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

Karin Kinnerud*

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Abstract

Housing and mortgage choices are among the largest financial decisions households make, and they substantially impact households' liquidity. In this paper, I explore how monetary policy affects aggregate demand by influencing these choices. To quantify this portfolio channel of monetary policy, I build a heterogeneous-agent life-cycle model with housing and long-term mortgage contracts. I find that, in response to an expansionary monetary policy shock, 90 percent of the direct increase in aggregate demand is a result of households' discrete reallocations of their housing and mortgage holdings. The direct demand response is largely driven by an improved consumption smoothing among constrained households, whose liquidity improves when they update their housing and mortgage choices. Both lower mortgage interest rates and endogenously higher house prices are essential for the portfolio adjustments, and ultimately the response in demand. I also find that the effectiveness of monetary policy is highly dependent on the flexibility of the mortgage market. When mortgages have adjustable interest rates, as opposed to fixed rates, house prices increase substantially more, and the aggregate response of consumption is more than six times as large.

Keywords: Monetary policy, household finance, mortgages, housing, 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)). For mortgages, the strength of cash-flow effects depends on how exposed households are to changes in mortgage interest rates, which varies with the types of contracts that are used, i.e., if mortgages have fixed or adjustable interest rates.[1] Moreover, substantial cash-flow effects occur instantly for households who adjust their discrete housing and mortgage choices, in response to changes in interest rates. If these households are constrained in their spending, there can be real and direct implications for aggregate demand.

In my quantitative heterogeneous-agent life-cycle model I analyze these forces. I focus on the role that discrete choices in the housing and mortgage market play for the direct demand response of monetary policy. 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. My sole focus is on the direct demand responses of households, and to isolate these effects I do not consider how the aggregate demand response could propagate

[1] This channel is studied in, e.g., Di Maggio et al. (2017) and Flodén et al. (2019).

further in a general equilibrium.[2] To analyze the effects of monetary policy, I feed in an exogenous real interest rate path, which corresponds to an empirically estimated response from a monetary policy shock. In response to the shock, many households adjust their housing and mortgage holdings, making some households less liquidity constrained, and others more constrained in their spending. I show that these transactions have important implications for the aggregate, explaining approximately 90 percent of the direct response in aggregate spending. Moreover, the aggregate consumption response is highly dependent on the effect on house prices and the type of mortgage contracts that are used.

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. As emphasized by Kaplan and Violante (2014) and Kaplan et al. (2018), these "wealthy hand-to-mouth" households can play a key role for aggregate responses to shocks, as they often respond strongly to changes in their cash flows. Importantly, when the illiquid asset can be financed with a mortgage, whose interest rate is affected by monetary policy, portfolio adjustments that involve large cash flows are optimal for many households. Hence, unlike in standard models, where there are no direct cash-flow effects of a monetary policy shock, in this model some households realize substantial changes in their cash flows *directly*, through their mortgage and housing choices.[3] [4] Moreover, the existence of mortgage financing also allows for many households to be both relatively poor, i.e., have large mortgage balances, and have high exposures to changes in the interest rate.

[2] I investigate changes in consumption demand, and I use the terms aggregate demand, aggregate consumption demand, and aggregate spending, interchangeably.

[3] Throughout the paper, *direct* effects on demand refer to changes in consumption that are not a result of general-equilibrium effects of changes in aggregate demand. In this model the direct effects therefore encompass the effects from changes in the bond rate, the mortgage interest rate, as well as changes in house prices (that are not caused by equilibrium effects on earnings).

[4] Also in most HANK models, intertemporal substitution and income effects are the main drivers of the direct effect on demand, and cash-flow effects occur over time in the form of general-equilibrium effects on labor income and changes in the return on savings.

These indebted households tend to be young homeowners who recently bought their first home. As young households expect higher earnings in the future, they mainly save for precautionary reasons and have high marginal propensities to consume.

The calibrated model matches salient life-cycle and cross-sectional features of the U.S. data, relating to housing, mortgage debt, 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 a monetary policy shock, I use a real interest rate shock that is empirically estimated. I consider a negative shock of 100 basis points (bp) to the nominal interest rate, which translates into an immediate reduction of the real interest rates on bonds and mortgages of approximately 80bp.

Results on aggregate responses and portfolio choice

In response to the expansionary monetary policy shock, I find that the direct effect on aggregate consumption demand, abstracting from general-equilibrium multiplier effects, is an increase by 0.6 percent. Moreover, aggregate mortgage debt grows by approximately 7 percent and house prices rise by 2.6 percent. I find that households' discrete portfolio adjustments of whether to rent, buy, or sell a house, and the use of mortgage refinancing, explain most of the direct effect on aggregate demand and debt. Specifically, if forcing households to not make any extensive-margin portfolio adjustments different from what they had done without the shock, the aggregate-demand response is 90 percent lower.[5] 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 aggregate-demand response. In fact, when keeping mortgage interest rates and house prices constant, in response to the monetary policy shock, the direct increase in aggregate demand is also reduced by almost 90 percent (0.06 vs 0.59 percent).

The decline in the mortgage interest rate causes almost all of the increase in house prices.[6] 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.

Many liquidity-constrained homeowners endogenously become less constrained in their spending as they choose to access their housing equity when mortgage interest rates decline and house prices rise. Households who use cash-out refinancing in response to the

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

[6] There is a minor increase in house prices if only the interest rate on bonds is affected by the shock and the mortgage interest rate is kept constant.

expansionary monetary policy shock contribute to a majority of the increase in aggregate spending. Hence, I confirm the importance of the refinancing channel, which has been emphasized in a number of papers (see, e.g., Wong (2019)). However, refinancing is not the only way through which homeowners can access their housing equity to increase consumption. The higher house prices make it optimal for more homeowners to sell their house in response to the shock. Homeowners who choose to become renters, due to the shock, represent 23 percent of the change in aggregate consumption, and homeowners who move to a new house in response to the shock, contribute with 8 percent. Hence, most of the consumption growth is a consequence of an improved consumption smoothing among liquidity-constrained homeowners.

There are several other discrete portfolio adjustments that contribute significantly to the response in aggregate spending, albeit with a smaller magnitude. Some renters choose to delay a house purchase, since house prices are temporary elevated. By avoiding to pay the transaction costs of buying and by not having to finance the down payment, these households become less liquidity constrained and increase consumption, as compared to if the shock had not occurred. On the contrary, some renters advance their house purchases, and some homeowners decide to stay in their house instead of moving to rental housing, due to the favorable mortgage conditions. These households end up cutting back on consumption, as they are more liquidity-constrained compared to if the shock had not happened.

These findings highlight the importance of the dynamics in the housing and mortgage markets for direct responses to interest rate changes. Moreover, I show that changes in earnings that arise over time in response to the initial increase in demand, strengthen the consumption smoothing motive of constrained households, and therefore contribute to stronger immediate demand responses. House prices rise even more when earnings increase, reinforcing the effects on consumption from the extensive-margin portfolio adjustments.

The role of the details of the mortgage market

In light of the results that discrete mortgage and housing choices constitute an important transmission channel, I proceed by investigating the importance of the mortgage market specifications. Specifically, I compare my results from the setting where the available mortgage is an adjustable-rate 30-year contract, to an economy where mortgages have fixed rates. With fixed-rate mortgages (FRMs), the consumption response is significantly smaller, following the temporary decline in the interest rate. Mortgagors benefit much less from the more persistent but smaller decrease of the interest rate of FRMs, as compared to adjustable-rate mortgages (ARMs). As a result, house prices increase less in the setting with FRMs, and the increase in aggregate consumption demand is much smaller.

The structure of the mortgage market also has interesting implications for households' savings behavior and debt levels. In the economy with ARMs, the increase in the mortgage balance of households who take up a new mortgage contributes to an overall rise in the aggregate debt level. However, there is also an increase in aggregate bond savings, following the interest rate reduction. This stands in sharp contrast to the economy with FRMs, where savings are reallocated to housing equity instead of liquid bonds. The deviation between the long-term mortgage interest rate and the return on bonds is the largest immediately after the interest rate shock occurs. As a result, it is relatively more favorable to save by paying off a mortgage as compared to in bonds, after the monetary policy shock. The aggregate mortgage balance decreases by almost 2 percent in the economy with FRMs, whereas it increases by approximately 7 percent in the setting with ARMs.

Overall, my findings show that the key driver of the direct response in aggregate consumption, is the improved consumption smoothing by 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., 2019). 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. Moreover, 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 these findings as motivating facts that I rationalize in my model. The mechanisms that I highlight are inherently difficult to study empirically. Specifically, counterfactual discrete choices are hard to predict. In the data, we can at best observe the tenure status of a household before and after a well-identified monetary policy shock, but we do not know the counterfactual change in tenure status, had there not been a shock. Changes in shares of households of different tenure status 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. I show that by including the third asset, the mortgage, the direct effects of interest rate shocks 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 direct 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 discrete housing and mortgage choices, changes in housing equity and optimal consumption can be rather lumpy. 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. Further, I explore the mechanisms through which house-price changes impact demand, by influencing both housing and mortgage choices of different households. I do so by including additional heterogeneity among households and by explicitly modeling the mortgage as a 30-year contract with either adjustable or fixed rate.

Several papers have focused on the refinancing channel of monetary policy. Chen et al. (2013) document that refinancing is negatively related to the business cycle. Moreover, in a simulation of the Great Recession, they find that depressed house values led to less refinancing. 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 monetary policy, but I also show that other transactions in the housing and mortgage markets are of quantitative importance. 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. Furthermore, I endogenize the response in house prices in these two environments, where I find that under ARMs, house prices respond much more strongly to an interest rate shock, a finding that is empirically supported; see Calza et al. (2013). I also show that the stronger response in house prices under ARMs contributes substantially to the amplified response in aggregate consumption.

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.[7] 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 long-term contracts with adjustable interest rate.[8] In this modeling environment, I am able to analyze the direct effects on demand of shocks to the real interest rate through changes in debt service costs, returns on liquid savings, and house prices.[9]

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 assets a, 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 earnings

[7] The model shares many features with Karlman et al. (2021).

[8] In Section 4.2, I compare my findings to an economy where long-term fixed-payment mortgages are used instead.

[9] General equilibrium effects of demand on wages and profits are not included in the main analysis. In Section 4.3, I analyze the implications of changes in aggregate income.

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. Long-term mortgages, that have to be paid off over time, are available to all homeowners. 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, and the number of periods left on a mortgage is given by $N = \min(J-j, l-ma)$, where ma is the mortgage age. I thus assume that mortgages have to be repaid in full by the age of certain death.[10] The minimum required mortgage payment is an age and mortgage-age dependent fraction $\chi_{j,ma}$ of the current mortgage balance

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

[10] 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.

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 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.[11] 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,

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

It consists of labor income or social security benefits y, any savings from liquid bonds less the mortgage balance including interest, the value of the house net of transaction costs, less maintenance costs and total tax payments Γ.[12] A household of the newborn cohort enters the economy with initial assets a.

[11] 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.

[12] 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.

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.[13] All working-age households, as indicated by $\mathbb{I}^w$, also pay a social security tax τ^{ss}, proportional to earnings. Further, 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 that refinances its mortgage, or is a homeowner that stays in its 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

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

$$\begin{aligned}
&q' = b' + p_h h' - m' && && (10)\\
&s = h' && \text{if } h' > 0 && (11)\\
&m' \geq 0 && \text{if } h' > 0 && (12)\\
&m' = 0 && \text{if } h' = 0 && (13)\\
&c > 0, s \in S, h' \in H, b' \geq 0, && &&
\end{aligned}$$

where $\mathbb{I}^k$ are indicator variables that take the value of one for the relevant case and zero otherwise.[14] 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

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

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

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.[15] 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 $\delta^r > \delta^h$.[16]

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.[17] Rental

[15]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).

[16]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.

[17]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

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. The present value of the accounting profits in steady state consists 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 the accounting 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, while 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.[18]

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

control and consumer protection in contracts, which contribute to the slow adjustment of rental rates to house-price changes.

[18]Note, if the whole stock of rental housing would be transacted in the market every period, 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.

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 related 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.

2.4 Solving the model

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 state space and the transitory earnings shocks are discretized to solve the model. The equilibrium house price 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.

To analyze the effects of an interest rate shock, I solve for a transitional equilibrium from an unexpected shock to the real interest rate.[19] Given the path of the real interest rate, I compute the transition path of the mortgage interest rate. For the analysis where mortgages have variable 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 mortgage contracts, 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. I assume that the long-term interest rate of fixed-payment mortgages is given by the geometric mean of the expected gross periodic mortgage interest rates, for the lifetime of the mortgage.

