggregate spending.

Finally, the households who choose to rent housing, regardless of the interest rate shock, on average increase consumption by 0.6 percent. This group represents 25.9 percent of all households and contributes with 15 percent to the increase in aggregate demand. These households are particularly affected by how rental rates change due to the shock. The rental rate follows the movement in the house price, but responds proportionally less than the house price to the interest rate shock (see Figure 10 in Appendix D). The initial increase in the rental rate makes the relative price of consumption to rental services decline. As a result, and combined with the higher earnings, almost all renters increase consumption in the period of the shock.

Implications for empirical analysis of consumption dynamics

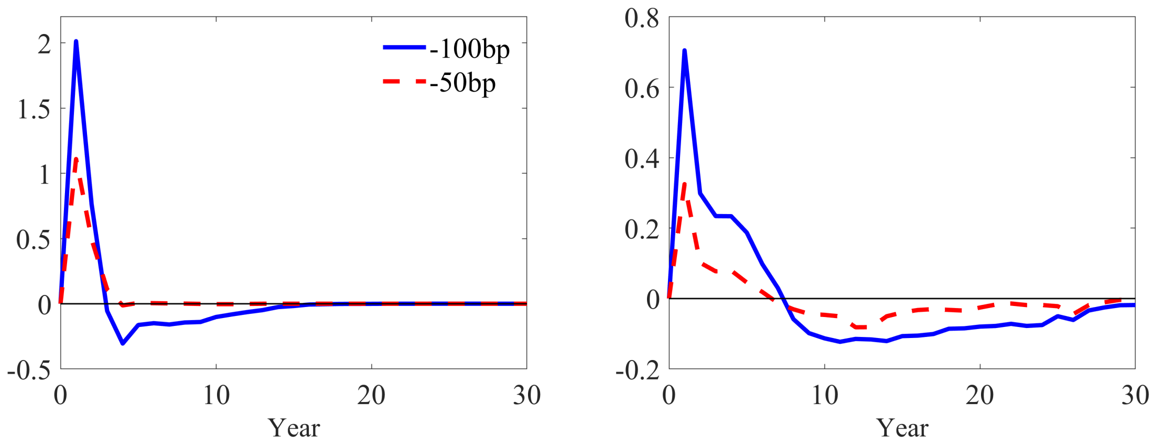
It is inherently difficult to empirically assess how monetary policy affects transactions in the mortgage and housing markets, and in turn, link it to changes in consumption. The results in this paper highlight a challenge with empirical investigations of the transmission of monetary policy through discrete choices. When there are sizeable frictions and transaction costs associated with choices, optimal consumption can be rather lumpy. Hence, for the individual household, consumption in the current period is not necessarily a good predictor of consumption in the next period, and unfortunately, in the data we do not observe the counterfactual consumption, housing choice, or liquidity position of a household, had a shock to the interest rate not occurred. For example, renters who choose to postpone their house purchase, due to temporary higher house prices, become less liquidity constrained as they no longer need to pay the transaction costs of buying. The findings in this paper indicate that these households contribute significantly to the direct response in aggregate demand. In the data, these households have relatively large liquid savings, and relatively small changes in consumption when the interest rate shock occurs as compared to the period before the shock. However, the relevant measure is of course not how their consumption changes over time, but rather how it changes compared to the counterfactual outcome, had the shock not occurred. Moreover, in the data it is difficult to differentiate between households who make a discrete choice due to a shock, e.g., refinance their mortgage, and those who would have done so regardless. At best, we are able to observe the status of households prior and following a well-identified monetary policy shock, and how the shares of households of different status change. However, as shown in Table 5, the observed discrete choices following an interest rate shock, which are given by the columns, mask a rich heterogeneity in terms of consumption responses across the unobserved counterfactual choices, which are represented by the rows.

Nonlinearity in the aggregate demand response

The previous sections show that extensive-margin portfolio adjustments of a small group of households impact the aggregate spending response to monetary policy. The frictions in the housing and mortgage markets that generate the lumpy consumption behavior consist of the down-payment requirement, the transaction costs when buying and selling a house, the refinancing costs, and the amortization requirement. With these relatively large frictions at play, does the size of the monetary policy shock impact the importance of extensive-margin portfolio adjustments? To examine potential nonlinearities in the response to monetary policy shocks, I consider a shock of half the size, i.e., an expansionary shock of 50bp.

Figure 6 presents the endogenous response in house prices and the impulse response function of aggregate demand to the -50bp interest rate shock. The figures convey that both house prices and consumption appear to respond linearly to changes in interest rates. Moreover, the first two columns of Table 7 show that discrete portfolio updates account for approximately half of the aggregate demand response also for the smaller shock. Similarly to the larger shock, refinancing explains roughly two thirds of the contribution from discrete choices, whereas updated housing choices make up the rest.

Although there are fixed costs associated with adjusting housing and mortgage holdings, small interest rate changes can still trigger such updates for households that are at the margin of making those choices, explaining the observed linearity. However, clearly, there are limits where the linearity breaks. For shocks approaching zero, extensive-margin adjustments should not play a role. At the other end of the spectrum, with increasingly large shocks the additional share of households that can improve their consumption smoothing by updating their mortgage and housing choices declines.

