Refinancing and The Transmission of Monetary Policy to Consumption*

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Abstract

This paper examines the role of the refinancing channel and the mortgage market structure for the transmission of monetary policy to consumption. First, I document heterogeneous consumption responses to monetary policy shocks. I find a large consumption response for homeowners who refinance or enter new loans, which is concentrated among younger people. Second, I develop a life-cycle model with fixed rate mortgages that explains these facts. Moving from a fixed to a variable rate mortgage structure reduces the heterogeneous effects of monetary policy on consumption by age. At the same time, the aggregate effects of monetary policy on consumption are increased substantially.

Keywords: Consumption; monetary policy; refinancing; heterogeneous responses; age

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1 Introduction

This paper studies the transmission of monetary policy to household consumption, the largest component of GDP. In standard macroeconomics models, changes in interest rates primarily affect household consumption directly through intertemporal substitution. Recent literature has debated the role of the intertemporal substitution effect, compared with other channels of monetary policy. Part of the debate has centered on the role of the mortgage market and refinancing. In this paper, I examine the question: What role does refinancing play in the transmission of monetary policy to consumption in the aggregate and in the cross section?

Cross-sectional responses by age, homeownership, and mortgage decisions highlight potential inequality effects of monetary policy. To the extent that policy makers care about the redistributive effects of monetary policy, empirical estimates of the cross-sectional consumption responses provide useful information for policy debates. For example, Feiveson et al. (2020) and Daly (2020) discuss the potential distributional considerations of monetary policy. This suggests that while aggregate effects are likely to remain primary concerns of the Federal Reserve, the cross-sectional implications are of importance in the policy arena. Moreover, as the Federal Reserve increasingly engages in non-conventional monetary policy that affects long-term rates, this has potentially important redistributive effects across the life cycle because of the differential effects on homeowners with mortgages versus renters and those without mortgages.

The paper makes two contributions relative to the literature: (i) by quantifying the response of consumption to monetary policy shocks by age and by mortgage decisions, and (ii) by examining which channels can explain the heterogeneity and sensitivity of consumption to changes in monetary policy, including the role that refinancing plays. To do so, I document new cross-sectional patterns in consumption responses using household-level micro data. I then develop a model that accounts for these empirical patterns.

My empirical work combines monetary shocks, measured using the high-frequency event study approach with micro consumption data from the U.S. Consumer Expenditure Survey (CEX). I supplement the consumption analysis with Freddie Mac mortgage data to examine loan adjustment propensities. I provide suggestive evidence on three key cross-sectional patterns in the data. First, I provide evidence of a larger semi-elasticity of consumption to monetary policy shocks for younger people. The response is roughly double the response of the average person in the economy. Young households account for about 80 percent of the aggregate response.

Second, I show that the response of consumption is driven by homeowners. There is no statistically significant response for renters. The larger response of homeowners is predominately due to households who adjust their loans following interest rate shocks.

Third, younger households are more likely to adjust their loans after expansionary monetary policy shocks. Moreover, I find that the household's propensity to adjust their loan rises with loan size. In the data, young people have much larger loan sizes as individuals take out a mortgage to purchase their home, which is then paid down over time. Old people have lower balances as they have paid down more of their mortgages relative to young people.

Overall, the empirical findings together provide motivating evidence that young homeowners who adjust their loans are an important driver of the aggregate consumption response. The empirical cross-sectional estimates provide important moments for testing the validity of quantitative models that incorporate housing and mortgage decisions. The counterfactuals performed in such a quantitative model are only informative insofar as they capture key moments in the data, specifically related to these housing and mortgage decisions. I develop a household model of mortgages and housing that is consistent with my empirical findings, in order to study the channels of monetary policy transmission.The features of model are: an uninsurable labor income risk, a life-cycle savings motive, and a fixed rate mortgage structure. Individuals pay a transaction cost to adjust their long-term assets, which includes their housing and their fixed rate mortgage. The interest rate on the mortgage is fixed unless individuals pay a cost to adjust their loan.

The model generates key life-cycle moments that closely match the corresponding moments in the data. These moments include the hump-shaped consumption profile, rising total wealth and homeownership rates, and declining debt holdings over the life cycle. The model also generates aggregate and heterogeneous age-specific responses to a monetary policy shock that are statistically indistinguishable from the analog moments in the data.

The cross-sectional results by age provide insight into why the refinancing channel matters for the aggregate response. The fixed rate mortgage structure generates heterogeneity in the pass-through of monetary policy to the mortgage balances and payments because individuals vary in their refinancing and new borrowing decisions. Individuals with larger loan sizes are more likely to adjust their loans when interest rates decline because interest savings rise with loan size, while some components of the adjustment costs remain fixed. In the model, consistent with the data, younger people have larger loans relative to older people, as they borrow against higher expected future income. Therefore, young people also have a higher propensity to adjust their loans when rates decline. At the same time, younger people are also more likely to be short-term liquidity constrained. As a result, there is a positive correlation between those who decide to refinance and short-term liquidity constraints, which can generate large consumption responses in the aggregate.

Understanding the monetary transmission mechanism is crucial for the conduct of monetary policy. A growing literature seeks to quantify the relative role of the direct and indirect transmission channels of monetary policy (see for example Kaplan, Moll and Violante (2018)). Examining the counterfactual exercise of moving from fixed to variable rate mortgages is relevant for understanding the transmission mechanisms of monetary policy. The model allows us to isolate the refinancing decision from other general equilibrium channels, such as changes in labor income and changes in household wealth due to asset price movements. I quantify the role of the refinancing channel by shutting down the refinancing decision and reestimating the model under a variable rate mortgage structure, without any fixed costs.

How consumption changes when we move from having fixed to variable rate mortgages is theoretically ambiguous. On the one hand, there is a decline in the covariance between those who experience changes in their mortgage rates and those with short-term constraints, since interest rates changes pass through to all mortgages under a variable mortgage structure. The decline in the covariance dampens the cross-sectional differences in consumption responses across households, as well as the aggregate response. On the other hand, more households have lower mortgage payments after expansionary monetary policy shocks, bolstering aggregate consumption.

I use the model to examine this trade-off between the effect from a lower covariance versus a larger number of households experiencing interest rate changes when we move from fixed to variable rate structures. I find that quantitatively, the overall interest income effect from more households experiencing a change in rates dominates. As a result, aggregate consumption responds more under a variable rate structure (consistent with empirical research from Di Maggio et al. (2017)), while the cross-sectional heterogeneity is smaller.