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 the interest rates and the house and rental prices. The equilibrium definitions are stated in Appendix A, and a more detailed description of the solution method is provided in Appendix B.

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 capture a steady state of the economy. Housing wealth and household debt have varied substantially over time, and the goal of the analysis is to investigate an interest rate shock that hits an economy that is in a steady state. Most of the parameter values are chosen from data or

[19] Note, I study monetary policy through its direct effect on the real interest rates on bonds and mortgages.

other studies. The remaining parameters are estimated by jointly minimizing the distance between several relevant equilibrium moments in the model and their data counterparts. A model period corresponds to one year.

3.1 External model parameters

A summary of the independently calibrated parameters are found in Table 10 of Appendix C.

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. In Appendix D.4, I show that my main results hold also in a setting where households have log preferences over consumption and housing services ($\sigma = 1$). 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. In the period leading up to the Great Recession, it became more common to borrow above 80 percent of the house value, but this period can be seen as an outlier. 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. (2020).

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 assets a 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 ages 23 to 25. The estimated variances are presented in Table 1.

Parameter	Description	Value
σ^2_α	Fixed effect	0.156
σ^2_ζ	Permanent	0.012
σ^2_ν	Transitory	0.061

Table 1: Estimated variances

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

The replacement rate R for retirees is chosen to be 50 percent of 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 Estimated parameters

The parameters that I estimate through simulated method of moments are listed in Table 2. The parameters are estimated 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	Median net worth, age 75/50	1.44	0.68
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: Estimated parameters

Note: Estimated parameters using simulated method of moments. The resulting 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 evaluated relative 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 estimated 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 estimate the depreciation rate of rental housing δ^r, I use the homeownership rate among households aged below 35 as a target moment. The overall homeownership rate is used to estimate the value of the smallest housing unit available to own $\underline{h}$. To account for the frictions in the mortgage market, I estimate 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 estimated 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. (2020).

The two parameters of the utility function of bequests are disciplined by two target moments related to savings. First, the parameter that captures the extent to which bequests are a luxury good $\bar{q}$ is estimated 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 bequest υ is calibrated to match the fraction of median net worth of households aged 75 over the median net worth of 50-year-olds. Finally, I estimate three parameters related 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 estimated to match the average marginal tax rate in the economy; while the progressivity parameter τ^p is estimated 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

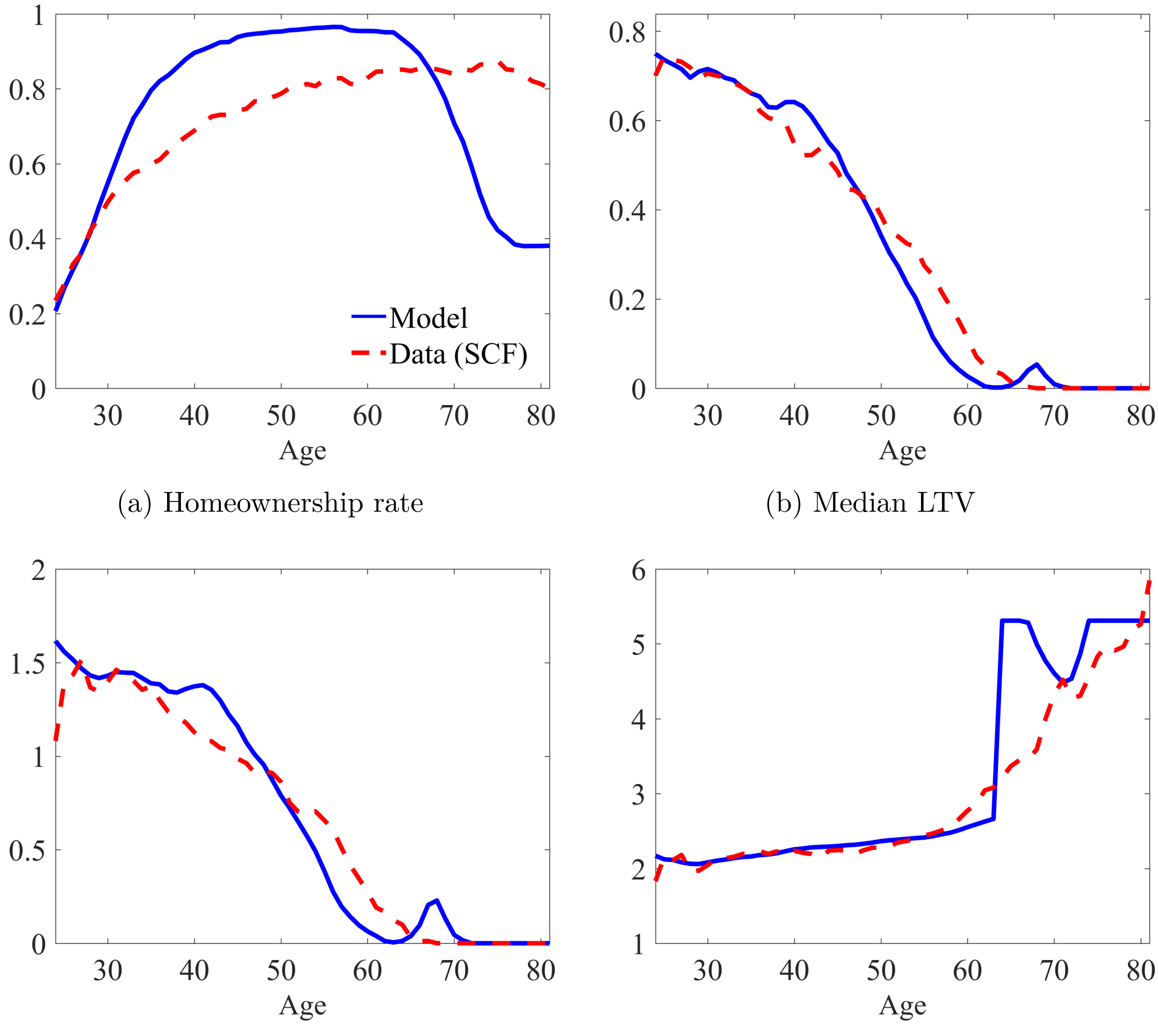
To evaluate how well the model reflects the data along dimensions that are not targeted in the estimation, I present a comparison between the model and the data for moments that are particularly important for how households respond to interest-rate changes. The effects of a change in the mortgage interest 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 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, LTV, and net worth-to-earnings, in the model versus the data is displayed in Figure 2, along with a correlation plot of leverage and liquid assets.[20]

A household with a liquid-asset-to-earnings ratio of less than 0.5 is often referred to as a hand-to-mouth household in the literature. In the model, 24 percent of households have a liquid-asset-to-earnings ratio of less than 0.5, 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.[21] The distributions of LTVs and net worth-to-earnings also match the data well. However, in the data there are households with LTVs above 0.8, which is the cap in the model. The extent to which homeowners with mortgages are constrained in their spending can be evaluated by the correlation between liquid asset-to-earnings and LTVs. The model shows the same pattern as that found in the data: more leveraged households tend to have less liquid savings.

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

[21] To match the share of liquidity-constrained renters in the data one could introduce, e.g., discount-factor heterogeneity. This would be particularly important if studying general-equilibrium effects on earnings. However, the purpose of this paper is to analyze the direct effects of monetary policy, where poor renters play a small role.



(a) Homeownership rate

(b) Median LTV

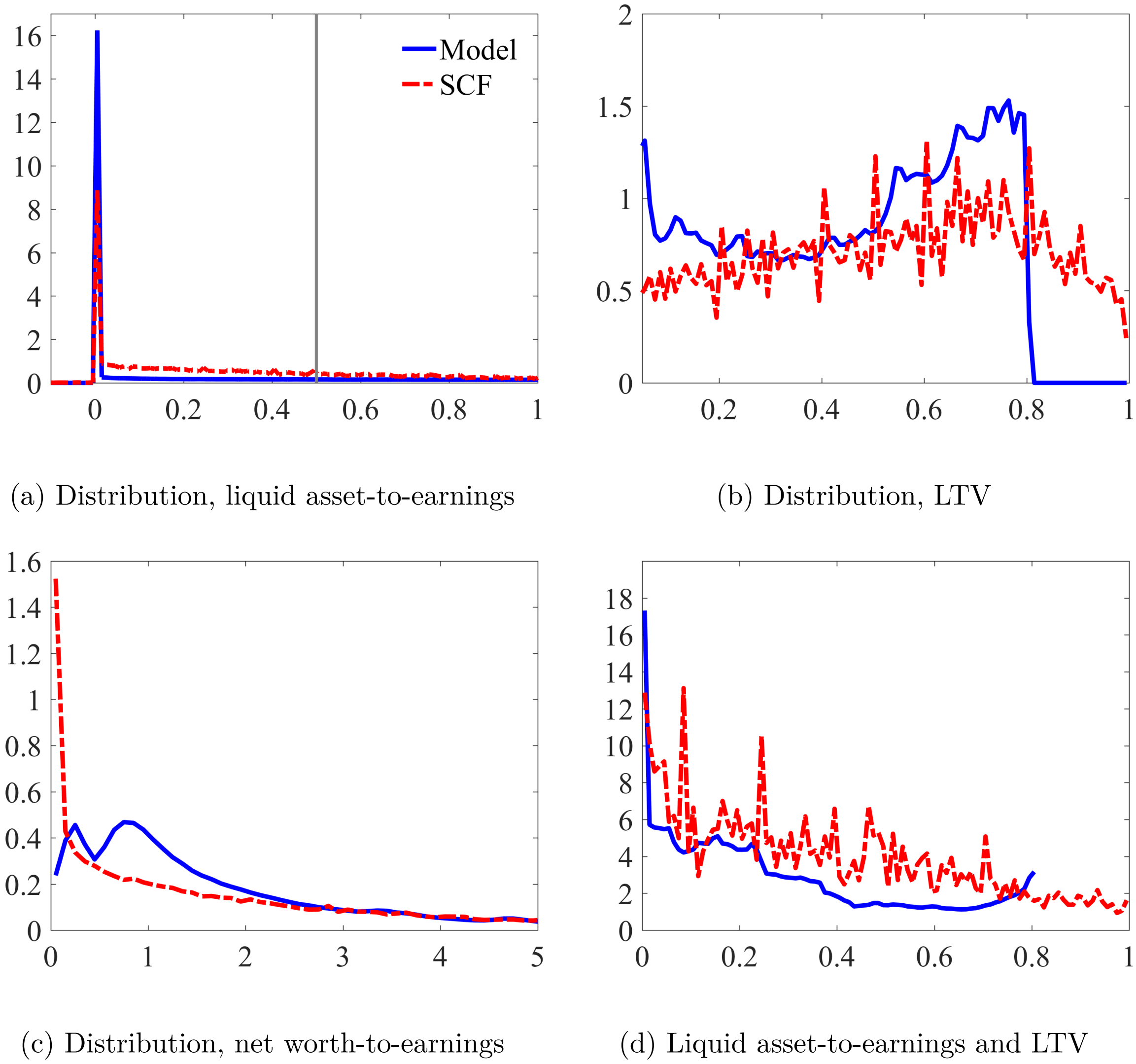
(c) Median mortgage-to-earnings

(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 portfolio choices of many 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 expansionary shock to the real interest rate on



(a) Distribution, liquid asset-to-earnings

(b) Distribution, LTV

(c) Distribution, net worth-to-earnings

(d) Liquid asset-to-earnings and LTV

Figure 2: Comparison between model and data: distributions

Note: Data refers to the Survey of Consumer Finances, for the survey years 1989 to 2013. Values of liquid asset-to-earnings above 300 in the data are censored.

bonds. I begin in Section 4.1 by assessing how monetary policy affects aggregate demand through households' housing and mortgage choices, and I proceed by quantifying the effects of changes in mortgage interest rates and house prices for aggregate spending. In Section 4.2, I investigate the importance of the mortgage-contract specification by comparing my main findings in the baseline setting with adjustable-rate mortgages (ARMs) to a setting where fixed-rate mortgages (FRMs) are used instead. Finally, in Section 4.3 I examine how changes in earnings influence the portfolio channel of monetary policy.

4.1 Housing and mortgage choices

Transmission of monetary policy and changes in liquidity

In this model, there are three main channels through which monetary policy affects households. 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. 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 what would be the result from 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. 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. Liquidity-constrained homeowners may in response to the decline in the interest rate choose to access their housing equity by refinancing or selling their 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 purchases if the mortgage conditions are unusually favorable, straining their liquidity. Moreover, some homeowners may decide to no longer refinance or sell their house, since the decline in the interest rate improves their finances, resulting in an optimal decrease in consumption relative to if the interest rate had not declined. Thus, to understand how the portfolio channel of monetary policy directly affects aggregate demand, a quantitative evaluation is necessary.