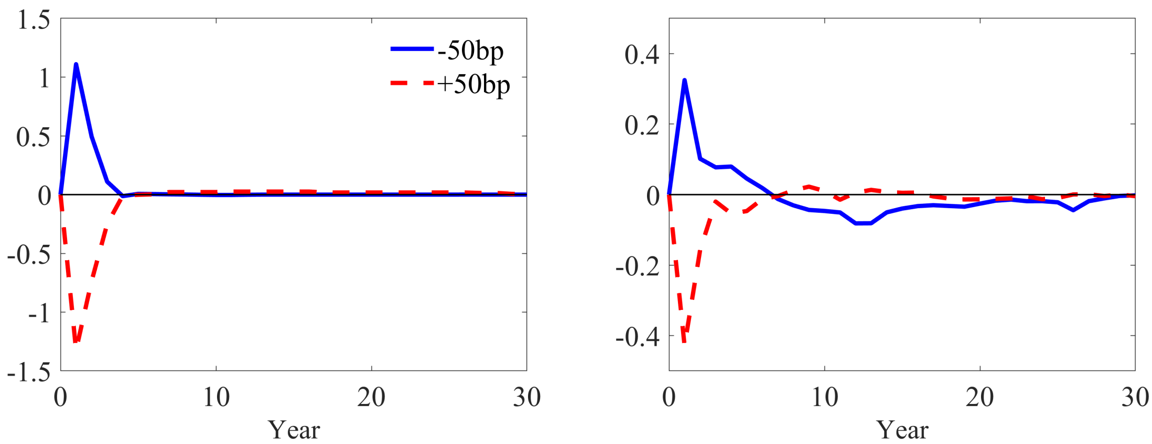


(a) House prices (%) (b) Consumption (%)

Figure 6: Impulse response functions for house prices and aggregate consumption
Note: The impulse response functions follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3, compared with a shock of half the size.

Asymmetry in the aggregate spending response

One of the key drivers of the demand response to expansionary monetary policy shocks is the improved consumption smoothing of liquidity-constrained households. Does this imply that contractionary shocks have a smaller impact? The unconstrained households should have symmetric responses to shocks of different signs. Is this also true for the liquidity constrained? An increase in the interest rate and the associated decline in house prices and earnings reduce homeowners ability to smooth consumption in a similar way that an expansionary shock allows for an improvement. However, the contractionary shock worsens the consumption smoothing of households that have a higher marginal value of current consumption, than those whose consumption smoothing improves following the expansionary shock. Moreover, the contractionary shock increases the share of liquidity-constrained households exhibiting hand-to-mouth behavior. As a result, aggregate demand contracts more in response to an interest rate increase, than it grows in response to the corresponding decrease, as seen in Figure 7 and Table 7. The table further reveals that extensive-margin portfolio updates account for 40 percent of the aggregate demand response, of which reduced refinancing explains roughly two thirds and updated housing choices account for the rest.



(a) House prices (%)

(b) Consumption (%)

Figure 7: Impulse response functions for house prices and aggregate consumption
Note: The impulse response functions follow an unexpected expansionary versus contractionary shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income.

	-100bp	-50bp	+50bp
Δ C, optimal portfolio choices	0.70	0.32	-0.43
Δ C, steady-state choice to refinance	0.45	0.20	-0.31
Δ C, steady-state discrete choices	0.34	0.15	-0.26

Table 7: Consumption responses (%)
Note: Aggregate consumption responses under different assumptions for extensive-margin portfolio adjustments. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The responses follow unexpected expansionary and contractionary shocks of different sizes to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, and house prices as presented in Figure 6a and 7a.

4.2 Mortgage contracts and transmission of monetary policy through mortgage interest rates

The analysis of the portfolio channel of monetary policy transmission suggests that cash-flow effects from updated housing and mortgage choices can significantly affect households' consumption choices. Empirical studies show that households who have mortgages with adjustable rate tend to respond strongly to monetary policy, since their cash flows are directly affected by changes in mortgage interest rates (see, for example, Di Maggio et al. (2017) and Flodén et al. (2020)). At the same time, when mortgages have fixed rate the incentive to refinance and take up a new mortgage could be larger, following an expansionary monetary policy shock. In this section, I therefore study the aggregate implications of the mortgage contract specification. Specifically, I compare the transmission of monetary policy in the baseline economy with FRMs to a setting with ARMs.

Adjustable-rate mortgages

In many countries mortgages with variable rate dominate, and it is arguably the type of debt contract most often used in quantitative models. There are two main differences between ARMs and FRMs. First, all mortgagors are affected by changes in the mortgage interest rate under ARMs, as opposed to only those who take up a new mortgage under FRMs, i.e., those who purchase a new home and use mortgage financing and those who refinance an existing mortgage. Second, ARMs have short mortgage rates, whereas the mortgage rate of FRMs is a 30-year rate. Beyond these differences, the mortgage contracts are equal, i.e., mortgages are amortized over 30 years, and the same LTV and PTI constraints and refinancing costs apply.

I begin by considering the same 100bp expansionary monetary policy shock as in the baseline analysis but in a setting where the available mortgage contract is of the adjustable-rate type.[19] A transitory monetary policy shock tends to lead to larger changes in the short mortgage interest rates of ARMs than the long rate of FRMs, but these rate changes only apply periodically. For ARMs, I assume that the mortgage interest rate in a given year is provided by the risk-free rate of return on bonds plus the exogenous credit spread κ.[20] The resulting mortgage interest rate path for ARMs is displayed in Figure 8, along with the interest rate paths of bonds and FRMs.

[19] Since the impulse response function for aggregate income is estimated using U.S. data, the effects on income are consistent with a mortgage market where the contracts are mostly of the fixed-rate type. In Appendix D.1, I therefore analyze the role of the response in aggregate income.

[20] Throughout the analysis, I assume that the credit spread κ remains constant. Eggertsson et al. (2019) find that the pass-through of policy-rate cuts to mortgage interest rates in normal times is around 80 percent within 30 days, using Swedish data where most mortgages are of the variable-rate type.