I also use the model to show that the refinancing channel explains a sizable share of the cross-sectional patterns by age. I find that the difference between the consumption response of young and old people declines by about 45 percent under the model with a variable mortgage structure. So, according to my model, the refinancing channel accounts for 45 percent of the difference in the consumption response of younger and older people. I show that the effect of the refinancing channel on the consumption responses by age is at least as large as the effect from changes in aggregate income and changes in house prices following monetary policy shocks.

A key implication of the quantitative exercises in my model is that the structure of the mortgage market is important for monetary policy, in terms of both the aggregate and cross-sectional effects on consumption. More generally, these calculations also suggest that the effect of the mortgage market structure on the transmission of monetary policy to consumption depends on the strength of the covariance term in refinancing. This covariance may vary across different countries or regions because of differences in, for instance, the population age composition.

Related literature

This paper contributes toward three main strands of literature. First, this paper adds to the literature that studies the relationship between consumption, mortgage refinancing, and homeownership. Studies such as Cochrane and Piazessi (2002), Hamilton (2008), Nakamura and Steinsson (2018), and others show that monetary shocks can have significant effects on long-term yields and asset prices. In this paper, I show that these changes in long-term rates can also affect real variables, particularly consumption, for households who differ in their mortgage decisions.

Recent empirical studies have focused on the consumption response, taking as given a change in the individual's mortgage rate. For instance, Di Maggio et al. (2017) exploit the change in the outstanding auto loan balance following anticipated rate resets on adjustable rate mortgages. Cloyne, Ferreira and Surico (2020) examine the consumption responses of outright homeowners and mortgagees in the US and UK. In this paper, I show that there is heterogeneity not only in the consumption response but also in the decision to adjust a loan or not. This highlights a novel feature of the transmission mechanism: large responses can occur if those who choose to adjust their loans are also those who spend a larger portion of the savings. I show that this decision is related to the age of the household: younger individuals are simultaneously more likely to be short-term liquidity constrained and more likely to adjust their loans when rates decline. The correlation between spending coefficients and refinancing decisions is a specific form of the correlation explored in Auclert (2019). His analysis abstracts from refinancing. In this paper, I show that refinancing decisions over the lifecycle can matter for the aggregate consumption response.

While this paper focuses on consumption, other recent studies have examined labor market effects of monetary policy. For example, Bergman, Matsa and Weber (2020) find that employment effects in tighter labor markets are larger for individuals with lower labor force attachment, while Leahy and Thapar (2019) find that the effects of monetary policy on employment and entrepreneurship are stronger in states with a larger share of people aged between 40 and 65.

On the theoretical front, papers such as Garriga, Kydland and Sustek (2017), Greenwald (2018), and Hedlund et al. (2017) also study monetary transmission to the mortgage market. However, these papers assume a representative borrower and generally abstract from life-cycle features of borrowers. Beraja et al. (2019) use a model that is closer to the one in this paper. Their paper highlights the role of collateralized borrowing across regions, whereas I explore the implications of the mortgage market structure for the cross-sectional and aggregate consumption responses. My findings complement Guren, Krishnamurthy and McQuade (2021), who study the optimal design of mortgages to reduce household consumption volatility and default.

The model developed in this paper is most closely related to the transaction cost models, where fixed costs of adjustment for illiquid assets generates lumpy adjustments. Recent examples are Alvarez, Guiso and Lippi (2012), Alvarez and Lippi (2009), and others. My framework builds on these models with liquid and illiquid assets by incorporating a number of additional features, which are important for generating the heterogeneous age-specific consumption responses to interest rate shocks. As in Kaplan and Violante (2014), I include uninsurable labor income risk and a life-cycle savings motive. I extend the framework in Kaplan and Violante (2014) to allow for a fixed rate mortgage structure, to separate the decision for refinancing existing mortgages from the decision to adjust other illiquid assets, such as housing. This allows me to examine the interaction between the mortgage structure and liquidity constraints and its implications for the transmission of monetary policy to consumption.

Structure of the paper. The rest of the paper is structured as follows. Section 2 describes the data. Section 3 discusses the empirical methodology and the empirical results. Sections 4 and 5 set up the model, and Section 6 discusses the model results. Section 7 concludes. The Appendix contains some further results and robustness exercises.

2 Data Description

My sample combines monetary policy shocks with quarterly data on household consumption and mortgage decisions from the Consumer Expenditure Survey and Freddie Mac.

Monetary policy shocks I measure monetary shocks using the high-frequency movements in the Federal Funds futures rate in a small window of time around Federal Open Market Committee (FOMC) announcements. Following Gürkaynak, Sack and Swanson (2005), Gorodnichenko and Weber (2016), and Nakamura and Steinsson (2018), I construct the monetary policy shock as

$$\epsilon_t = \frac{D}{D-t}\left(ff^0_{t+\triangle^+} - ff^0_{t-\triangle^-}\right), \tag{1}$$

where t is the time of the monetary announcement, $ff^0_{t+\triangle^+}$ is the Federal Funds futures rate shortly after t, $ff^0_{t-\triangle^-}$ is the Federal Funds futures rate just before t, and D is the number of days in the month. The $D/(D-t)$ term adjusts for the fact that the Federal Funds futures settle on the average effective overnight Federal Funds rate. I consider a 60-minute time window around the announcement that starts $\triangle^- = 15$ minutes before the announcement. This narrow window makes it highly likely that the only relevant shock during that time period (if any) is the monetary policy shock. My shock series begins in 1989 and ends in 2007, before the financial crisis.[1]

Following Cochrane and Piazzesi (2002) and others, I aggregate the identified shocks to a quarterly frequency if there is more than one shock in the quarter, in order to merge with the consumption data. Table 1 shows that the aggregated shocks are similar to the raw data.[2]

[1] I stop the sample in December 2007 in order to study a period of conventional monetary policy, which is the focus of the economic model.

[2] As noted in Ottonello and Winberry (2020), the shocks have very similar properties if they are instead weighted by the number of days in the quarter after the shock occurs.