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. Empirical findings suggest that general-equilibrium effects on earnings tend to arise with a lag, whereas asset prices are much quicker to respond. Hence, any immediate cash-flow effects from an interest rate shock, should arise solely from portfolio adjustments. In the main part of the analysis, I therefore allow for house prices to adjust endogenously, while I keep earnings constant. By doing so, I focus on the direct effects of monetary policy. It is of course important to investigate whether expected changes in future earnings influence the direct responses and portfolio adjustments of households. In Section 4.3, I therefore compare my findings from the main analysis to a setting where I include a response in aggregate earnings.

The portfolio choice: housing, mortgages, and liquid savings

To study the effects of an interest rate shock, I use an empirically estimated path of the real interest rate from a shock of -100 basis points (bp) to the nominal interest rate. The estimated path of the real interest rate is the impulse response function from the identified Romer and Romer (2004) monetary policy shock in Auclert et al. (2020). The negative shock of 100bp to the nominal interest rate translates into an immediate reduction of the real interest rate on bonds of approximately 80bp. For the short-term mortgage interest rate of ARMs I assume a full pass-through of the shock. Hence, 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.[22] In Figure 3, the path of the real mortgage interest rate along with the path of the real interest rate on bonds are presented.

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. 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 prices. Importantly, any cash-flow effects through changes in mortgage interest payments or returns on savings occur at the earliest one period after the shock.

[22]In this analysis I assume that the credit spread remains constant over time. It would be straightforward to analyze a different pass-through to mortgage interest rates. 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.

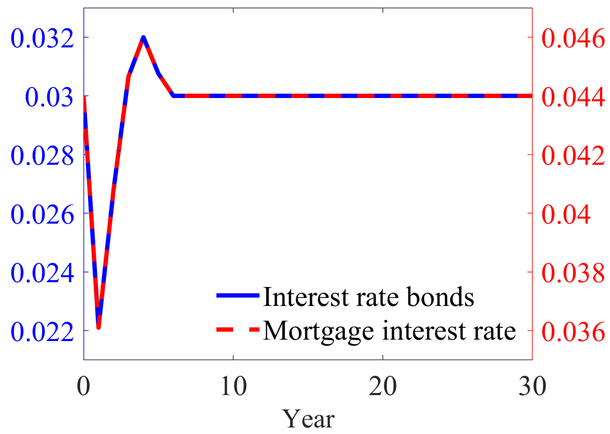


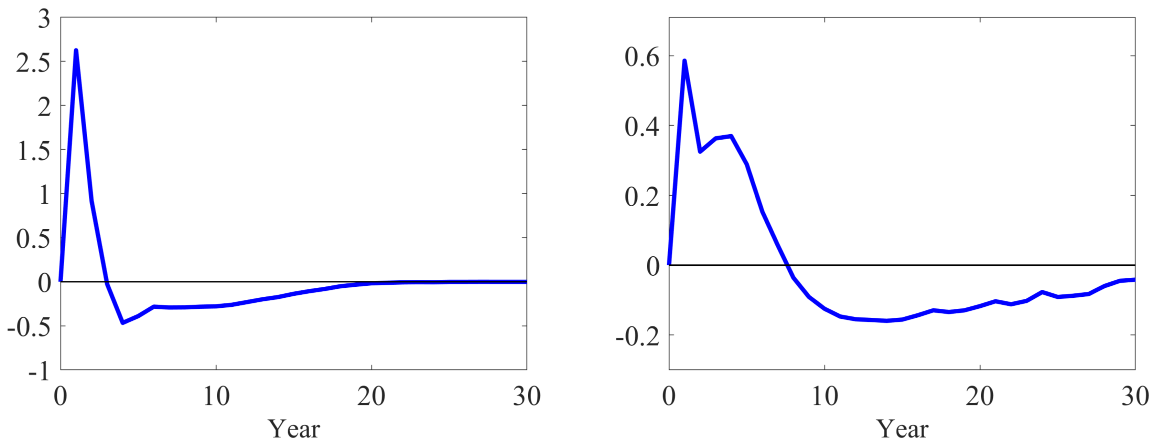
Figure 3: Yearly real interest rates
Note: The paths of the interest rate on bonds and mortgages. The paths follow an unexpected nominal interest rate shock of -100bp, where the path of the real interest rate on bonds corresponds to the estimated impulse response function in Auclert et al. (2020). The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

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. As evident in the figure, the demand for housing increases following the interest rate shock, pushing up house prices. 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. Moreover, there is an increase in aggregate consumption demand. Figure 4b, presents the IRF for consumption.[23] In the period of the shock, consumption rises by approximately 0.6 percent, and house prices increase by about 2.6 percent.

At a first glance, the IRFs may look somewhat unorthodox, with the relatively steep reversals after the initial increases. However, bear in mind that aggregate income is kept constant in this analysis. As such, the main effect of a change in the real interest rate is a shift in the use of resources over time. Thus, there is a drop in consumption following the initial increase. In a general-equilibrium analysis, this drop in consumption would be counteracted by an endogenous response of households' earnings (through employment and wages). In Section 4.3, where I present a step towards such an analysis, I show that the decline in consumption is then more gradual.

To understand the mechanisms behind the direct increase in aggregate demand we need to understand who the households are that respond strongly, and why they do so. I begin by computing consumption responses for the four mutually exclusive categories of

[23]For visual purposes, I do not show the full transition paths in the figures, but the choice of the transition period length was made to ensure that all variables converge to their steady-state levels.



(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, as displayed in Figure 3.

households in the model: house buyers, refinancers, stayers who follow their amortization plan, and renters. The first row in Table 3 presents the immediate mean consumption response separately for these four groups. The groups are defined based on the tenure status of households in the period of the interest rate shock. The deviation in consumption is then computed as the difference in the mean consumption of a group of households in the period when the interest rate shock occurs as compared to the mean consumption of the same households in the steady state.

	Overall	Buyer	Refinancers	Stayers	Renters
Δ C, optimal portfolio choices	0.59	1.46	5.98	-0.34	0.90
Δ C, steady-state tenure choices	0.06	0.70	1.89	-0.21	0.30

Table 3: Consumption responses (%)
Note: A decomposition of mean consumption responses of buyers, refinancers, stayers, and renters, 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 separation into buyers, refinancers, stayers, and renters is based on the tenure choice in the period of the interest rate shock. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rate, as displayed in Figure 3.

Not surprisingly, households who refinance their mortgage are clearly the households who increase consumption the most. In response to the 100bp expansionary monetary policy shock, this group of households increase consumption by almost 6 percent. Note that since mortgages have adjustable interest rates, homeowners use refinancing only in order to take up a larger mortgage than stipulated by their amortization plan. When mortgage interest rates decrease and house prices rise, these households find it optimal to use cash-out refinancing to increase consumption. Since these homeowners find it worthwhile to pay the refinancing costs, they must be liquidity constrained, explaining the strong increase in consumption once they access their housing equity. One can also note that both house buyers and renters respond relatively strongly as well, whereas stayers reduce their consumption on average. To understand these responses better, we need to decompose the results further.

Extensive-margin portfolio adjustments

The first row of Table 3 does not differentiate between households who belong to a certain category due to the shock, and those who would have belonged to that category regardless of the interest rate shock. To quantify the role of extensive-margin adjustments of households' portfolios, I compute the mean consumption response of the four types of households, if they are not allowed to update by switching between the four categories, 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, 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 responses are displayed in the second row of Table 3.

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 90 percent of the increase in aggregate spending is wiped out (an increase of 0.06 percent as compared to the equilibrium increase of 0.59 percent). It is still the case that households who refinance their mortgage increase consumption the most, house buyers and renters respond postitively, whereas stayers decrease consumption. However, the average responses are more muted for all four categories, and importantly the shares of households in the different groups have changed.

What type of extensive-margin portfolio adjustments are important for the direct response in aggregate demand? Table 4 presents the mean consumption response of households who make each possible discrete portfolio update, as well as the share of households of each type, in parenthesis.[24] The rows indicate the tenure choice if the interest rate shock had not occurred, and the columns specify the optimal tenure 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 represent discrete updates.

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

	Buyers	Refinancers	Stayers	Renters
Buyers	0.9 (4.6)	7.7 (0.1)	-12.5 (0.4)	5.1 (0.6)
Refinancers	15.0 (0.2)	1.9 (4.6)	-11.2 (0.4)	15.3 (0.0)
Stayers	4.0 (1.2)	13.2 (3.1)	-0.2 (57.8)	27.7 (0.5)
Renters	-4.5 (0.6)	-10.3 (0.1)	-18.9 (0.4)	0.3 (25.5)

Table 4: 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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 3.

Let us start by analyzing homeowners who choose to access their housing equity due to the shock. The third row of Table 4 shows the mean consumption response of households who would have stayed in their home and followed their amortization schedule if the interest rate shock had not occurred. When the interest rates decrease and house prices increase some of these homeowners, the liquidity constrained, 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 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 selling their house and buying a new home (column 1) or by becoming a renter (column 4). The consumption responses for all of these households are large and positive, as their extensive-margin portfolio adjustments increase their liquidity. Homeowners who choose to buy a new house increase consumption by 4 percent, those who choose to refinance increase consumption by 13 percent, and those who become renters find it optimal to hike consumption by 28 percent.

There are also homeowners who access their housing equity 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 15 percent, as seen in the second row of Table 4. 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 but refinance their mortgage to access their housing equity. This group of households increase consumption by almost 8 percent due to the interest rate shock. 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, lower consumption by 10 percent.

Other homeowners choose to no longer access their housing equity, due to the shock. The consumption responses of these households are displayed in the third column in Table 4 (rows 1, 2, and 4). In general, these households endogenously become more liquidity constrained, due to their portfolio choice, and decrease their consumption significantly. The lower mortgage interest rate and higher house prices improve the 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 the average consumption of this group of households increases by 5 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 5 percent.

To quantitatively assess the importance of the different types of extensive-margin portfolio adjustments, Table 5 presents the relative contribution of each type for the overall aggregate-demand response. There are two types of portfolio adjustments that stand out as contributing the most to the response in aggregate spending. First, households who choose to refinance their mortgage due to the shock represent 69 percent of the change in aggregate consumption. Second, households who take the opportunity to sell their house and become renters, when house prices are temporarily elevated, contribute to 23 percent of the response in aggregate demand. However, other portfolio-adjustment types contribute significantly as well. Overall, the model shows that extensive-margin portfolio adjustments account for much of the direct change in aggregate demand in response to monetary policy, and constitute an important transmission channel.

Let us also discuss the consumption responses of households who do not change their tenure status, as represented by the main diagonals in Table 4 and 5. The absolute magnitudes of the consumption responses of these groups are smaller than for those who make extensive-margin 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 0.9 percent. 4.6 percent of all households make up

	Buyers	Refinancers	Stayers	Renters
Buyers	0.07	0.01	-0.08	0.06
Refinancers	0.06	0.15	-0.08	0.01
Stayers	0.08	0.69	-0.18	0.23
Renters	-0.05	-0.01	-0.12	0.14

Table 5: 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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 3.

this group, which leads to a 7 percent contribution to the overall increase in aggregate 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 a large heterogeneity among the different households, where a significant share responds by reducing consumption.[25] Households in this group have an additional adjustment margin by updating the house size that they buy, contributing further to the heterogeneous responses in consumption within the group.

Homeowners who refinance their mortgage regardless of the interest rate shock, increase consumption by 1.9 percent due to the shock. This group comprises 4.6 percent of all households and contributes with 15 percent to the overall increase in aggregate demand. Refinancers benefit from both the lower mortgage interest rates 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 when taking up a new mortgage, the higher house prices allow them to take on more debt, making them less liquidity constrained.

The households who choose to stay in their house and comply with their amortization schedule, irrespective of the interest rate shock, are relatively unconstrained in their spending and their behavior is well described by their Euler equation. Hence, intertemporal substitution and income effects determine most of these households' consumption responses. In the baseline calibration, the coefficient of intertemporal substitution is equal to 0.5, hence, income effects dominate. However, there is a large heterogeneity in terms of income effects within this group. Some households have large mortgages and others have already paid off their mortgage in full. This heterogeneity translates into large

[25] Appendix D.2 presents the distributions of consumption responses of households who make each possible extensive-margin portfolio adjustment.

differences in consumption responses within the group, with some households increasing consumption substantially whereas others cut down on consumption. The average decline in consumption of 0.2 percent in the group suggests that households on average have negative income effects due to the lower return on savings.[26] This group makes up 57.8 percent of all households and contributes with negative 18 percent to the overall increase in aggregate spending.