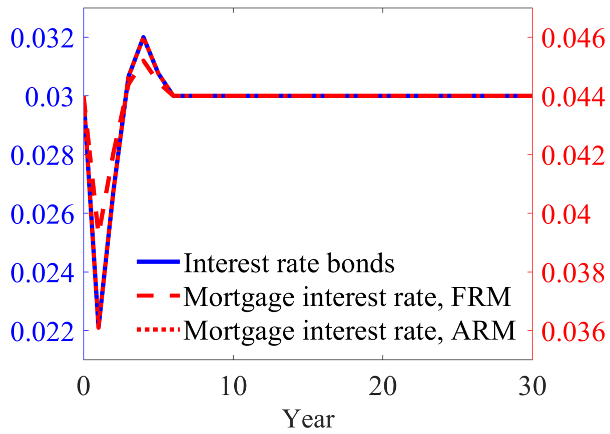


Figure 8: Real interest rates

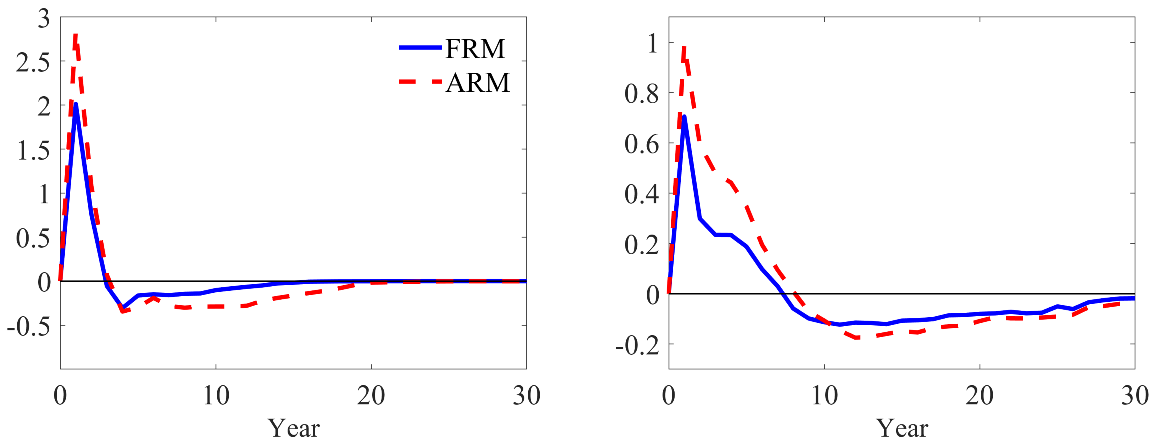
Note: The paths of the interest rate on bonds, the mortgage interest rate on ARMs, and the long mortgage interest rate on FRMs. The paths follow an unexpected nominal interest rate shock of -100bp, where the path of the real interest rate on bonds corresponds to the estimated impulse response function in Auclert et al. (2020). The mortgage interest rates read off the right-hand side y-axis.

Figure 9 presents the equilibrium path of house prices and the IRF for consumption under the two different mortgage regimes. Consistent with empirical findings, see, e.g., Calza et al. (2013), the house-price response is significantly larger in the more flexible mortgage market with ARMs.[21] Furthermore, aggregate demand increases more when mortgages are of the adjustable-rate type (0.99 as compared to 0.70 percent).

The strong response in house prices under ARMs follows from marginal house buyers who appreciate the sharp drop in mortgage rates in the near term under ARMs. Most buyers finance their house purchase with a mortgage, and tend to be liquidity constrained. They therefore place a high value on lower mortgage rates in the near term. Moreover, since mortgages are paid off over 30 years, it is more favorable to have lower rates early on, as compared to a less reduced rate that lasts for the life of the mortgage, which is the case for FRMs.

To understand the difference in aggregate demand between the two economies, Table 8 clarifies the role of discrete portfolio updates, including the choice to refinance. First, one can note that extensive-margin portfolio adjustments play a significant role for the transmission of monetary policy, also under ARMs, but to a somewhat smaller extent. Discrete-choice updates account for approximately 40 percent of the initial aggregate demand response under ARMs, whereas this number is roughly 50 percent under FRMs. This finding is consistent with the empirical evidence that direct cash-flow effects, which do not involve any portfolio adjustments, are strong when mortgages have adjustable

[21]Several studies that focus on different European countries, where mortgages with variable rate are more common, also find relatively strong effects on house prices, see, e.g., Bjørnland and Jacobsen (2010) and Nocera and Roma (2018).



(a) House prices (%) (b) Consumption (%)

Figure 9: Impulse response functions for house prices and aggregate consumption
Note: A comparison between the baseline model with fixed-rate mortgages and the comparable model with adjustable-rate mortgages. The impulse response functions follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rates as displayed in Figure 8 and aggregate income as in Figure 3b.

rate. Second, the choice to refinance actually plays a much larger role for aggregate demand under ARMs, as compared to FRMs. Note that when mortgages have adjustable interest rate, homeowners use refinancing only in order to take up a larger mortgage than stipulated by their amortization plan. Since house prices increase substantially more under ARMs than under FRMs, more households find it optimal to use cash-out refinancing to increase consumption, and those who do can extract more equity from their home. Under ARMs, the share of households who refinance due to the shock is 1.2 percentage points higher than under FRMs. As a result, there is an improved consumption smoothing when mortgages have variable rate, explaining much of the stronger consumption response.