Table 1: Summary statistics of monetary policy shocks

	Raw shocks	Quarterly shocks
Median (ppts)	0.000	-0.005
Mean (ppts)	-0.019	-0.042
Standard deviation (ppts)	0.086	0.124
Min (ppts)	-0.463	-0.479
Max (ppts)	0.152	0.261
Number of shocks	164	72

Notes: Summary statistics of the monetary policy shocks in percentage points (ppts). "High-frequency" shocks are estimated using equation (1). "Aggregated" shocks are based on summing the shocks within the quarter.

The time aggregation relies on the assumption that shocks are orthogonal to economic variables in that quarter. This assumption is analogous to the literature that identifies monetary policy shocks using vector autoregressions (VAR), assuming that the monetary policy shock is orthogonal to movements in other real variables within that quarter (Christiano, Eichenbaum and Evans (1999)). However, the high-frequency approach is more general than the VAR literature because it does not need to be identified conditional on a specific set of variables in the VAR. The Federal Funds futures contracts incorporate any (broader) information to which the market has access. Another advantage of using high-frequency identification is that we can estimate the responses to monetary shocks without imposing linearity or invertibility of the specification, since the variables can be regressed directly on the identified shocks (Jordà (2005)).

Table 1 shows that the aggregated shocks have features similar to those of the raw high-frequency shocks. There are 72 quarterly monetary policy shocks over 1990-2007. The median is approximately 0. Two standard deviations of the quarterly shock is 25-29 basis points. The largest expansionary shock is 46 basis points, in the fourth quarter of 1991. Large expansionary shocks of 40-50 basis points were seen in the period 1991-1992 and in 2000. As discussed in Romer and Romer (2004), shocks could stem from a range of factors leading to random variations in policies. For instance, these factors could include differences in the meeting participants, in terms of their personalities and idiosyncratic views on the state of the economy, which are arguably orthogonal to the aggregate state of the economy. Among the monetary policy shocks, 15 percent of expansionary shocks occur during recession periods, compared with 8 percent of contractionary shocks. The expansionary shocks occur earlier in the sample, 1990-1994. There is no evidence of serial correlation in the shocks. The times series of the shocks are depicted in Appendix A, Figure 3.

The small size and transitory nature of the shocks make it challenging to obtain tight standard errors for estimated responses of real variables to the shocks, particularly for the aggregate variables.

There is, however, greater precision for estimates of the *differential* responses across household groups. The cross-sectional variation *across* groups is substantially larger than the time-series variation in the aggregate. The differential responses are useful for understanding the transmission mechanisms of monetary policy.

In Appendix E, I redo the empirical analysis for an alternative measure of monetary policy shock based on the "path" of interest rates. The shock is based on the second component of the unanticipated change over the 60-minute time window discussed above. Gürkaynak, Sack and Swanson (2005) (GSS) decompose the shock into two orthogonal components: (i) surprises in the current monthly rate and (ii) surprises in the path of the futures rate. The second component, which GSS refer to as the "path" factor, is interpreted as the forward guidance shock. The estimation uses principal components analysis to extract two factors from changes in the 3-, 6-, 9- and 12-month ahead futures on 3-month eurodollar deposits and Overnight Index Swap rates.[3]

Consumption data I use data from the Consumer Expenditure Survey (CEX) interview sample. The CEX interview survey is a rotating panel of households that are selected to be representative of the US population. Each household is interviewed about their expenditures for up to four consecutive quarters. Expenditures on detailed categories over the preceding three months are recorded at each interview. Expenditure categories encompass durable goods, non-durable goods and services. I deflate the expenditure using the inflation index from the Bureau of Labor Statistics and the national income and product accounts separately for each category. Demographic variables, including family status, earnings, income, and age of family members, are also recorded. My analysis sample contains 235,933 households over the period 1989-2007, which overlaps with the sample period of my monetary policy shocks. See Appendix B.1 for details on the construction of the categories and a discussion of robustness around measurement issues.

Housing and mortgage data The CEX survey also provides information on mortgages and homeownership. I use the CEX detailed expenditure files on owned living quarters and other owned real estate, as well as mortgages, over the sample period of 1990-2007.

Table 2 summarizes some well-known key mortgage and homeownership decisions in the data. For instance, homeownership rises with age, whereas mortgage balance and duration decline with age. In the data, young people have larger loan sizes, and longer durations and are more leveraged (higher loan-to-valuation ratios). Many older households have lower loan balances, as part or all of the loan has already been repaid.

[3] I thank Alejandro Justiniano for sharing with me the shocks estimated in Justiniano et al. (2012).

Table 2: Mortgage Statistics

	Young 25-34	Middle 35-64	Old 65+
Homeownership rate	46%	72%	79%
Fraction with mortgages	42%	55%	23%
Median loan size	110,328	98,061	65,497
Median loan duration (years)	27.25	22.25	17.25
Median credit utilization rate	36%	25%	13%
Average fraction of loans at fixed rates	78%	80%	83%

Notes: This table shows homeownership and mortgage statistics for each age group. The statistics are based on the CEX data for the mortgage statistics and Equifax data for the credit utilization rates.

Using the CEX data, I examine loan adjustments, which include households that entered into a new mortgage after refinancing or home purchase. I supplement the analysis using loan-level panel data of 30-year mortgages from the Freddie Mac Single Family Loan-Level data set. In total, there are approximately 17 million loans in the sample period 2000-2007.

The Freddie Mac data set differs from the CEX data in a number of ways. It has less information about the household (for example, it does not have the family size or age of the head(s) of households) and does not link to consumption. However, it has more information about the loan, including the FICO credit score, delinquency status, and interest rates. The loan balance can also be observed continuously since it is a loan-level panel, which is not possible in the CEX data. These extra dimensions allow me to examine the relationship between loan adjustment decisions and loan size and to control for loan-specific characteristics.

While there is insufficient information in the CEX to separate loan adjustments in refinances versus new housing purchases, it is possible to examine the responses of these two margins in the Freddie Mac loan-level data. In Appendix B.2, Table 22, I provide some evidence that suggests that the majority of loan adjustments to monetary policy shocks are refinances. The responses of refinances to monetary policy shocks are statistically significant at a 1 percent level.

In Appendix B.2, Table 21, I compare the unconditional share of loans that adjust each quarter and the propensity to adjust loans following monetary shocks implied by different data sets: the CEX data, Freddie Mac data, and CoreLogic loan data. Table 21 shows that these moments are consistent across the different data sets.

Mortgage rates Mortgage rate data are from the Freddie Mac Primary Mortgage Market Survey. These rates are deflated using expected inflation from the Federal Reserve Bank of Cleveland.