Finally, the households who choose to rent housing, regardless of the interest rate shock, on average increase consumption by 0.3 percent. This group represents 25.5 percent of all households and contributes with 14 percent to the overall increase in aggregate demand. These households are particularly affected by how rental rates change due to the shock. The rental rate follows the movements in the house price, but responds proportionally less than the house price to the interest rate shock (see Figure 11 in Appendix D.1). The initial increase in the rental rate makes the relative price of consumption to rental services decline. As a result, almost all renters increase consumption in the period when the shock occurs. The lower return on savings has a negative income effect on all renters, however, households differ with respect to their expected future house purchases and uses of mortgages. As a result, there is still some heterogeneity in consumption responses within the group.

To summarize, the portfolio channel of monetary policy plays a significant role in the transmission of monetary policy. Specifically, extensive-margin adjustments of housing and mortgage choices account for almost 90 percent of the initial response in aggregate demand. These portfolio adjustments directly affect cash flows of many liquidity-constrained households, and consequently their consumption choices. As been pointed out in a large empirical and theoretical literature, households who refinance their mortgage in response to expansionary monetary policy play an important role for aggregate spending. However, refinancing is not the only way through which homeowners can access their housing equity to increase consumption. Homeowners who choose to move to a new house or who sell their house and become renters account for 31 percent of the increase in aggregate demand. Hence, it is not only the flexibility of the mortgage market that is important for the effectiveness of monetary policy, but the flexibility of the housing market proves crucial as well.

[26] In Appendix D.4, I show that under log preferences these households increase consumption slightly on average. In that case, when income and substitution effects cancel out, the higher house prices contribute to the increase.

Changes in mortgage interest rates and house prices

The previous section showed that portfolio adjustments substantially impact the aggregate spending response to monetary policy, by endogenously affecting the liquidity of many households. The portfolio adjustments also lead to potentially important general-equilibrium effects on house prices. What are the implications of the instantly higher house prices for aggregate demand? On the one hand, the higher house prices affect how much house buyers need to save to comply with the required down payment when purchasing a house. On the other hand, the higher house prices increase the wealth and housing equity of existing homeowners.

To quantify the role of changes in both mortgage interest rates and house prices, I compute the IRFs under the following assumptions i) Mortgage interest rates and house prices adjust endogenously; ii) Mortgage interest rates are constant; iii) House prices are constant; and iv) Both house prices and mortgage interest rates are constant.[27] Table 6 presents the aggregate consumption response in the period of the shock, under the different equilibrium assumptions.

	p_h & r_m adjust	fixed r_m	fixed p_h	fixed p_h & r_m
Δ aggregate consumption	0.59	0.31	0.33	0.06

Table 6: Consumption responses (%)

Note: A decomposition of mean consumption responses under different equilibrium assumptions for house prices and mortgage interest rates. 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, as displayed in Figure 3, when applicable.

Table 6 clearly illustrates that both the lower mortgage interest rate and the higher house prices amplify aggregate demand. If not allowing for house prices and the mortgage interest rate to change, the direct effect on aggregate spending is at the same level as when not allowing for extensive-margin adjustments in response to the shock: an increase of 0.06 percent as compared to the equilibrium increase of 0.59 percent. In fact, when keeping the mortgage interest rate and house prices fixed, the share of households who make extensive-margin portfolio adjustments due to the monetary-policy shock is significantly reduced from 7.6 percent to 0.5 percent.[28]

[27] In case ii), where mortgage interest rates are constant, I use the house-price path from i), i.e., the equilibrium house prices when both mortgage interest rates and house prices adjust.

[28] The type of extensive-margin adjustment that dominates (0.4 percent) is households who choose to buy a house instead of renting, due to the interest rate shock. When the mortgage interest rate is kept constant, house prices would instantly increase slightly in equilibrium, due to the decline in the bond rate. Thus, when house prices are fixed, the excess demand shows up by more renters deciding to buy a house in the period of the shock.

In the previous section, we saw that homeowners who choose to refinance their mortgage or sell their house due to the interest rate shock, account for most of the increase in aggregate spending. House-price increases and reductions in mortgage interest rates benefit these homeowners substantially. As already alluded to, the lower mortgage interest rates reduce the future costs of mortgagors, who therefore need to save less for precautionary reasons. In addition, many mortgagors want to consume more as a result of the positive income effect associated with the lower future mortgage payments. Moreover, as the housing equity of existing homeowners increases with elevated house prices, it becomes optimal for more households to pay the transaction costs to access that illiquid wealth. In particular, households who use cash-out refinancing can extract a larger amount before being constrained by the LTV requirement. Overall, lower mortgage interest rates and higher house prices lead to more homeowners accessing their housing equity, and on average, these households increase consumption to a greater extent.

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. In fact, the results in this paper highlight two challenges with empirical investigations of the transmission of monetary policy through discrete choices. First, when there are sizeable frictions and transaction costs associated with discrete 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, tenure 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 would 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 change over time, but rather how it changes compared to the counterfactual outcome, had the shock not occurred. Another example is households who choose to stay in their house instead of becoming renters, due to the shock. Many of these households are not changing their consumption much when the shock occurs, as compared to in the period before the shock. However, had the shock not happened, they would have become renters with more liquidity at hand, and they would have had a higher consumption. 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 tenure choices of households prior and following a well-identified monetary policy shock, and how the shares of households of different tenure status change. However, as shown in Table 4, the observed tenure 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.

Second, when discrete choices are available, the timing of measurements is crucial to empirically disentangle the transmission mechanisms of monetary policy. In models with borrowing constraints and adjustment costs, such as the model in this paper, households with low liquid assets in relation to earnings tend to respond strongly to changes in their cash flows. Although this prediction may be true, a high frequency of measurement is required to confirm this in the data, since discrete choices can substantially change the liquidity of households. For example, the date of refinancing is needed to link this choice to consumption in the correct period, and to be able to draw the correct conclusions about the role of general-equilibrium effects on earnings. To give another example, households who choose to buy a house due to the interest rate shock, may respond strongly to general-equilibrium effects on earnings arising over time, despite having high liquid savings before the shock.

4.2 Fixed-rate mortgages

So far, the analysis has assumed that the mortgage contract is a 30-year mortgage with adjustable rate. In many countries the predominantly used mortgage has a variable rate, and it is arguably the type of debt contract most often used in quantitative models. However, the most commonly used mortgage in the U.S. is a 30-year fixed-payment contract, i.e., the mortgage interest rate is fixed. In this section, I analyze how the main findings in the previous section compare when considering an economy with FRMs.

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, under ARMs the mortgage rate is short term, whereas it is long-term for FRMs. Hence, for FRMs, a temporary change in the short-term real interest rate leads to a smaller change in the mortgage interest rate, but this rate applies for 30 years. I assume that the current 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.[29] The resulting mortgage interest rate path for FRMs following the same unexpected, expansionary shock to the real interest rate as in the previous section, is displayed in Figure 5. A household that takes up a new mortgage in the period when the interest rate shock occurs receives a mortgage interest rate of 4.37 percent for the next 30 years, instead of the steady-state rate of 4.40 percent. Beyond the fixing period length of interest rates, the mortgage contracts in the two settings are equal, i.e., mortgages are amortized over 30 years, and the same LTV and PTI constraints and refinancing costs apply.

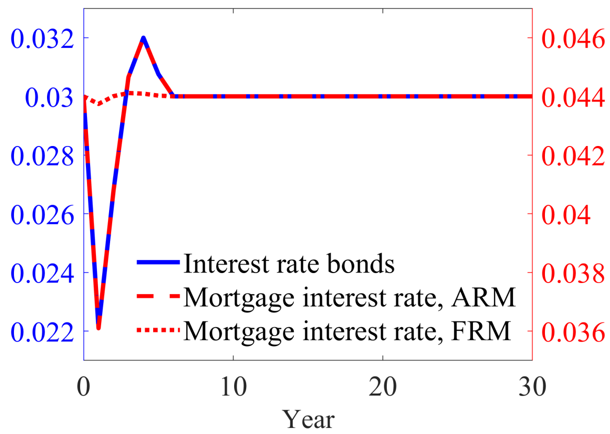


Figure 5: Real interest rates

Note: The paths of the interest rate on bonds, the mortgage interest rate on ARMs, and the long-term 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.

A growing empirical literature suggests that if mortgages have adjustable rates, as opposed to fixed rates, there are stronger responses to monetary policy.[30] Figure 6 presents the equilibrium path of house prices and the IRF for consumption under the two different mortgage specifications. Consistent with empirical findings, see, e.g., Calza et al. (2013), the house-price response is significantly smaller in the less flexible mortgage market with FRMs. Furthermore, aggregate demand increases only slightly in the period of the interest rate shock, when mortgages are of the fixed-rate type, and there is a subsequent decrease in demand after the initial spike.

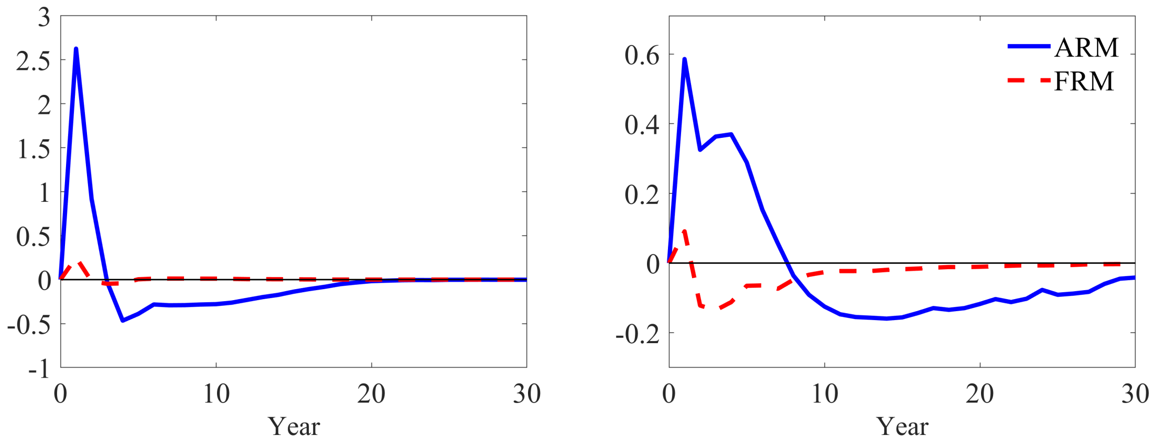
In the economy with ARMs, changes in mortgage interest rates and house prices could

[29] I assume that the credit spread κ remains constant over time, and that term premia are not affected by the monetary policy shock. In the data, we can note that the pass-through of temporary changes in the central bank's policy rate to long-term interest rates, is often larger than what is predicted by the expectations hypothesis of the term structure. It would be straight forward to consider another path of the long-term interest rate, but here I use the expectations hypothesis in order to make a clean comparison with the setting with ARMs.

[30] See, for example, Calza et al. (2013), Di Maggio et al. (2017), and Flodén et al. (2019).

explain most of the direct increase in aggregate demand. The marginal house buyer, who finances their purchase with a mortgage, appreciates lower mortgage rates in the near term. With FRMs, the temporary monetary-policy shock leads only to minor changes of the mortgage interest rate, as seen in Figure 5. Hence, there is only a small increase in house prices. Since the response in mortgage interest rates and house prices is rather small under FRMs, the economy behaves similarly to the setting in the previous section where these prices were kept fixed, and the aggregate-demand response was muted.

Table 7 presents the aggregate consumption responses in the period of the shock, under different equilibrium assumptions for mortgage interest rates and house prices. One can note that there is an amplification in aggregate spending due to the lower mortgage interest rate and higher house prices, also under FRMs. In relative terms, the amplification is large (a 50 percent increase), but in absolute terms it is rather small.



(a) House prices (%)

(b) Consumption (%)

Figure 6: Impulse response functions for house prices and aggregate consumption
Note: A comparison between the baseline model with adjustable-rate mortgages and the comparable model with fixed-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 5.