Overall, the structure of the mortgage market impacts the effectiveness of monetary policy. In particular, the higher house prices under ARMs allow for larger equity withdrawals for homeowners who refinance their mortgage or sell their home. In fact, the difference in the house-price response in these two settings accounts for approximately 41 percent of the difference in aggregate consumption demand (in the setting with ARMs, demand increases by 0.87 instead of 0.99 percent if imposing the equilibrium house-price response from the economy with FRMs).

The pass-through to mortgage interest rates

In the data, we can note that the pass-through of unexpected, temporary changes in the central bank's policy rate to long interest rates varies over time, due to for example changes in term premia. To disentangle the importance of the pass-through rate of monetary policy

	ARM	FRM
Δ C, optimal portfolio choices	0.99	0.70
Δ C, steady-state choice to refinance	0.60	0.45
Δ C, steady-state discrete choices	0.58	0.34

Table 8: Consumption responses under ARMs versus FRMs (%)

Note: Aggregate consumption responses under different assumptions for extensive-margin portfolio adjustments. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rates as in Figure 8, aggregate income as in Figure 3b, and house prices as in Figure 9a.

to mortgage interest rates, I compare the baseline scenario with a 60 percent pass-through to two alternative settings. First, I assume that the long mortgage interest rate of an FRM is given by the geometric mean of the expected gross yearly mortgage interest rates (the ARM rates), for the next 30 years, in line with the expectations hypothesis of the term structure. Second, I consider the scenario where there is 100 percent pass-through, such that the long rates respond one-for-one with the short rates.

A comparison of the initial consumption response and the equilibrium house-price response for the different pass-through scenarios are presented in Table 9, along with the responses under ARMs. Not only does the pass-through rate to mortgage interest rates impact the effectiveness of monetary policy, it also explains most of the difference in the demand response between FRMs and ARMs. When there is full pass-through of the monetary policy shock to the long interest rates of FRMs, the aggregate-spending response is very similar to that under ARMs.

With full pass-through to long rates, ARMs and FRMs still differ in two important ways. First, only households who take up a new mortgage access the lower rate under FRMs, whereas all mortgagors are directly affected by changes in mortgage rates under ARMs. Second, the lower mortgage rate lasts until a mortgage is fully repaid under FRMs, whereas mortgagors under ARMs only experience lower rates temporarily. As it turns out, the implications of these two differences for the initial response in aggregate demand are largely the same.[22] Marginal house buyers clearly prefer that the lower mortgage rate persists, which causes house prices to rise more under FRMs. The higher house prices in turn benefit liquidity-constrained homeowners who access their housing wealth to increase consumption. However, this additional benefit is roughly as important for aggregate demand as the lower mortgage rate for all existing mortgagors under ARMs who would have needed to make extensive-margin portfolio adjustments to access the lower rate

[22]This finding also holds if considering a contractionary monetary policy shock. The aggregate consumption response to a 50bp contractionary shock is -0.55 percent in an economy with ARMs, and -0.59 percent in a setting with FRMs with full pass-through.

under FRMs. Hence, mortgage markets that are characterized by more adjustable-rate contracts do not necessarily contribute to a stronger impact of monetary policy, but this depends on the pass-through to mortgage rates.

Taken together, the pass-through of monetary policy to long mortgage rates significantly affects aggregate demand. This finding is relevant for assessing the effects of unconventional monetary policy, suggesting that there are potentially large effects of quantitative easing. Specifically, if the central bank can affect long mortgage interest rates through their asset-purchase programs, both house prices and consumption respond strongly.[23] Moreover, my findings shed light on the transmission mechanism by highlighting the role of adjustments of both mortgage *and* housing choices in response to changes in long mortgage rates.

	FRM geo avg	FRM 60% pass-through	FRM 100% pass-through	ARM
Δ C	0.48	0.70	1.02	0.99
Δ p_h	0.59	2.01	3.33	2.85

Table 9: Consumption and house-price responses (%)

Note: Aggregate consumption responses and endogenous house-price effects under different assumptions for the pass-through of monetary policy to mortgage interest rates. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The responses follow an unexpected shock to the real interest rate on bonds as in Figure 3 and aggregate income as in Figure 3b.

5 Concluding remarks

Over the past decades, there have been important developments in macroeconomic research that emphasize that different households respond very differently to changes in their environment, and that this can have implications for aggregate responses to policy changes. Many households are liquidity constrained and respond strongly to changes in their cash flows. In this paper, I explore one channel through which monetary policy can directly influence households' cash flows, namely, by affecting their mortgage and housing choices. I construct a heterogeneous-agent life-cycle model to study how different households' mortgage and housing choices impact their spending, in response to changes in interest rates. Moreover, I quantify the role of changes in mortgage interest rates and house prices for the response in aggregate consumption to a monetary policy shock.

Although less than 6 percent of households adjust their housing and mortgage choices in response to a 100bp expansionary monetary policy shock, I find that these choices account for 50 percent of the response in aggregate demand. Most of the increase in consumption is driven by an improved consumption smoothing among constrained households, whose

[23] Di Maggio et al. (2019) present empirical evidence on the refinancing channel of quantitative easing.

liquidity rises when they update their housing and mortgage portfolio. I also find that both changes in mortgage interest rates and house prices are crucial for the extensive-margin portfolio adjustments and in turn the aggregate spending response. As the reduction in the policy rate feeds into mortgage interest rates, there is an endogenous rise in house prices. Higher house prices increase the wealth of existing homeowners, allowing for an improved consumption smoothing among those who choose to access their housing equity by either refinancing, moving to a new house, or moving to rental housing. The higher house prices also discourage some renters from buying a house, making them less constrained in their spending. Furthermore, I show that the structure of the mortgage market impacts the effectiveness of monetary policy. The extent to which a monetary policy shock passes through to long mortgage interest rates is a key determinant of the response in house prices as well as aggregate demand. If long rates respond equally strong as short rates to monetary policy shocks, the aggregate consumption response is remarkably similar in economies with fixed-rate and adjustable-rate mortgages.