Consistent with the literature, I find that these long-term interest rates respond to the monetary shocks described earlier. Table 3 shows the OLS estimate of the contemporaneous change in the 30- and 15-year mortgage rates after a 1 percentage point monetary policy shock. I obtain a point estimate of about 56 basis points with a standard error of about 25 basis points, so the estimates are significant at a 5 percent level. Taking sampling uncertainty into account, the estimates are consistent with the literature: Gertler and Karadi (2015) find pass-through ranging from 17 to 48 basis points, and Gilchrist, López-Salido and Zakrajšek (2015) find pass-through of 0.68.

Table 3: Response of Mortgage Rates to Monetary Policy Shocks

Change in mortgage rate	30-year Real (I)	15-year Real (II)	30-year Nominal (I)	15-year Nominal (II)
Coefficient	0.599	0.562	0.662	0.594
Standard error	(0.281)	(0.255)	(0.341)	(0.384)
P-value	0.037	0.032	0.056	0.127

Notes: This table shows the change in the mortgage rates to a 1 percentage point monetary policy shock. The mortgage rates are obtained from the Freddie Mac Primary Mortgage Market Survey. The rates are deflated using inflation expectations from the Federal Reserve Bank of Cleveland.

3 Heterogeneous Responses to Monetary Policy

This section documents heterogeneity in the impact of monetary policy on consumption by age and mortgage decisions. First, I provide suggestive evidence that young households increase their consumption by relatively more than old households when interest rates decline. Second, I show that households that change their home-loan status have a relatively larger consumption response to monetary policy shocks than renters and those who do adjust their loans. Finally, I show that younger households are more likely to adjust their loans when rates decline. These findings together suggest that mortgage decisions by young households are important for understanding the transmission of monetary policy to consumption.

3.1 Heterogeneous consumption responses by age

I begin by estimating the differential response of consumption by age groups to interest rate shocks using the following baseline regression:

$$\triangle \ln C_{ht} = \alpha_1 \text{Age}_{h,t-k} + \sum_k \beta_k^a \cdot \epsilon_{t-k} \cdot \text{Age}_{h,t-k} + \alpha_2 X_{ht} + \lambda_{s(t)} + \lambda_h + \nu_{ht} \tag{2}$$

for household h in quarter t. The regressions are estimated using the CEX household weights so that the sample can be representative of the population.

In equation 2, $\triangle \ln C_{ht}$ denotes the change in real consumption for household h over quarter t; X_{ht} denotes household-level controls, which include changes over the quarter in number of children and total number of family members, and fixed effects for the calendar month that the household's survey is conducted; $\lambda_{s(t)}$ denotes fixed effects for quarterly seasonality and NBER recession dates; and λ_h denotes household fixed effects. The monetary policy shocks at date t are denoted by ϵ_t.[4] The residual is denoted by ν_{ht}. In the specifications, I include nine lags based on standard lag-length selection criteria.

The vector Age_{ht} is a set of age group dummies referring to the average age of the head(s) of household, and $\text{Age}_{ht} \in \{1(\text{young}), 1(\text{middle}), 1(\text{old})\}$ is full set of age indicator variables. In the baseline results, I define young individuals as those aged 25-34 years, as this is the primary age range for first-time home purchases. Middle-aged is defined as 35-64 years, and old individuals are those between ages 65 and 75. Defining age groups in this way captures any differential consumption response to interest rate shocks that may be related to homeownership decisions. The broad age ranges also ensure that there is a sufficient number of households to reliably estimate age-specific responses using the CEX data set.

The semi-elasticity of consumption to a contractionary monetary policy shock that occurred k periods ago is given by the sum of the β coefficients for age group a from period 1 to k. The standard errors are clustered by time to capture potential correlations across households' consumption responses to the aggregate monetary policy shocks and are computed using the delta method.

For robustness, I also consider estimating a version of equation (2) that includes time fixed effects, λ_t (dropping one of the age group interactions). Including time fixed effects means that the levels of the age-specific semi-elasticities are not estimated. However, estimates of the cross-sectional differences between the age groups in their responses are still obtained.

Table 4 reports the differences between the age groups in their average consumption response over the year following a monetary policy shock.[5] The coefficients are normalized to report the response to an expansionary monetary policy shock (i.e., a decline in rates).[6] Column (I) is based on equation (2). Columns (II) and (III) include time fixed effects and vary in the household controls.

[4]Similar to many existing studies in the literature, equation (2) does not condition on the sign of the shock as the sample of shocks lack sufficient power to statistically distinguish between the responses to expansionary shocks and the responses to contractionary shocks.

[5]I report the average response over the year, as these moments map naturally to the model-equivalent moments in Section 4. However, the results are qualitatively robust to computing year-end semi-elasticities instead. Specifically, this is the average over the coefficients over the year implied by the quarterly regressions. The dynamics of the quarterly responses are shown in Appendix G.

[6]That is, the response to a one standard deviation expansionary monetary policy shock multiplies the coefficients by -1 and the standard deviation of monetary policy shocks.

The p-values for the test of equality between the responses of the group are computed using the delta method. For example, a p-value of less than 0.1 rejects the null of equal consumption between age groups at a 10 percent significance level.

Table 4: Heterogeneous responses to expansionary monetary policy shocks, by age

	(I)	(II)	(III)
Young-Middle			
Coefficient	2.29	2.26	2.64
Standard error	(1.25)	(1.27)	(1.32)
P-value	0.07	0.08	0.05
Young-Old			
Coefficient	2.42	3.90	4.21
Standard error	(1.80)	(2.08)	(2.06)
P-value	0.18	0.07	0.05
Middle-Old			
Coefficient	0.12	1.64	1.56
Standard error	(1.52)	(1.72)	(1.74)
P-value	0.94	0.34	0.37
Recession fixed effects	Yes	Yes	
Income interactions		Yes	Yes
Education interactions		Yes	Yes
Time fixed effects			Yes

Notes: This table shows the differences between age groups in their average semi-elasticities of consumption over the year, in response to a one standard deviation expansionary monetary policy shock. Columns (I) and (II) are based on equation (2), and vary in their set of household controls. Column (III) includes time fixed effects (dropping one of the set of age group interactions). The standard errors and corresponding p-values for the coefficients are computed using the delta method. See text for more detail.