The portfolio choice under FRMs

As most of the aggregate demand response under ARMs was accounted for by households who made extensive-margin portfolio adjustments, let us also explore the portfolio channel of monetary policy under FRMs. In the economy with ARMs, 7.6 percent of households made an extensive-margin portfolio adjustment in response to the interest rate shock, in the period of the shock. Importantly, liquidity-constrained homeowners who chose to access their housing equity due to the interest rate shock, could be accounted for the

	p_h & r_m adjust	fixed r_m	fixed p_h	fixed p_h & r_m
Adjustable-rate mortgages	0.59	0.31	0.33	0.06
Fixed-rate mortgages	0.09	0.09	0.06	0.06

Table 7: Consumption responses (%)

Note: A decomposition of mean consumption responses under different equilibrium assumptions for house prices and mortgage interest rates, and a comparison between the baseline model with adjustable-rate mortgages and the economy with fixed-rate mortgages. 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 rates, as displayed in Figure 5, when applicable.

whole increase in aggregate spending. Table 8 presents the mean consumption response of households who make each possible discrete portfolio update, as well as the share of households of each type, in parenthesis, in the economy where mortgages have fixed rates. Again, the rows indicate the tenure choice if the interest rate shock had not occurred, and the columns specify the optimal tenure choice in the period of the shock. When summing up the off-diagonal shares of households, we can conclude that only 0.8 percent of household make extensive-margin portfolio adjustments in this setting.[31]

Homeowners who choose to access their housing equity due to the interest rate shock still respond by increasing consumption substantially (see row 3, columns 1, 2, and 4). However, merely 0.2 percent of households find it optimal to make such an adjustment when mortgages have fixed rates. Many liquidity-constrained homeowners are only temporary constrained in their spending, and therefore benefit more from a mortgage interest rate that is temporarily lowered substantially, rather than a small decrease that lasts for long. In addition, since mortgages are paid off over time, it is more preferential to have low interest rates early on, rather than the shock being smoothed out over time, as with FRMs. As a result, the consumption response of liquidity-constrained homeowners is smaller under FRMs than ARMs. Few households find it worthwhile to pay the transaction costs to take up a new mortgage only to receive a slightly lower mortgage rate. Moreover, since the house-price increase is small, there is less of an increase in housing equity to extract by selling or refinancing, resulting in smaller benefits of these types of transactions under FRMs as compared to ARMs.

Under FRMs, there are virtually no homeowners who choose to access their housing equity in a different way due to the interest rate shock. Furthermore, only a small share of homeowners find it optimal to no longer access their housing equity due to the shock, as seen in the third column of Table 8. Similar to the setting with ARMs, some renters postpone their house purchase due to the higher house prices. These households contribute

[31]Figure 10 displays the dynamics of the share of households of each tenure type.

positively to the increase in aggregate demand. Moreover, a few renters decide to advance their house purchase to take advantage of the lower mortgage interest rate. In contrast to the setting with ARMs, these households increase consumption on average. Just as with ARMs there is a large heterogeneity within this group, as they have an additional adjustment margin by updating the size of the house they purchase (see Appendix D.2).

Households who refinance their mortgage due to the shock, instead of staying in the house and following the amortization plan, contribute with 21 percent to the overall increase in aggregate demand (see Table 11 in Appendix D.1). Renters who decide to no longer buy a house due to the shock contribute with 19 percent. However the two groups of households that contribute the most to aggregate spending, in the setting with FRMs, are renters and stayers who do not update their tenure status due to the interest rate shock. These groups represent 26 and 62 percent of all households, respectively. As previously discussed, there is a large heterogeneity in consumption responses within these groups, in particular among stayers, as seen in Appendix D.2. Households with different mortgage and savings balances experience vastly different income effects due to the shock.

	Buyers	Refinancers	Stayers	Renters
Buyers	-0.1 (5.2)	-10.4 (0.0)	-3.4 (0.1)	6.6 (0.3)
Refinancers	11.3 (0.0)	0.1 (5.0)	-11.8 (0.1)	7.6 (0.0)
Stayers	10.7 (0.0)	15.2 (0.2)	0.1 (62.4)	26.7 (0.0)
Renters	0.5 (0.1)	-13.3 (0.0)	-17.2 (0.0)	0.2 (26.4)

Table 8: Consumption responses and shares (%), under FRMs

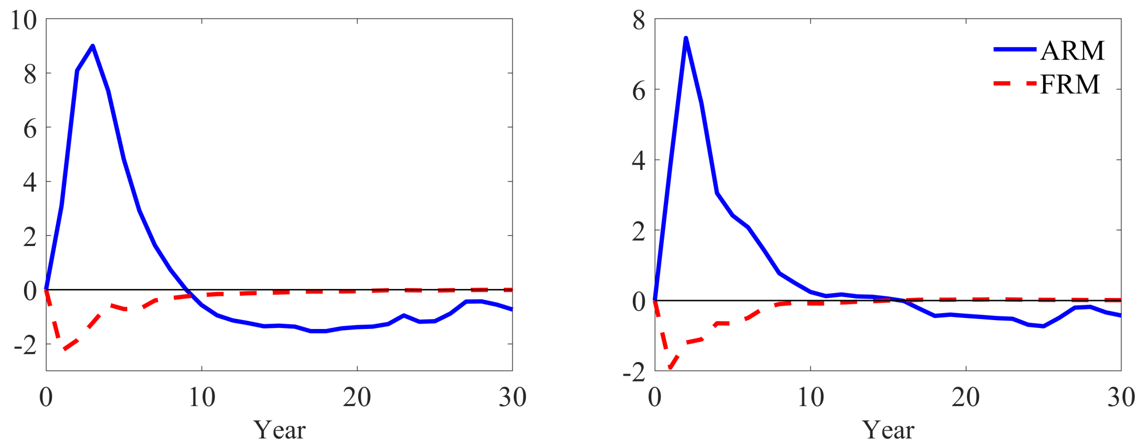
Note: Mean consumption responses of households who make each possible extensive-margin portfolio adjustment. The share of all households who make each portfolio update is in parenthesis, in percent. The deviations of consumption, in percent, are computed for the period when the interest rate shock occurs. The columns are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 5.

Overall, the structure of the mortgage market substantially impacts the effectiveness of monetary policy. Adjustable-rate mortgages contribute to much stronger responses in consumption following an expansionary interest rate shock, as compared to when fixed-rate mortgages are used. The amplification is largely driven by constrained homeowners who access their housing equity in order to smooth consumption. Furthermore, the higher house prices under ARMs enable larger cash-outs for refinancing households, and make more renters postpone the purchase of a house.

Mortgage-market implications for household debt

To finance the direct increase in consumption, there is a decline in aggregate savings in response to the expansionary monetary policy shock. Let us also consider the reallocations of savings between liquid bonds and illiquid housing equity, following the shock. The relevant savings rate for mortgagors is their mortgage interest rate, since it is higher than the return on risk-free bonds. The main reason why mortgagors also save in bonds is for liquidity purposes. The difference between the mortgage interest rate and the return on risk-free bonds impacts the choice of how much to save in housing equity versus bonds.

For fixed-rate mortgages, the deviation between the two rates is the largest immediately after the interest rate shock occurs, as mortgage interest rates are long-term and bond rates adjust periodically. In addition, existing mortgagors who do not refinance their mortgage are not at all affected by the change in the mortgage interest rate. By paying off their mortgage, they save at the rate previously specified in their mortgage contract. Hence, it is favorable to allocate more savings to housing equity and less to bonds. This is exactly what we see in Figure 7. The aggregate mortgage balance decreases in response to the shock, while savings in liquid bonds decline.



(a) Liquid savings (%) (b) Mortgage balances (%)

Figure 7: Impulse response functions for savings in liquid bonds and mortgage balances
Note: A comparison between the baseline model with adjustable-rate mortgages and the comparable model with fixed-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 5.

When mortgages have adjustable rates, on the other hand, there is a constant spread between the mortgage interest rate and the bond rate, also after the interest rate shock. Since a relatively large share of homeowners choose to access their housing equity by taking up a larger mortgage, the aggregate mortgage balance increases, and liquid savings actually also increase in response to the expansionary shock (see Figure 7).

4.3 Response in aggregate income

Many studies have shown that an endogenous response in labor income following a monetary policy shock is an important part of transmission. However, in order for there to be general-equilibrium effects on earnings, there must first be direct effects on demand. This paper highlights the role of choices in the housing and mortgage market for the direct response in aggregate demand, and inspects the mechanisms at work. Nevertheless, it is important to examine if and how these portfolio choices are affected if there are general-equilibrium effects on earnings.

This section presents how the main results are affected by including a response in aggregate income to the interest rate shock. Specifically, I use an empirically estimated path of output from the shock of -100bp to the nominal interest rate. The estimated path of aggregate output is the impulse response function from the identified Romer and Romer (2004) monetary policy shock in Auclert et al. (2020), which is consistent with the estimated path of the real interest rate that is used in the analysis. The resulting response in output is displayed in Figure 8. I let the earnings of all working-age households adjust proportionally to the change in aggregate income.

It is important to note that this analysis has two major caveats. First, including a response in aggregate income that affects all working-age households in the same way, does clearly not account for how general-equilibrium effects are likely to influence different households very differently. Second, 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. The results in this paper suggest that the direct demand effects from an interest rate shock are significantly larger when mortgages have adjustable rate. Hence, the aggregate response in income would likely be larger in such an economy. This analysis should therefore mostly be viewed as a robustness exercise to gain insights in qualitative implications of including a general-equilibrium response through the labor market.

The equilibrium paths of house prices and the IRFs for consumption to the real interest rate shock, under the two different mortgage specifications, and when aggregate income responds as in Figure 8, are presented in Figure 9. One can first note that the general patterns of the responses in house prices and aggregate consumption are similar to those when aggregate income is kept constant. In addition, the difference in the initial responses in the setting with ARMs vs FRMs is similar in absolute terms. In both settings, the initial house-price increase is approximately 0.3 percentage points higher, and aggregate consumption increases by an additional 0.4 percentage points, when including the response

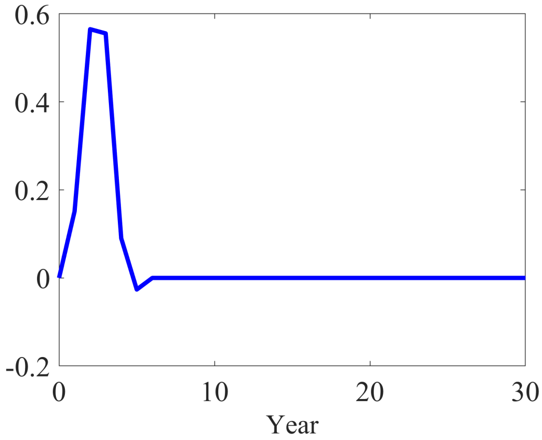
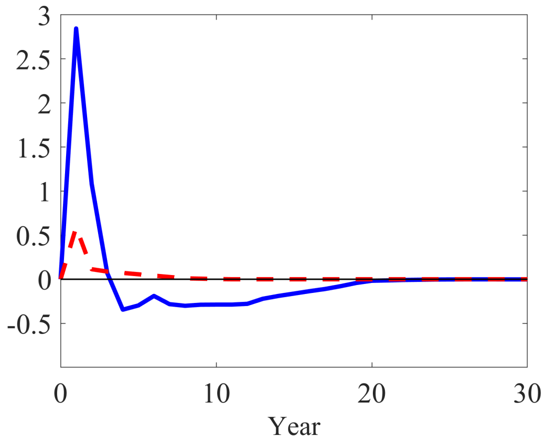
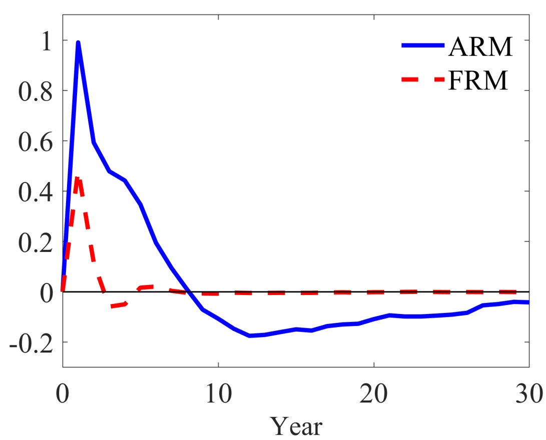


Figure 8: Response in aggregate income (%)
Note: The response in aggregate income follows an unexpected nominal interest rate shock of -100bp, where the path of aggregate income in the figure corresponds to the estimated impulse response function for output in Auclert et al. (2020).

in aggregate income. Thus, the response in earnings leads to stronger responses in aggregate demand in the short term, and the subsequent decline appears more gradual.



(a) House prices (%)



(b) Consumption (%)

Figure 9: Impulse response functions for house prices and aggregate consumption
Note: A comparison between the baseline model with adjustable-rate mortgages and the comparable model with fixed-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 5, and changes in aggregate income as in Figure 8.

A decomposition of the initial consumption responses across the four categories of households is provided in Table 9. It is clear that the increase in aggregate income causes a higher mean consumption response across all household types, and in both the setting with ARMs and FRMs. Moreover, the absolute increase in demand of each household type is remarkably similar in the setting where mortgages have adjustable rates as compared to fixed rates.