The findings in this paper add to the growing literature on the importance of changes in households' mortgage payments and refinancing activities for the transmission of monetary policy. I quantify the contribution of different portfolio adjustments in the housing and mortgage markets, for the effect on aggregate demand. In particular, I emphasize the role of changes in housing choices. My results suggest that a detailed understanding of the flexibility in not only the mortgage market but also the housing market is an important input into the analysis of monetary policy.

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Appendices

A Equilibrium definitions

A.1 Stationary equilibrium

Households are heterogeneous with respect to age $j \in \mathcal{J} \equiv \{1, 2, ..., J\}$, owner-occupied housing $h \in \mathcal{H} \equiv \{0, \underline{h}, ..., \overline{h} = \overline{s}\}$, mortgage $m \in \mathcal{M} \equiv \mathbb{R}_+$, mortgage age $ma \in \mathcal{MA} \equiv \{1, 2, ..., L\}$, permanent earnings $n \in \mathcal{N} \equiv \mathbb{R}_{++}$, and cash-on-hand $x \in \mathcal{X} \equiv \mathbb{R}_{++}$. Let $\mathcal{Z} \equiv \mathcal{H} \times \mathcal{M} \times \mathcal{MA} \times \mathcal{N} \times \mathcal{X}$ be the non-deterministic state space with $\mathbf{z} \equiv (h, m, ma, n, x)$ denoting the vector of individual states. Let $\mathbf{B}(\mathbb{R}_{++})$ and $\mathbf{B}(\mathbb{R}_+)$ be the Borel σ-algebras on $\mathbb{R}_{++}$ and $\mathbb{R}_+$, respectively, $P(\mathcal{H})$ the power set of $\mathcal{H}$, and $P(\mathcal{MA})$ the power set of $\mathcal{MA}$, and define $\mathscr{B}(\mathcal{Z}) \equiv P(\mathcal{H}) \times \mathbf{B}(\mathbb{R}_+) \times P(\mathcal{MA}) \times \mathbf{B}(\mathbb{R}_{++}) \times \mathbf{B}(\mathbb{R}_{++})$. Further, let $\mathbb{M}$ be the set of all finite measures over the measurable space $(\mathcal{Z}, \mathscr{B}(\mathcal{Z}))$. Then, $\Phi_j(Z) \in \mathbb{M}$ is a probability measure defined on subsets $Z \in \mathscr{B}(\mathcal{Z})$ that describes the distribution of individual states across agents of age $j \in \mathcal{J}$. Finally, denote the time-invariant fraction of the population of age $j \in \mathcal{J}$ by Π_j.

Definition 1. A stationary recursive competitive equilibrium is a collection of value functions $V_j(\mathbf{z})$ with associated policy functions $\{c_j(\mathbf{z}), s_j(\mathbf{z}), h'_j(\mathbf{z}), m'_j(\mathbf{z}), b'_j(\mathbf{z})\}$ for all j; prices (p_h, p_r); quantities of the total housing stock $\bar{H}$ and the total rental housing stock $\bar{S}$; and a distribution of agents' states Φ_j for all j such that:

1. Given prices (p_h, p_r), $V_j(\mathbf{z})$ solves the Bellman equation (14) with the corresponding set of policy functions $\{c_j(\mathbf{z}), s_j(\mathbf{z}), h'_j(\mathbf{z}), m'_j(\mathbf{z}), b'_j(\mathbf{z})\}$ for all j.

2. Given $p_h = p'_h$, the rental price per unit of housing services p_r is given by equation (15).

3. The quantity of the total housing stock is given by the total demand for housing services[24]

$$\bar{H} = \sum_{\mathcal{J}} \Pi_j \int_Z s_j(\mathbf{z}) d\Phi_j(Z).$$

4. The quantity of the total rental housing stock is given by the total demand for rental

[24] I assume a perfectly elastic supply of both owner-occupied housing and rental units in steady state. This implies that supply always equals demand, and markets clear.

housing services

$$\bar{S} = \bar{H} - \sum_{\mathcal{J}} \Pi_j \int_Z h_j(\mathbf{z}) d\Phi_j(Z).$$

5. The distribution of states Φ_j is given by the following law of motion for all $j < J$

$$\Phi_{j+1}(\mathcal{Z}) = \int_Z Q_j(\mathbf{z}, \mathcal{Z}) d\Phi_j(Z),$$

where $Q_j : \mathcal{Z} \times \mathscr{B}(\mathcal{Z}) \to [0,1]$ is a transition function that defines the probability that a household at age j transits from its current state $\mathbf{z}$ to the set $\mathcal{Z}$ at age $j+1$.

A.2 Transitional equilibrium

Let $\Phi_{tr,jt}(Z_t) \in \mathbb{M}$ be a probability measure defined on subsets $Z_t \in \mathscr{B}(\mathcal{Z})$ that describes the distribution of individual states across agents of age $j \in \mathcal{J}$ at time period t.