The estimates suggest that young people adjust their consumption more than middle-aged and older households. Specifically, the young increase consumption by about 2.3-2.6 percentage points more than middle-age households, which is statistically significant at a 5-10 percent level. In contrast, the difference in consumption responses of the middle-aged relative to older households is statistically insignificant at a 10 percent level. Reassuringly, including additional controls such as time fixed effects amplifies the statistical significance of the estimates.

Table 5 computes the contribution of each age group to the aggregate consumption response. Column (I) depicts the average annual responses, and column (II) gives the unconditional share of the level of non-durable expenditure for each age group, based on the CEX data. The product of columns (I) and (II) gives the percentage point contribution of the group to the aggregate response in column (III). The standard errors and p-values are computed based on the delta method. The contribution as a share of the overall response is given in column (IV).

Table 5 suggests that young households increase consumption by about 2.26 percent over the year following a monetary policy shock. For an average young household with annual consumption of $40,000, this is equivalent to a $904 increase in consumption over the year. The response of the young accounts for about 80 percent of the aggregate consumption response. The contribution is statistically significant at a 10 percent level. The estimates of responses in levels are less precise than the estimates of differential responses between groups. Nonetheless, the estimates are consistent with the idea that young households contribute more to the overall response than older age groups.

Table 5: Contribution by Age Group to Aggregate Consumption Response

	Annual Response	Share of Consumption	Contribution to total	
			in ppts	share of total
	(I)	(II)	(III)	(IV)
Young				
Coefficient	**2.26**	**0.32**	**0.72**	**0.86**
Standard error	(1.07)		(0.34)	(0.54)
P-value	0.04		0.04	0.11
Middle				
Coefficient	**0.18**	**0.57**	**0.10**	**0.12**
Standard error	(0.83)		(0.48)	(0.49)
P-value	0.83		0.83	0.81
Old				
Coefficient	**0.12**	**0.11**	**0.01**	**0.02**
Standard error	(1.45)		(0.16)	(0.19)
P-value	0.94		0.94	0.93

Notes: This table shows the average semi-elasticities of consumption over the year, by age group, to a one standard deviation expansionary monetary policy shock. Column (I) is based on equation (2). Column (II) shows each age group's share of overall consumption within the consumption category. Columns (III) and (IV) give the contribution of each age group to the total response in percentage points and percentage of total, respectively. Column (III) is computed based on the product of (I) and (II). (IV) is computed based on (III) divided by the semi-elasticity within each consumption category. The standard errors and p-values are computed using the delta method.

One potential concern is that the regressions may be picking up responses related to recessions, when expansionary shocks are more likely to occur. I consider these aggregate factors in two ways. First, the estimation of Table 4, column (I), includes recession fixed effects (similar to Tenreyro and Thwaites (2016)). Second, in column (II), I include time fixed effects to capture any confounding aggregate factors. The results are little changed, suggesting that the timing of the shocks is not driving the differential results.

The estimates are also robust to including controls for income and an indicator for college education attainment, both interacted with monetary policy shocks (Table 4, column (II)). Although we cannot completely rule out all income factors, the estimates provide suggestive evidence that other factors, in addition to income, may explain consumption differences by age. Sections 3.2 and 3.3 explore the role of mortgages and loan adjustments.

3.2 Heterogeneous consumption responses by mortgage decisions

The second dimension of heterogeneity that I study is the variation in consumption responses conditional on households' mortgage and homeownership decisions.

In the US, most mortgages have fixed rates. This means that changes in interest rates affect households' mortgage rates only if they decide to adjust their loan by entering a new mortgage or refinancing an existing loan. Households could also increase the amount borrowed without changing their mortgage payments when interest rates decline, if they are not against their mortgage borrowing constraints. The increase in balance is also known as "cash-out" refinancing and is one way that households can extract equity from their housing.

I study the heterogeneity by mortgage and homeownership decisions by dividing the CEX sample into three groups: (i) households that own a home and adjust their loan, (ii) households that own a home and do not adjust their loan, and (iii) renters. I define a loan adjustment as a new mortgage transaction that arises from either refinancing an existing loan or entering into a new loan contract when a household buys a new home. A household belongs to the first group if it had a mortgage loan adjustment over the past year. I show that the results are qualitatively robust to considering different horizons for defining a loan status change in Appendix D, Table 24.

To explore the heterogeneity by mortgage and homeownership decisions, I estimate

$$\triangle \ln C_{ht} = \alpha_1 M_{h,t-k} + \sum_k \beta_k \epsilon_{t-k} \cdot M_{h,t-k} + \alpha_2 X_{ht} + \lambda_{s(t)} + \lambda_h + \nu_{ht}, \tag{3}$$

where $\triangle \ln C_{ht}$ denotes the change in real consumption for household h over quarter t; X_{ht} denotes household-level controls, which include changes over the quarter in number of children and total number of family members, and fixed effects for the calendar month that the household's survey is conducted; $\lambda_{s(t)}$ denotes fixed effects for quarterly seasonality; and λ_h denotes household fixed effects. The monetary policy shocks are denoted by ϵ_{t-k}. The residual is denoted by ν_{ht}, and $M_{h,t-k}$ denotes the indicator variables for each of the three groups described above (own home and adjust loan, own home and not adjust loan, and renting).

For robustness, I also consider estimating a version of equation (2) that includes time fixed effects, λ_t (dropping one of the age group interactions). Including time fixed effects means that the levels of the age-specific semi-elasticities are not estimated. However, estimates of the cross-sectional differences between the age groups in their responses are still obtained.

Table 6 reports the average consumption response over the year following a monetary policy shock across the three mortgage and homeownership groups. Table 7 gives the difference between the groups. The coefficients are normalized to report the response to an expansionary monetary policy shock (i.e., a decline in rates). The p-values for the test of equality between the responses of the group are computed using the delta method. For example, a p-value of less than 0.1 would reject the null of equal consumption between age groups at a 10 percent significance level.

Homeowners that adjust their mortgages Tables 6 and 7 provide some suggestive evidence that the response of consumption is driven by those who change their home-loan status (i.e., they refinanced an existing loan or purchased a home). The consumption effect is statistically insignificant for households who do not have a change in their home-loan status and for renters.