		Overall	Buyers	Refinancers	Stayers	Renters
ARM						
	income adjusts	0.99	2.11	6.69	-0.03	1.39
	fixed income	0.59	1.46	5.98	-0.34	0.90
FRM						
	income adjusts	0.48	0.80	1.37	0.27	0.94
	fixed income	0.09	0.03	0.37	0.02	0.31

Table 9: Consumption responses (%)

Note: A decomposition of mean consumption responses of buyers, refinancers, stayers, and renters, and for different mortgage contract specifications: adjustable-rate mortgages versus fixed-rate mortgages. The deviations of consumption, in percent, are computed for the period when the real interest rate shock occurs. The separation into buyers, refinancers, stayers, and renters is based on the tenure choice in the period of the interest rate shock. The responses follow an unexpected shock to the real interest rate on bonds, with the corresponding changes to the mortgage interest rates as displayed in Figure 5. When income adjusts, the changes in aggregate income are as in Figure 8.

How does the response in aggregate income affect the extensive-margin portfolio adjustments of households, and does it affect what type of updates contribute the most to the aggregate consumption response? Let us start by considering the economy with ARMs, and compare Table 4 to the corresponding table when aggregate income adjusts (see Table 12, in Appendix D.3). The share of households who make each extensive-margin portfolio update does hardly change when including the response in aggregate income. However, the mean consumption response for almost all groups is larger when allowing for income to increase, with the exception of a few groups whose responses do not change much. Overall, the main findings are robust to including the response in aggregate income: extensive-margin portfolio adjustments are important for aggregate responses, in particular, homeowners who access their housing equity due to the shock can explain a vast majority of the initial increase in demand (see Table 13, in Appendix D.3).

In the setting with FRMs, the share of households who make each extensive-margin portfolio update is also largely unchanged, when including the response in aggregate income (see Table 14, in Appendix D.3). However, there is one exception; the share of renters who postpone buying a house due to the shock, increases from 0.3 percent to 0.9 percent. When aggregate earnings increase, the initial rise in house prices is larger, causing some renters to not buy a house. Again, almost all groups have a larger mean consumption response when income adjusts, with the exception of a couple of groups who respond similarly. Overall, households who choose to refinance their mortgage and those who postpone buying a house due to the shock contribute significantly to the increase in aggregate demand, just as in the analysis where income is held constant (see Table 15, in Appendix D.3). Moreover, the two groups of households that contribute the most to the aggregate-demand response, are renters and stayers who do not update their tenure status due to the interest rate shock.

The main findings from the previous sections remain, when including a response in aggregate income to the interest rate shock. That is, the immediate aggregate response in consumption is significantly larger when mortgages have adjustable rates as opposed to fixed rates. Moreover, the increase in demand is largely driven by households who make extensive-margin portfolio adjustments. In addition, similar to the baseline analysis, aggregate savings in liquid bonds increase in response to the expansionary shock under ARMs, but decrease when contracts have fixed rate. This is accompanied by an increase in the aggregate mortgage balance under ARMs, and a decrease under FRMs (see Figure 16 in Appendix D.3).

Why is it the case that the main mechanisms survive when including a response in aggregate income? All working households instantly receive a positive cash flow from their higher labor income. The short-run increase in earnings immediately make households less liquidity constrained. However, importantly, expected earnings increase even more, as seen in Figure 8. The main driver of the increase in aggregate consumption, following the expansionary interest rate shock, is liquidity-constrained homeowners, who expect higher earnings in the future, and therefore find it optimal to access their housing equity to increase consumption today. As most of the increase in earnings occurs in the periods after the shock, most of these households still find it optimal to make extensive-margin portfolio adjustments to smooth consumption. In fact, they find it optimal to increase consumption even more in the short term, since their future earnings are now higher. Moreover, house prices increase more when aggregate income adjusts, increasing the available housing equity of homeowners, and disencouraging some renters from buying a house. To summarize, the relatively small initial increase in income and the larger increases that follow, do not change the optimal discrete portfolio choices of most households.

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 direct response in aggregate consumption to a monetary policy shock.

Although less than 8 percent of households adjust their discrete housing and mortgage choices in response to a 100bp expansionary monetary policy shock, I find that these choices account for 90 percent of the direct response in aggregate demand. Most of the increase in consumption is driven by an improved consumption smoothing among constrained households, whose 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 aggregate spending response. As the reduction in the policy rate feeds into mortgage interest rates, there is an endogenous increase in house prices. Higher house prices increase the wealth of existing homeowners, allowing for an improved consumption smoothing in particular among those who choose to access their housing equity by either refinancing, moving to a new house, or moving to rental housing. Moreover, I show that the structure of the mortgage market impacts the effectiveness of monetary policy. Specifically, the increase in both house prices and consumption is significantly larger when mortgages have adjustable rates as opposed to fixed rates.

The findings in this paper contribute to the growing literature on the importance of changes in households' mortgage payments and refinancing activities for the transmission of monetary policy. In particular, I quantify the contribution of different types of portfolio adjustments in the housing and mortgage markets, for the direct effect on aggregate demand. My results suggest that a detailed understanding of the flexibility in both the housing and the mortgage market is an important input into the analysis of monetary policy. In future work, it would be of interest to incorporate the mechanisms in my model in a general-equilibrium framework to consider channels through which the direct effects could propagate further. Along other dimensions, it would be worthwhile investigating a possible house price path dependence of the transmission of monetary policy, and potential asymmetries in the response to interest rate shocks of different magnitudes and with opposite signs.

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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[32]

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

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

[32] 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 $\{r_t\}_{t=1}^{t=\infty}$ 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 $\{(p_{h,t}, p_{r,t})\}_{t=1}^{t=\infty}$; sequences 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 $Q_{tr,jt} : \mathcal{Z} \times \mathscr{B}(\mathcal{Z}) \rightarrow [0, 1]$ 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).[33]

[33] 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.[34]

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 initial 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.

[34] 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^r_p	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

D.1 Impulse response functions

Figure 10 shows how the shares of homeowners, refinancers, buyers, and stayers change in response to the interest rate shock, contrasting the setting with ARMs and the economy with FRMs. Figure 11 displays the path of the rental rate in response to the shock.

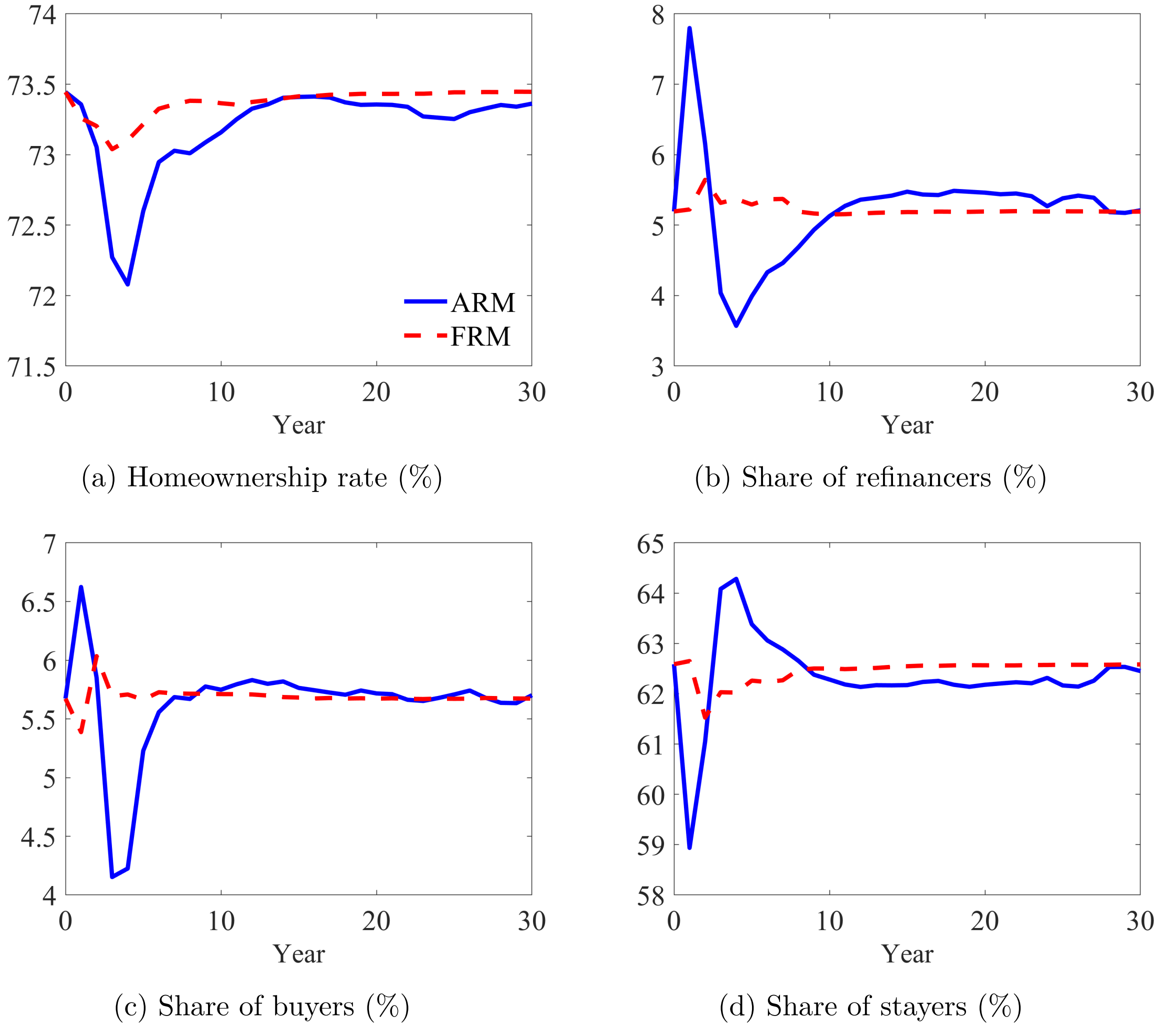


Figure 10: Impulse response functions for tenure-status shares

Note: A comparison between the baseline model with adjustable-rate mortgages and the comparable model with fixed-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 5.

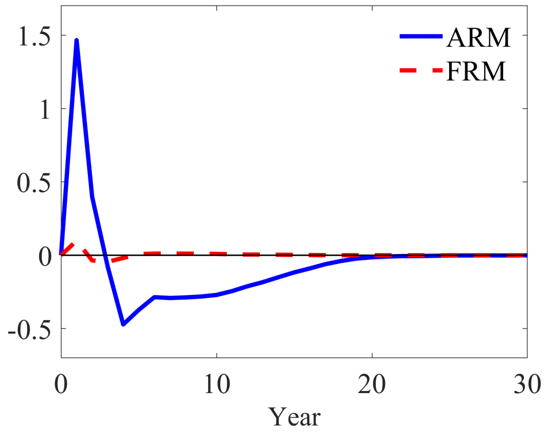


Figure 11: The response of the rental rate (%)

Note: A comparison between the baseline model with adjustable-rate mortgages and the comparable model with fixed-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 5.