Definition 2. Given a sequence of interest rates on bonds $\{r_t\}_{t=1}^{t=\infty}$, interest rates on mortgages $\{r_t^m\}_{t=1}^{t=\infty}$, aggregate earnings $\{Y_t\}_{t=1}^{t=\infty}$, and initial conditions $\Phi_{tr,j1}(Z_1)$ for all j, a transitional recursive competitive equilibrium is a sequence of value functions $\{V_{jt}(\mathbf{z})\}_{t=1}^{t=\infty}$ with associated policy functions $\{c_{jt}(\mathbf{z}), s_{jt}(\mathbf{z}), h'_{jt}(\mathbf{z}), m'_{jt}(\mathbf{z}), b'_{jt}(\mathbf{z})\}_{t=1}^{t=\infty}$ for all j; a sequence of prices $\{(p_{h,t}, p_{r,t})\}_{t=1}^{t=\infty}$; a sequence of quantities of total housing demand $\{H_t\}_{t=1}^{t=\infty}$, total rental housing demand $\{S_t^D\}_{t=1}^{t=\infty}$, and total rental housing supply $\{S_t^S\}_{t=1}^{t=\infty}$; and a sequence of distributions of agents' states $\{\Phi_{tr,jt}\}_{t=1}^{t=\infty}$ for all j such that:

1. Given prices $(p_{h,t}, p_{r,t})$, $V_{jt}(\mathbf{z})$ solves the Bellman equation with the corresponding set of policy functions $\{c_{jt}(\mathbf{z}), s_{jt}(\mathbf{z}), h'_{jt}(\mathbf{z}), m'_{jt}(\mathbf{z}), b'_{jt}(\mathbf{z})\}$ for all j and t.

2. Given $p_{h,t}$, $p_{h,t+1}$, S_t^S, and $\bar{S}$, the rental price per unit of housing service is $p_{r,t}$ for all t, and is given by equation (16), where for a given t, $S = S_t^S$.

3. The housing market clears:

$$\begin{aligned} & H_t = \bar{H} \quad \forall t \\ \text{where} \quad & H_t = \sum_{\mathcal{J}} \Pi_j \int_{Z_t} s_{jt}(\mathbf{z}) d\Phi_{tr,jt}(Z_t) \quad \forall t \\ \text{and} \quad & \bar{H} \text{ is the total housing stock in steady state.} \end{aligned}$$

4. The rental market clears:

$$
\begin{aligned}
& S_t^D = S_t^S \quad \forall t \\
\text{where} \quad & S_t^D = H_t - \sum_{\mathcal{J}} \Pi_j \int_{Z_t} h'_{jt}(\mathbf{z}) d\Phi_{tr,jt}(Z_t) \quad \forall t \\
\text{and} \quad & S_t^S \text{ is the total rental housing supply in period } t.
\end{aligned}
$$

5. Distributions of states $\Phi_{tr,jt}$ are given by the following law of motion for all $j < J$ and t:

$$
\Phi_{tr,j+1,t+1}(\mathcal{Z}) = \int_{Z_t} Q_{tr,jt}(\mathbf{z}, \mathcal{Z}) d\Phi_{tr,jt}(Z_t),
$$

where $Q_{tr,jt} : \mathcal{Z} \times \mathscr{B}(\mathcal{Z}) \to [0, 1]$ is a transition function that defines the probability that a household of age j at time t transits from its current state $\mathbf{z}$ to the set $\mathcal{Z}$ at age $j + 1$ and time $t + 1$.

B Computational method and solution algorithm

See Karlman et al. (2021) for a detailed description of the computational method. To summarize, I use the general generalization of the endogenous grid method G^{2}EGM by Druedahl and Jørgensen (2017) to solve for the value and policy functions. The state space is discretized, where the number of grid points for permanent earnings N_N, cash-on-hand N_X, housing sizes N_H, bonds-over-earnings N_B, and loan-to-value N_{LTV}, are 9, 39, 4, 20, and 21, respectively. At lower levels of cash-on-hand and bonds-over-earnings, the grid points are denser.

All monetary policy shocks are unexpected and I adjust individual states for changes in the house price and taxes. Specifically, cash-on-hand x needs to be adjusted because (i) the value of the house changes; (ii) the property tax payment is affected; and, (iii) of changes in tax deductions due to changes in property taxes. In addition, I need to adjust for changes in the loan-to-value due to changes in the house price.

B.1 Solution algorithm

B.1.1 Steady state

Solving the steady state:

1. Impose house price $p_h = 2.60$ and compute p_r from equation (15).[25]

[25] This seemingly arbitrary choice for p_h does not matter for the results. It was chosen to simplify the

2. Solve the household problem recursively, and obtain the value and policy functions.
3. Simulate using optimal decision rules.
4. Use simulated values to compute the total housing stock $\bar{H}$ and the total rental stock $\bar{S}$. From the simulation I also get the distribution of agents' states Φ_j for all j.

B.1.2 Transition

Let $\Phi_{init,j}$ be the distribution of households' states in the initial steady state. Further, let t denote the transition period, and assume that the economy has returned to steady state in $t = T + 1$. Choose T large enough so that by increasing T the transition path is unaffected.[26]

Solving the transition:

1. Guess $\{p_{h,t}\}_{t=1}^{t=T}$ and $\{S_t^S\}_{t=1}^{t=T}$, and compute $\{p_{r,t}\}_{t=1}^{t=T}$ using the steady-state rental housing stock $\bar{S}$.
2. Recursively solve for the value and policy functions for all ages $j \in \mathcal{J}$ and time periods $t \in \mathcal{T}$. For $t = T + 1$, take the value and policy functions from the steady state.
3. Given the price $p_{h,1}$, for each $j \in \mathcal{J}$, adjust the initial individual states such that the initial distribution $\Phi_{init,j}$ reflects unexpected changes in the house price from the steady state.
4. Simulate using the adjusted initial distribution and optimal decision rules. Use simulated values to compute the sequence of total housing demand $\{H_t\}_{t=1}^{t=T}$ and total rental housing demand $\{S_t^D\}_{t=1}^{t=T}$.
5. Compute the sequence of excess demand for housing $\{ED_{H,t}\}_{t=1}^{t=T}$ and for rental housing $\{ED_{S,t}\}_{t=1}^{t=T}$, and the Euclidean norms of these sequences.
   (a) If the norm is larger than some tolerance level, update $\{p_{h,t}\}_{t=1}^{t=T}$ using the rule $p'_{h,t} = p_{h,t} + ED_{H_t} * \epsilon_{p_h}$ and $\{S_t^S\}_{t=1}^{t=T}$ using the rule $S_t^{S'} = S_t^S + ED_{S,t} * \epsilon_S$, for all $t \in \mathcal{T}$ and go back to step 1.
   (b) If the norms are within the tolerance level, convergence is achieved.

conversion from an earlier version of the model that had a model period length of three years.