Households who adjust their loans increase their consumption by 4 percent, which is statistically significant at a 10 percent level (Table 6, column (I)). These findings are robust to including income and education controls in the regression specifications (columns (II) and (III)). For the households that choose to adjust, their annual consumption amount is about $\$40,000$ per year. A 4 percent increase in spending implies, on average, a rise in spending of $\$1,608$. Across all households that hold a mortgage (i.e., averaging across those who adjust as well as those who do not adjust), consumption increases by 0.3 percent, which is equivalent to about \$153 for the average household.

To interpret the magnitudes of the consumption responses, one useful benchmark is the change in mortgage payments and balances. Consider a mortgage rate decline from 6 to 5.93 percent. For households who choose to adjust their mortgage, the median mortgage is about \$221,700. For these households, the decline in mortgage rates results in a reduction of \$120 in payments each year, which is equivalent to \$1,671 over the life of a 30-year mortgage (comparable to the increase in consumption). This means that the homeowner can extract the savings in payments up front today by increasing their balance by up to \$1,671 at the lower mortgage rate without raising their existing payments. If the household's change in mortgage rates is even larger than 0.07 percent, then the potential home equity extraction may be even greater.

There is evidence that homeowners extract home equity following monetary policy shocks. For instance, Bhutta and Keys (2016) (appendix, page 2) find evidence in Equifax data of home equity extraction of \$1,860 when rates decline.[7] Eichenbaum, Rebelo and Wong (2018) estimate that for households who adjust their loans, their balance increases by about 1.15 percent in response to a one standard deviation monetary policy shock, which is equivalent to \$2,300 for a household with a \$200,000 median loan size. Studies such as Di Maggio et al. (2017) and Mian and Sufi (2014) estimate that most of the home equity extraction is used toward consumption. These studies

[7] The estimated marginal increase in home equity extraction of \$1,860 in Bhutta and Keys (2016) (appendix, page 2) is computed across all mortgagees, including those who do not extract home equity. In their sample, about 11% of households extract home equity on average. Therefore, conditional on having positive home equity extraction, an additional \$16,909 is extracted when the adjustable mortgage rate declines by 1ppt (\$1,860 divided by 11%). Adjustable mortgage rates decline by 0.94 in response to a 1 ppt expansionary monetary policy shock. Therefore, a 1 standard deviation expansionary monetary policy shock (0.124 ppts) implies an increase in home equity extraction of \$1,971 (\$16,909 times 0.124 times 0.94). This is comparable with the back-of-the-envelope payment savings of \$1,671 inferred from the point estimates in the CEX data.

Table 6: Consumption Responses by Housing and Mortgage Decisions

	(I)	(II)
Adjust Loan		
Coefficient	4.02	4.25
Standard error	(2.18)	(2.12)
P-value	0.07	0.05
Do not adjust loan		
Coefficient	0.08	0.19
Standard error	(0.49)	(0.65)
P-value	0.88	0.77
Renters		
Coefficient	0.44	0.51
Standard error	(0.39)	(0.47)
P-value	0.26	0.29
Recession fixed effects	Yes	Yes
Income interactions		Yes
Education interactions		Yes

Notes: This table shows the average semi-elasticity of consumption responses to a one standard deviation expansionary monetary policy shock over the year. Columns (I) and (II) are based on equation (3), and vary in the set of household controls. The standard errors and p-values are computed using the delta method.

highlight the potential role of equity extraction for generating large consumption responses, which is consistent with the consumption estimates in this paper.

Naturally, other factors, besides changes in mortgage balances, may underlie the differences in consumption responses in Tables 6 and 7. For example, some households may be purchasing household items when they move houses (Benmelech, Guren and Melzer (2017)). In addition, house prices can appreciate after an expansionary shock. Extraction of home equity from any accumulated housing wealth can also contribute toward the rise in spending. A third factor that could be contributing toward the consumption responses is the rise in labor income after an expansionary monetary policy shock, which may be particularly relevant for constrained young households (Cloyne, Ferreira and Surico (2020)). In Section 4, I develop a quantitative model to isolate the role of refinancing for generating the heterogeneous responses to monetary policy shocks, relative to other potential channels such as aggregate income and house price effects.

Renters and homeowners who do not adjust their mortgages Table 7 also shows that renters have on average a slightly larger consumption response than homeowners who do not adjust their loans. However, the response is not statistically significant. On the one hand, homeowners may experience a positive wealth effect relative to renters, associated with any increases in house prices when interest rates decline. However, it is not obvious this will translate to large differences

Table 7: Differential Consumption Responses by Housing and Mortgage Decisions

	(I)	(III)	(III)
Adjust loan vs. Do not adjust loan			
Coefficient	3.95	4.05	4.03
Standard error	(2.45)	(2.43)	(2.43)
P-value	0.11	0.10	0.10
Adjust loan vs. Renters			
Coefficient	3.59	3.74	3.98
Standard error	(2.02)	(2.16)	(2.18)
P-value	0.08	0.09	0.07
Do not adjust loan vs. Renters			
Coefficient	-0.36	-0.32	0.05
Standard error	(0.71)	(0.46)	(0.46)
P-value	0.61	0.49	0.92
Recession fixed effects	Yes	Yes	
Income interactions		Yes	Yes
Education interactions		Yes	Yes
Time fixed effects			Yes

Notes: This table shows the difference in the average semi-elasticity of consumption responses to a one standard deviation expansionary monetary policy shock over the year. Columns (I) and (II) are based on equation (3), and vary in the set of household controls. Column (III) includes time fixed effects (dropping one of the set of age group interactions). The standard errors and p-values are computed using the delta method.

in consumption responses between the two groups if households do not withdraw equity from their home. The overall consumption responses depend on their marginal propensity to consume out of wealth. The finding that renters do not differ much from homeowners that do not have a loan status change suggests that equity extraction may be important for generating sizable consumption responses to changes in interest rates.

These findings are consistent with Cloyne, Ferreira and Surico (2020), who find that homeowners with mortgages respond more than outright owners and renters. In this paper, I further split the group of homeowners with mortgages into subgroups of who adjust and those who do not adjust their mortgages (the latter group includes current outright owners). The further split of homeowners with mortgages provides new suggestive evidence of the importance of loan adjustments for understanding the transmission of monetary policy. The dynamic loan adjustment decision is relevant in countries with fixed rate mortgage structures such as the US.