	Buyers	Refinancers	Stayers	Renters
Buyers	-0.04	-0.03	-0.03	0.19
Refinancers	0.02	0.04	-0.15	0.00
Stayers	0.04	0.21	0.30	0.06
Renters	0.00	-0.01	-0.07	0.47

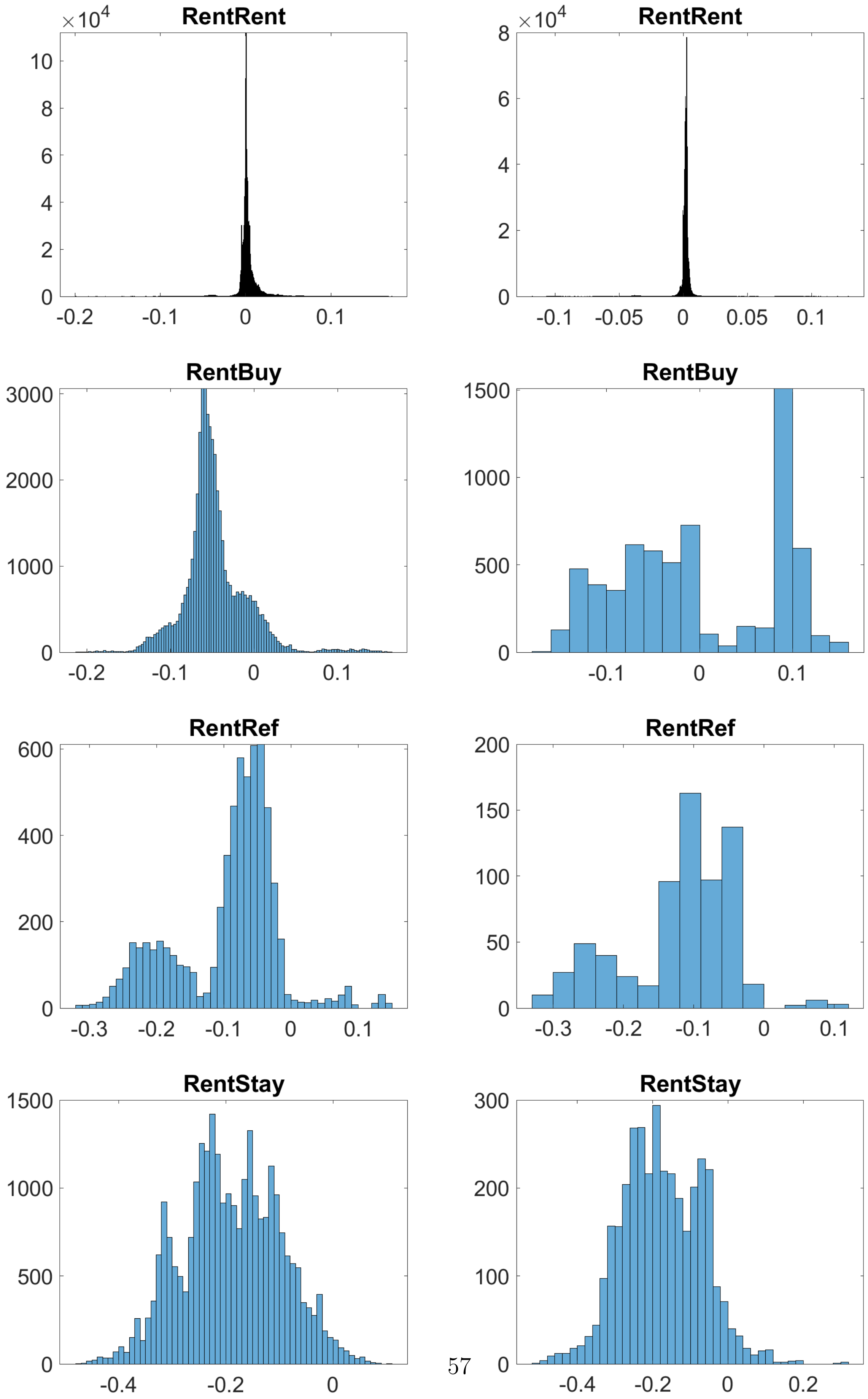
Table 11: Contributions to the direct response in aggregate demand, under FRMs

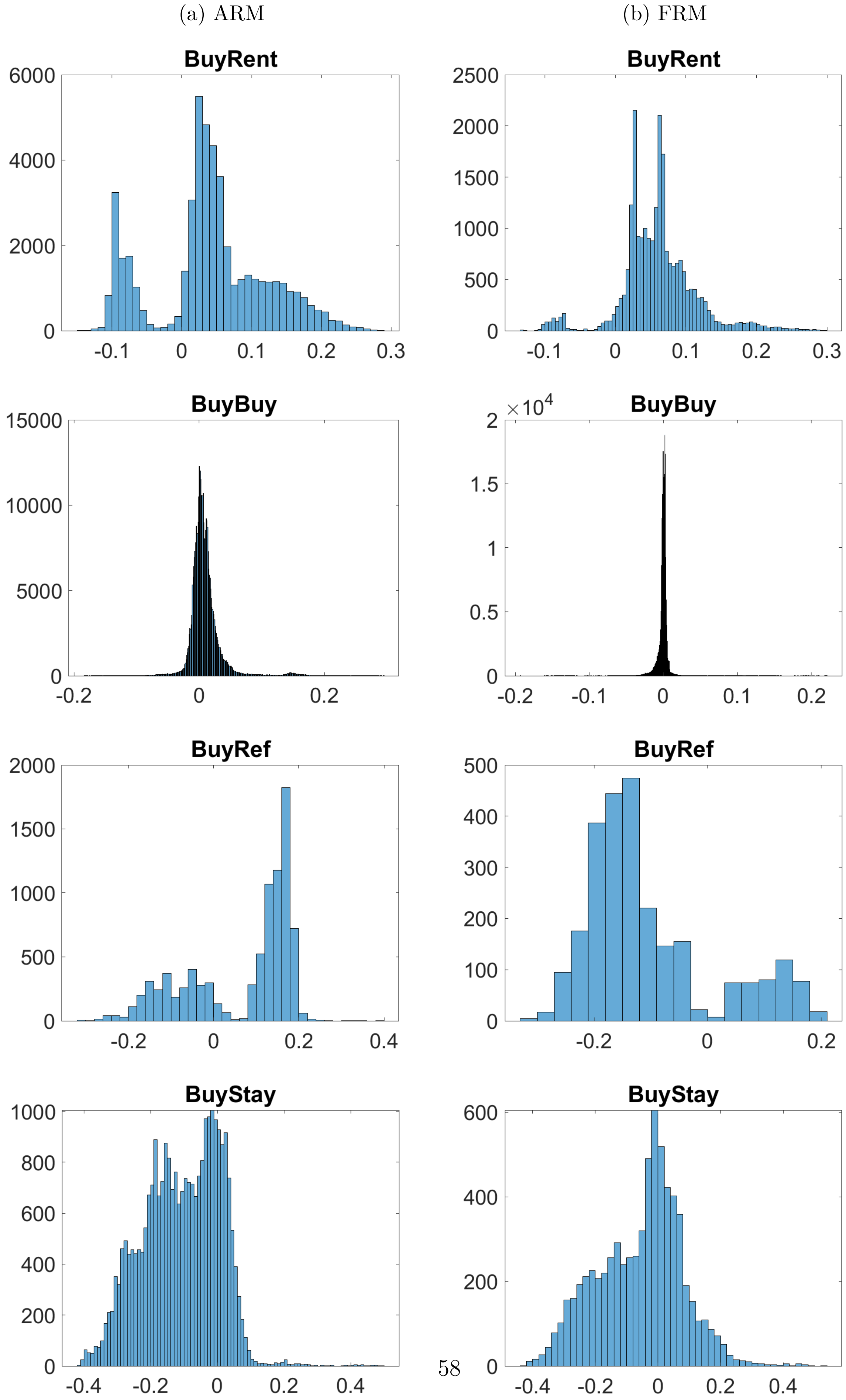
Note: Contributions to the aggregate consumption response, of households who make each possible extensive-margin portfolio adjustment, for the period when the interest rate shock occurs. The columns are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 5.

D.2 Distributions of responses

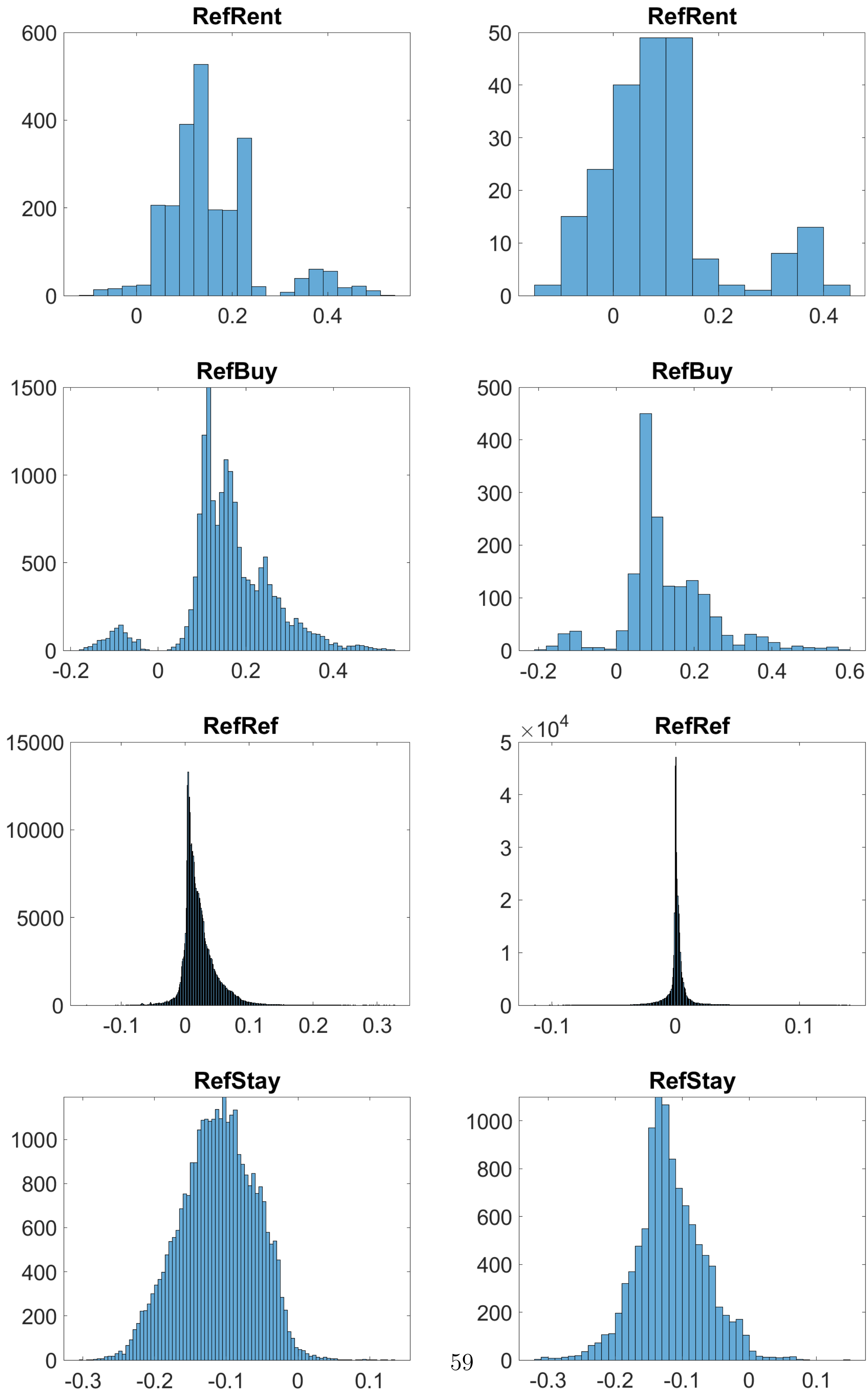
The following pages display the distributions of households' consumption responses in the period of the 100bp expansionary monetary policy shock, based on their housing and mortgage choices. The first word in the title refers to the choice had there not been an interest rate shock, and the second word refers to the actual choice when the interest rate shock occurs. Column one shows the distributions for the setting where ARMs are used, whereas the second column presents the distributions under FRMs.