[26] I set $T = 30$, and $T = 40$, depending on the experiment.

C Independently calibrated parameters

Parameter	Description	Value
σ	Coefficient of relative risk aversion	2
r	Interest rate	0.03
κ	Yearly spread, mortgages	0.014
τ^l	Local labor income tax	0.05
τ^c	Capital income tax	0.15
τ^{ss}	Payroll tax	0.153
τ^h	Property tax	0.01
l	Mortgage contract length	30
θ	Down-payment requirement	0.20
ψ	Payment-to-income requirement	0.28
δ^h	Depreciation, owner-occupied housing	0.03
ς^I	Home insurance	0.005
ς^b	Transaction cost if buying house	0.025
ς^s	Transaction cost if selling house	0.07
ς_p^r	Proportional refinancing cost	0.01
R	Replacement rate for retirees	0.50
B^{max}	Maximum benefit during retirement	0.61

Table 10: Independently calibrated parameters, taken from the data or other studies
Note: The table lists calibrated parameter values, and where relevant, these are annual.

D Additional results

Table 11 displays the mean change in liquid savings of households who make each possible discrete portfolio update, in the baseline setting with FRMs, after the 100bp expansionary monetary policy shock. The rows indicate the optimal discrete choice if the interest rate shock had not occurred, and the columns specify the optimal choice in the period of the shock. Figure 11 shows how the shares of buyers, refinancers, movers, stayers, and renters change in response to the -100bp interest rate shock, contrasting the baseline setting with FRMs and the economy with ARMs. Figure 10 presents the path of the rental rate in response to the shock.

	Buyers	Refinancers	Movers	Stayers	Renters
Buyers	13	-	-	-	347
Refinancers	-	96	14	-95	1585
Movers	-	63	2	-93	223
Stayers	-	2172	7	-6	3838
Renters	-62	-74	-4	-99	-1

Table 11: Change in liquid savings (%)

Note: Mean changes in liquid savings of households who make each possible extensive-margin portfolio adjustment. The deviations of liquid savings, in percent, are computed for the period when the interest rate shock occurs. The columns indicate the optimal choice to be a buyer, refinancer, mover, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the optimal choice if the interest rate shock had not occurred. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate and aggregate income, as displayed in Figure 3, and house prices as in Figure 4a.

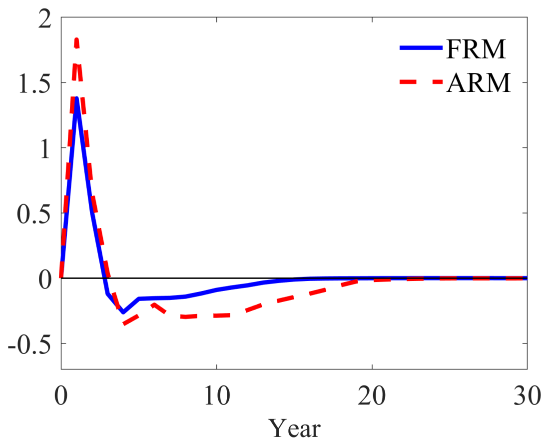
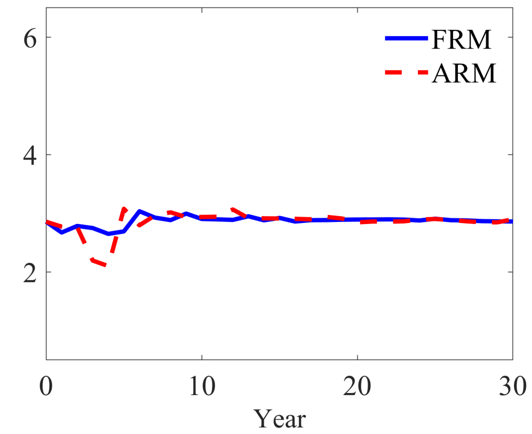
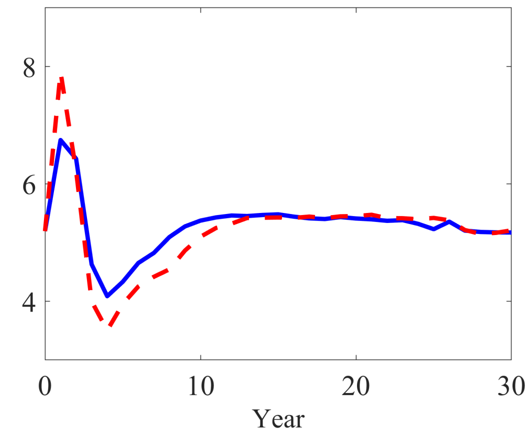


Figure 10: The response of the rental rate (%)

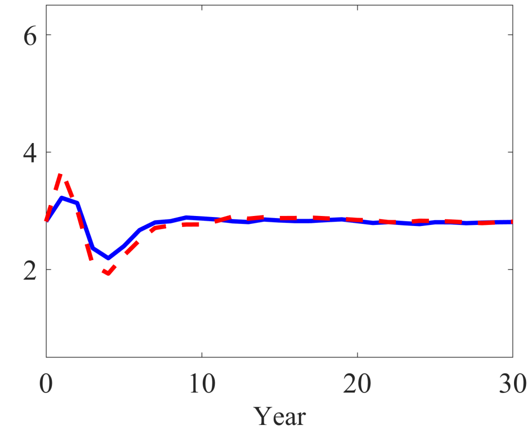
Note: A comparison between the baseline model with fixed-rate mortgages and the comparable model with adjustable-rate mortgages. The impulse response functions follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rates as displayed in Figure 8 and aggregate income as in Figure 3b.