Further decompositions by mortgage decisions and age It is possible to further split the three housing and mortgage categories into young and middle-aged groups.[8] Once we condition on the housing and mortgage groups, there is less difference in consumption responses between

[8]Not enough observations are available to examine loan adjustment decisions for old households since the majority of old homeowners have paid off their mortgages and therefore fall in the classification of owning a home and not adjusting their loan.

the young and middle-aged group, in terms of both point estimates and significance (Table 8). This finding is broadly consistent with the idea that loan adjustment decisions matter for the heterogeneous consumption responses across age groups.

Table 8: Differential Consumption Responses by Age, Housing, and Mortgage Decisions

Young vs. Middle	All	Subset of households		
		Adjust loan	No adjust	Renters
Coefficient	2.31	0.01	1.40	-3.35
Standard error	(1.26)	(9.59)	(1.75)	(1.94)
P-value	0.07	1.00	0.43	0.09

Notes: This table shows the differential consumption responses to a 1 standard deviation expansionary monetary policy shock, based on equation (3). Column 1 corresponds to column (I) of Table 4. Columns 2-4 further condition on the housing and mortgage groups of the young and middle-aged households. The standard errors and corresponding p-values for the coefficients are computed using the delta method. See text for more detail.

These estimates are robust to including controls for income and an indicator for college education attainment, both interacted with monetary policy shocks. While these controls do not rule out all potential income factors, such as changes in income expectations by age, it provides some suggestive evidence that the consumption differences by age are not only driven by income differences alone between the housing and mortgage groups. These estimates are also robust to including time fixed effects. The specification with time fixed effects is reported in Appendix D, Table 25.

3.3 Heterogeneous loan adjustment decisions by age

Given that the loan adjustment decision is important for the consumption response, I now examine how the adjustment decision varies with age.

First, I document the average share of households in different demographic groups without conditioning on any shocks. Table 9 shows the unconditional average share of households in the three groups: own a home and adjusted their loan in the past year, own a home and did not adjust their loan in the past year, and those that continuously rented during the year.

The summary statistics in Table 9 show that, on average, young households are more likely to change loan status in the past year than middle-age and older households. About 31 percent (0.19/(0.19+0.4)) of young homeowners had a loan status change in the past year. These magnitudes are also broadly consistent with existing literature on refinancing. For instance, using Danish data, Andersen et al. (2015) find that about 22.5 percent of households refinanced in 2010. Inaction is lower for young households, as refinancing probabilities are 30-40 percentage points higher for young households relative to older households. While the paper has a different sample period and country, these magnitudes are broadly in line with the average fractions in this paper.

Keys, Pope and Pope (2016) also examine refinancing behavior using a sample of US households in 2010-2012. They estimate that between 20 to 40 percent of homeowners fail to refinance, despite potential interest savings from doing so. This implies that 60-80 percent of homeowners do respond to lower interest rates over 2010-2012, equivalent to an average of 20-27 percent of homeowners refinancing each year. The magnitudes are broadly in line with those described in this paper.

Table 9: Average Mortgage and Housing Decisions by Age

Average fraction of households	**Young**	**Middle**	**Old**
	25-34	35-64	65+
Own house and adjust loan	0.19	0.04	0.04
Own house and do not adjust loan	0.31	0.70	0.78
Renters	0.50	0.26	0.18

Notes: This table shows the average share of households that had a loan-status change in the past year, households that did not have a loan-status change in the past year, and households who remained renters continuously over the past year. The averages are baseline shares, unconditional on any shocks.

Second, I examine the marginal increase in loan adjustment over the year after a 1 ppt shock. The marginal refinancing responses are estimated based on the following regression:

$$P_{ht} = b_0 + \sum_{k=1}^{K} \beta_k^a \epsilon_{t-k} \cdot \text{Age}_{h,t-k} + \alpha_1 \text{Age}_{h,t-k} + \alpha_2 X_{ht} + \lambda_{s(t)} + \lambda_h + \nu_{ht}, \tag{4}$$

where P_{ht} is an indicator equal to one if household h adjusts their loan in quarter t; X_{ht} denotes household-level controls, which include changes in number of children and number of family members, age of the head of household, and fixed effects for the calendar month that the household's survey is conducted; and $\lambda_{s(t)}$ and λ_h denote quarterly seasonality and household fixed effects, respectively. The monetary policy shocks are denoted by ϵ_{t-k}. The residual is denoted by ν_{ht}.

Table 10, panel A, reports the marginal responses in loan adjustment over the year to a 1 percentage point monetary policy shock. Panel B reports the differential response between the age groups. Standard errors are computed based on the delta method. The estimates in the first column of Table 10 imply that a 25 basis point monetary policy shock leads to an additional 2.5 percentage point increase in young households entering a new loan (estimate of 0.1 times 0.25). This is roughly equivalent to an additional 4 percent of young homeowners (marginal effect of 0.025 divided by the average share of homeowners (1-0.41) from Table 9). In comparison, less than 1 percent of middle-age and old households change their loan status when rates decline. The marginal response of the

Table 10: Marginal Propensities to Change Loan Status, Conditional on an Expansionary Shock

Panel A: Extra propensity to adjust loan over the year after a shock	**Young**	**Middle**	**Old**
Coefficient	0.10	0.02	-0.03
Standard error	(0.01)	(0.02)	(0.02)
P-value	0.01	0.42	0.21
Panel B: Differential response	**Young - Middle**	**Young-Old**	**Middle-Old**
Coefficient	0.08	0.13	0.05
Standard error	(0.03)	(0.03)	(0.02)
P-value	0.12	0.04	0.08

Notes: Panel A shows the marginal propensities of households to have a loan-status change over the past year following an expansionary monetary policy shock. Panel B shows the differential responses. The standard errors and p-values are computed based on the delta method.

young is statistically different from that of the response of the old at a 5 percent level (column 1 of Table 10, panel B). The marginal response of the middle-aged is also statistically different from that of the response of the old at a 10 percent level (column 3 of Table 10, panel B). Overall, across all homeowners of all age groups, the marginal response is around 1.3 percent in response to a 25 basis points expansionary monetary shock. These magnitudes are broadly consistent with Bhutta and Keys (2016) (Table 5 column 5, page 1762) who use Equifax data to consider cash-out refinancing propensities in response to short-term interest rate movements.[9]

Given Tables 9-10, we can compute the overall share of *homeowners* that adjust their loans after a monetary policy shock. This is given by the unconditional share of homeowners who adjust, plus the additional propensity to adjust when there is an expansionary monetary policy shock. Table 11 shows that 33 percent of young homeowners adjust their loans after a one standard deviation monetary policy shock.[10] In comparison, around 5 percent of middle-aged homeowners and old homeowners adjust their loans.