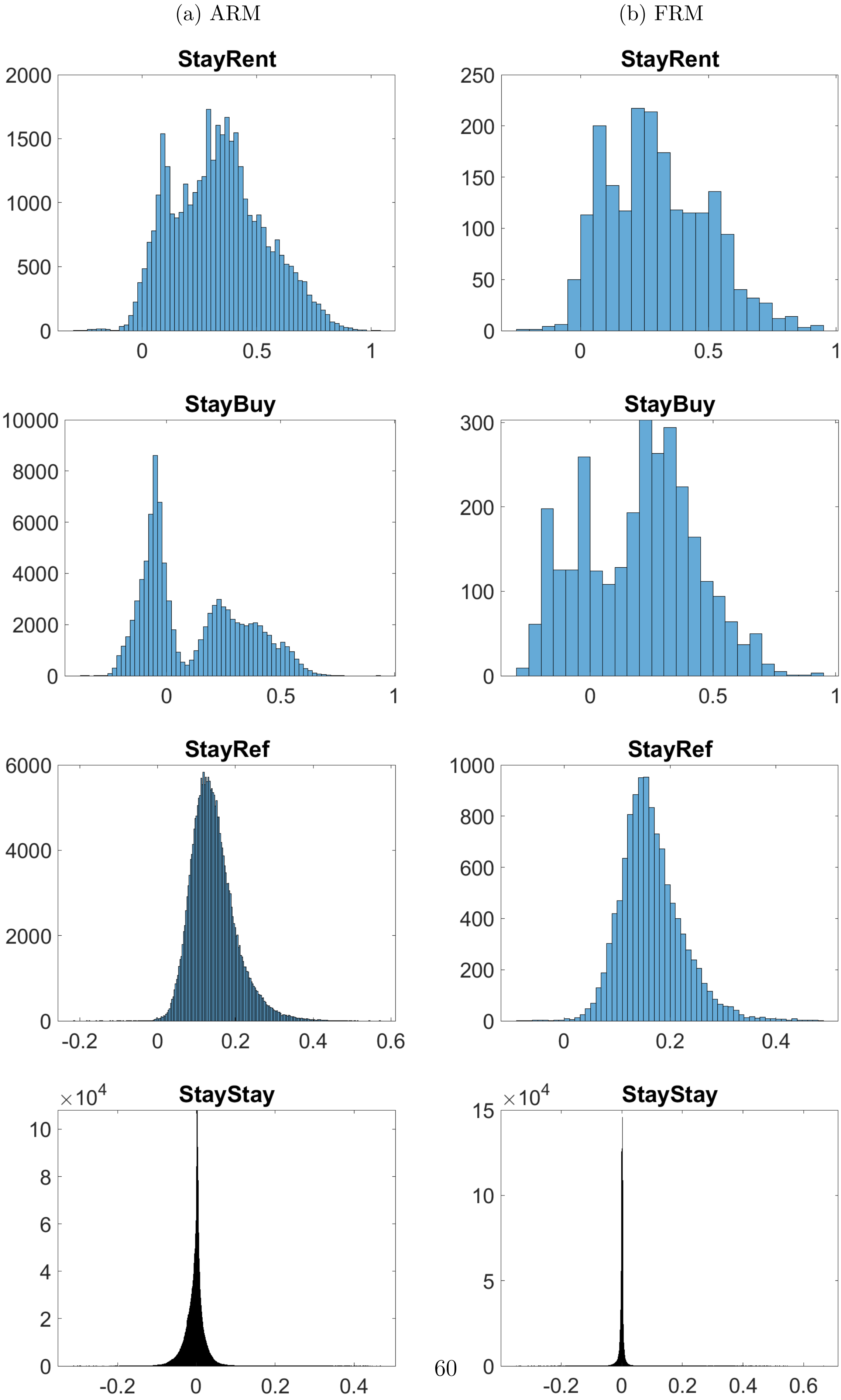
(a) ARM (b) FRM


RentRent
RentRent
RentBuy
RentBuy
RentRef
RentRef
RentStay
RentStay


(a) ARM
(b) FRM
BuyRent
BuyBuy
BuyRef
BuyStay
BuyRent
BuyBuy
BuyRef
BuyStay

(a) ARM (b) FRM


RefRent
RefRent
RefBuy
RefBuy
RefRef
RefRef
$\times 10^4$
RefStay
RefStay



(a) ARM
(b) FRM
StayRent
StayRent
StayBuy
StayBuy
StayRef
StayRef
StayStay
StayStay

D.3 Response in aggregate income

	Buyers	Refinancers	Stayers	Renters
Buyers	1.4 (4.5)	7.9 (0.1)	-12.2 (0.4)	6.1 (0.7)
Refinancers	15.3 (0.2)	2.5 (4.5)	-11.1 (0.4)	15.0 (0.0)
Stayers	4.8 (1.3)	13.7 (3.2)	0.1 (57.6)	27.8 (0.5)
Renters	-3.9 (0.5)	-9.7 (0.1)	-18.9 (0.4)	0.8 (25.6)

Table 12: Consumption responses and shares (%), under ARMs

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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 3, and changes in aggregate income as in Figure 8.

	Buyers	Refinancers	Stayers	Renters
Buyers	0.06	0.01	-0.05	0.04
Refinancers	0.03	0.12	-0.05	0.01
Stayers	0.06	0.44	0.08	0.15
Renters	-0.02	-0.01	-0.07	0.19

Table 13: Contributions to the response in aggregate demand, under ARMs

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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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 change to the mortgage interest rate, as displayed in Figure 3, and changes in aggregate income as in Figure 8.

	Buyers	Refinancers	Stayers	Renters
Buyers	0.3 (4.6)	-1.8 (0.0)	-3.7 (0.2)	7.0 (0.9)
Refinancers	13.5 (0.0)	0.7 (4.9)	-11.0 (0.2)	8.4 (0.0)
Stayers	24.0 (0.1)	15.2 (0.3)	0.3 (62.1)	28.8 (0.1)
Renters	4.8 (0.0)	-15.7 (0.0)	-17.7 (0.1)	0.6 (26.4)

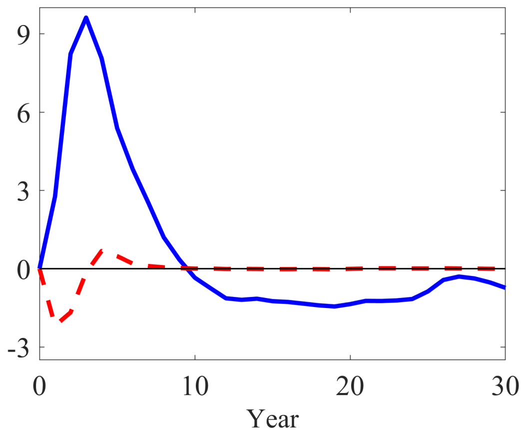
Table 14: Consumption responses and shares (%), under FRMs

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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 5, and changes in aggregate income as in Figure 8.

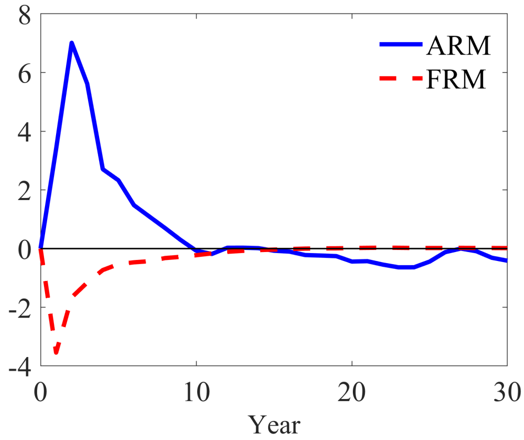
	Buyers	Refinancers	Stayers	Renters
Buyers	0.03	-0.00	-0.01	0.12
Refinancers	0.01	0.06	-0.05	0.00
Stayers	0.04	0.09	0.39	0.05
Renters	0.00	-0.00	-0.03	0.30

Table 15: Contributions to the response in aggregate demand, under FRMs

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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 5, and changes in aggregate income as in Figure 8.



(a) Liquid savings (%)



(b) Mortgage balances (%)

Figure 16: Impulse response functions for savings in liquid bonds and mortgage balances
Note: A comparison between the baseline model with adjustable-rate mortgages and the comparable model with fixed-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 5, and changes in aggregate income as in Figure 8.

D.4 Log utility

To assess the robustness of my findings with respect to households' preferences, I compute the impulse response functions to the interest rate shock in a setting where households have log preferences over consumption and housing services, i.e., $U_j(c, s) = e_j \log\left(c^{\alpha} s^{1-\alpha}\right)$. Since the income and substitution effects cancel out under these preferences, the role of discrete housing and mortgage choices is isolated further. The re-estimated parameters and a comparison of the target moments in the model versus the data are presented in Table 16.

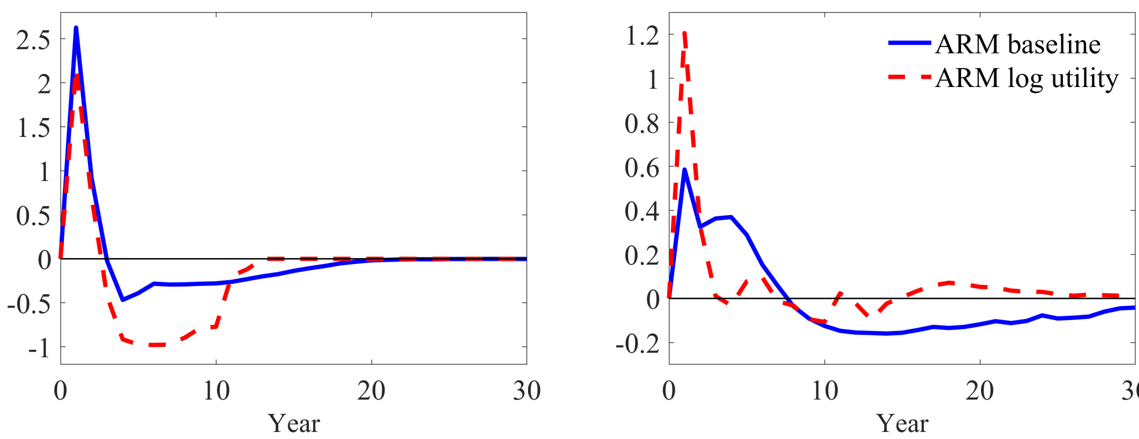
The path of the house price and the impulse response function for aggregate consumption are displayed in Figure 17, along with a comparison to the baseline setting where the coefficient of relative risk aversion is equal to 2 (intertemporal elasticity of substitution of 0.5). First, we can note that the response in house prices is similar, but slightly muted, under log preferences. Second, the direct response in aggregate consumption is almost twice as large under log preferences. However, aggregate spending returns back to steady state faster than in the baseline setting.

Table 17 presents the mean consumption response of households who make each possible extensive-margin portfolio adjustment in response to the shock, as well as the share of households of each type, in parenthesis, under log preferences. As in the main analysis, the rows indicate the tenure choice had there not been an interest rate shock, and the columns specify the optimal tenure choice in the period of the shock. When

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	0.39
$\underline{h}$	Min. owned house value	0.35	Homeownership rate	0.70	0.75
ς^r	Fixed refinancing cost	0.11	Refinance rate	0.08	0.08
$\bar{q}$	Luxury of bequests	8.8	Net worth p75/p25, age 68-76	5.37	4.32
υ	Utility shifter of bequests	38	Median net worth, age 75/50	1.44	1.93
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 main text	

Table 16: Estimated parameters in model with log preferences ($\sigma = 1$)

Note: Estimated parameters using simulated method of moments. The resulting 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 evaluated relative to the mean of expected annual earnings during working life that is normalized to one.



(a) House prices (%)

(b) Consumption (%)

Figure 17: 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, as displayed in Figure 3.

examining Table 17, we see that the shares of households who make different extensive-margin portfolio adjustments are largely similar to the baseline setting (see Table 4). Moreover, the mean consumption response of most types is similar, although there are some differences that explain the discrepancy in the aggregate. Not surprisingly, the biggest change occurs for households who stay in their house regardless of the interest rate shock. As these households are among the least liquidity constrained, their consumption responses largely reflect the trade-off between income and substitution effects. In the baseline setting, most of these households are hurt by the negative income effect from the lower return on savings, and they therefore reduce consumption on average. When income and substitution effects from the change in the interest rate cancel out, the change in the house price instead makes these households increase consumption marginally on average. This group makes up a majority of households, and their average positive response in consumption contributes to the higher aggregate-demand response under log preferences. In addition, households who rent regardless of the interest rate shock increase consumption more on average, under log preferences. When the negative income effect through the lower return on savings is offset by the effects of intertemporal substitution, these renters find it optimal to increase consumption more. Similar to the baseline setting, these households increase consumption since the relative price of consumption to rental housing decreases with the higher house prices. Households who had bought a house if it was not for the shock, and choose to rent when the shock hits, also increase consumption more under log preferences, through the same mechanism. Finally, those who use refinancing instead of moving to a new house, due to the shock (row 1, column 2), respond negatively instead of positively on average, under log utility. However, there are almost no households who make this portfolio adjustment.

In terms of the contributions of the different extensive-margin portfolio adjustments for aggregate demand, these are largely the same under log preferences as in the baseline economy. Table 18 shows the relative contribution of households who make each possible extensive-margin portfolio adjustment, for the overall response in aggregate consumption, which can be compared to Table 5.

Overall, the importance of discrete housing and mortgage choices for the direct demand response to an interest rate shock, prevail when households have log preferences over consumption and housing services. Even the specific types of extensive-margin portfolio adjustments that are important for the aggregate remain the same. We can also conclude that the direct effect on demand is dampened when income effects dominate intertemporal substitution, as is the case in most models.

	Buyers	Refinancers	Stayers	Renters
Buyers	1.2 (3.8)	-3.3 (0.0)	-8.3 (0.2)	14.0 (0.4)
Refinancers	2.5 (0.1)	1.8 (4.2)	-12.1 (0.2)	11.3 (0.0)
Stayers	4.4 (1.0)	16.7 (3.9)	0.1 (60.8)	34.1 (0.3)
Renters	-7.1 (0.7)	-14.5 (0.1)	-18.7 (0.1)	0.9 (24.2)

Table 17: Consumption responses and shares (%), under ARMs and log utility

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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 3.

	Buyers	Refinancers	Stayers	Renters
Buyers	0.04	-0.00	-0.02	0.05
Refinancers	0.00	0.07	-0.02	0.00
Stayers	0.04	0.59	0.05	0.08
Renters	-0.05	-0.01	-0.02	0.19

Table 18: Contributions to the direct response in aggregate demand, under ARMs and log utility

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 are based on the choice to be a buyer, refinancer, stayer, or renter in the period of the interest rate shock; whereas the rows indicate the 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, as displayed in Figure 3.

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