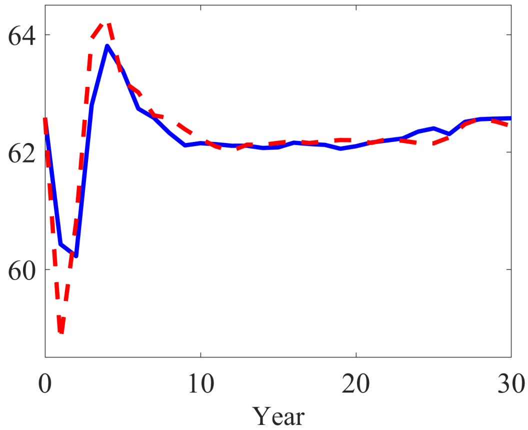
(a) Share of buyers (%)



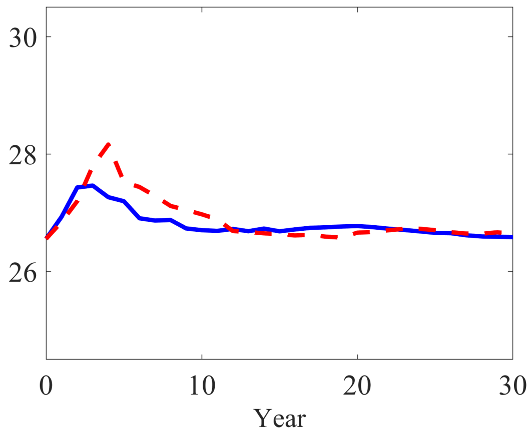
(b) Share of refinancers (%)



(c) Share of movers (%)



(d) Share of stayers (%)



(e) Share of renters (%)

Figure 11: Changes in shares of households making each discrete choice

Note: A comparison between the baseline model with fixed-rate mortgages and the comparable model with adjustable-rate mortgages. The changes follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rates as displayed in Figure 8 and aggregate income as in Figure 3b.

D.1 The role of changes in aggregate income

The findings in this paper highlight the importance of the dynamics in the housing and mortgage markets for responses to interest rate changes. In this section, I examine how changes in earnings influence the housing and mortgage choices, and ultimately the aggregate consumption response to the interest rate shock. Let us therefore compare the results from the baseline setting to a scenario where earnings are not affected by the interest rate shock. Table 12 demonstrates the importance of discrete portfolio updates in the economy with FRMs and ARMs, and for different assumptions of the earnings response.

First, extensive-margin portfolio adjustments account for almost the entire increase in aggregate demand under ARMs, and even more so under FRMs, when earnings are kept constant. In fact, when not allowing households to update their discrete choices due to the shock, the aggregate demand response is similar to the setting where both mortgage interest rates and house prices are not responding to the shock (see Table 3). Second, the aggregate consumption response is approximately 0.40 percentage points larger due to changes in earnings, in both the setting with FRMs and ARMs. As noted in the main analysis, the initial increase in earnings is relatively small, as seen in Figure 3b. However, earnings are expected to be significantly higher in the future, following the shock, which affects consumption choices today. Third, the consumption response is substantially larger in the economy with ARMs as compared to FRMs, when earnings do not respond to the shock. Since the earnings response is a general-equilibrium effect of direct changes in demand, this finding suggests that the response in earnings is likely larger when mortgages have adjustable rate, implying that the difference between the two settings is larger.

	FRM	FRM (ΔY = 0)	ARM	ARM (ΔY = 0)
Δ C, optimal portfolio choices	0.70	0.29	0.99	0.59
Δ C, steady-state discrete choices	0.34	-0.03	0.58	0.06

Table 12: Consumption responses under ARMs versus FRMs (%)
Note: Aggregate consumption responses under different assumptions for extensive-margin portfolio adjustments and changes in earnings. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate as in Figure 8, aggregate income as in Figure 3b, when relevant, and house prices respond endogenously.

The first finding highlights that the main transmission mechanism of changes in mortgage interest rates and house prices is through their effect on households' housing and mortgage choices. The second finding shows that there is an amplifying effect on these choices if earnings adjust to the interest rate shock. As discussed in the main analysis, households who increase consumption the most are those who increase their liquid asset holdings by adjusting their mortgage and housing choices. Many of these households are temporary liquidity constrained and expect higher earnings in the future, and therefore find it optimal to increase consumption today. When earnings adjust to the shock, most of the increase in earnings occurs in the periods after the shock, hence, the consumption-smoothing motive of these households is even stronger. As a result, most of these households still find it optimal to make extensive-margin portfolio adjustments and increase consumption even more. Moreover, under both FRMs and ARMs, house prices increase by an additional 0.3 percentage points when including the response in earnings, increasing the available housing equity of homeowners, and discouraging some renters from buying a house. Overall, the relatively small initial increase in earnings and the larger increases that follow, do not change the optimal discrete portfolio choice of most households.