For robustness, I also consider different time horizons for defining a change in loan status,

[9]Note that the 1.3 percent increase in the fraction of homeowners who adjust their mortgage after a 25 basis points monetary policy shock is equivalent to a marginal effect of 7.37 after a 1ppt decline in the 1-year adjustable mortgage rate (1.3 times 4 times 0.944, since about 0.944 percent of the 1 ppt expansionary monetary policy shock passes through to the 1-year adjustable mortgage rate). About 5/7ths of this 7.37 percent increase comes from refinancing (from Table 22). This implies that following a 1ppt fall in the 1-year ARM, an additional 5.26 percent of homeowners refinance. This compares with the estimate of 3.335 percent in Table 5, column 5, of Bhutta and Keys (2016). These estimates are slightly larger than Bhutta and Keys (2016) but remain within the standard errors.

[10]This is computed as $(0.19 + \sigma_\epsilon \times 0.1)/(1 - 0.41)$, The coefficient 0.19 is the baseline share of young homeowners that adjust, 0.1 is the young's marginal propensity to adjust after a 1 ppt monetary shock, $(1 - 0.41)$ is the share of homeowners, and σ_ϵ denotes the standard deviation of monetary policy shocks.

Table 11: Total Share of Homeowners Who Adjust after an Expansionary Monetary Policy Shock

Share of homeowners with loan adjustment after a 1sd shock	**Young**	**Middle**	**Old**
Coefficient	0.33	0.05	0.05
Standard error	(0.05)	(0.02)	(0.004)
P-value	0.02	0.11	0.01

Notes: The table gives the total share of homeowners that have a loan-status change in the past year (via either refinancing or entering a new loan when making a home purchase) following an expansionary monetary policy shock. This is the total share of homeowners, which is given by the baseline average plus the marginal propensity to adjust after the shock. See text for more detail. The standard errors and p-values are computed based on the delta method.

ranging from 2 to 4 quarters after a monetary shock has occurred. The results are not statistically different across the different time horizons (Appendix D, Table 24). The cross-sectional results are also robust to including time fixed effects (reported in Appendix D, Table 26).

Loan size and propensity to adjust One potential reason why young households are more likely to adjust their loans when rates decline is because they have larger loan sizes. In the presence of fixed transaction costs, agents with larger loan sizes are more likely to adjust their loans when rates decline since their interest savings are greater relative to the fixed costs. In the data, individuals take out a mortgage to purchase their home and pay down the mortgage over time. So, naturally, older people have lower loan balances since part or all of the loan has already been paid down (as seen in Table 2), which may reduce their incentive to refinance relative to younger households when interest rates fall.

To examine the role of loan size, I reestimate equation (4), controlling for the log of the loan size interacted with the monetary policy shocks. Table 12, panel B, shows the differences in responses by age after controlling for loan size. Panel A gives the baseline estimates, without controlling for loan size, for comparison to panel B. We can see that the differences in the propensities to adjust loans between the age groups become smaller in magnitude and are statistically insignificant, after controlling for the loan size effect. The change in these coefficients from panel A to B provides suggestive evidence that the life-cycle profile of mortgage size may explain part of why the young are more likely to adjust their loans after monetary shocks. The cross-sectional results panel B are robust to including time fixed effects (reported in Appendix D, Table 27).

In Appendix C, Table 23, I provide further evidence that loan adjustment propensities rise with loan size. The large number of observations in the Freddie Mac data allows me to split the loan size into finer decile bins. The relationship is roughly linear with loan size.

Table 12: Marginal Propensities to Change Loan Status

Panel A: Baseline estimates, not controlling for (loan size)*shock	Young - Middle	Young-Old	Middle-Old
Coefficient	0.08	0.13	0.05
Standard error	(0.03)	(0.03)	(0.02)
P-value	0.12	0.04	0.08

Panel B: Differential response, controlling for (loan size)*shock	Young - Middle	Young-Old	Middle-Old
Coefficient	0.003	0.03	0.03
Standard error	(0.08)	(0.08)	(0.01)
P-value	0.97	0.75	0.04

Notes: This table shows the differential marginal propensities of households to have a loan-status change in the past year, given an expansionary monetary policy shock. Panel A does not condition on loan size and its interaction with the monetary policy shocks. Panel B shows the differential responses in a specification that does condition on loan size and its interaction with the monetary policy shocks. The standard errors and p-values are computed based on the delta method.

Summary Taken together, these empirical results contribute to the literature that highlights an important role of mortgages for the monetary transmission to consumption (e.g., Di Maggio et al. (2017), Cloyne, Ferreira and Surico (2020), and Beraja et al. (2019)). While Di Maggio et al. (2017) examine the response to a given anticipated rate change, I highlight the importance of the loan adjustment decision for the transmission of monetary policy. I show that younger individuals (who have higher propensities to spend relative to older individuals) are more likely to adjust their loans when rates decline, which can generate large consumption responses in the aggregate. My results also suggest that the mortgage channel depends critically on the decision and ability of homeowners, particularly the young, to adjust their loans.

It is worth noting that, given the relatively small sample size and noise in the CEX data, there is statistical uncertainty in the estimated coefficients. The estimates of the consumption responses are generally statistically significant at a 5-10 percent level. I view this evidence as suggestive that the loan adjustment margin is a mechanism that is potentially relevant for the transmission of monetary policy and motivation for further exploration of the mechanism within the quantitative model. A potentially fruitful avenue for future work would be the development of consumption and mortgage data sets with long time series and larger samples to generate more precise estimates of the heterogeneous consumption responses.

4 Model

I now build a household model of housing and mortgage decisions in order to interpret the cross-sectional evidence in Section 3 and understand the transmission mechanism of monetary policy.

Households in the model face exogenous idiosyncratic and aggregate shocks. The shock processes generate dynamics that resemble business cycle fluctuations in the data. This allows me to examine the household's policy decisions in an environment with realistic dynamics in prices and aggregate variables while preserving the household heterogeneity in income and mortgages.

The model contains two key features. First, following recent work such as Kaplan and Violante (2014), Kaplan, Moll and Violante (2018), and Berger et al. (2018), I assume that households pay a transaction cost to adjust their long-term assets. Transaction costs are paid when entering a new loan or refinancing an existing mortgage. Second, I model a fixed rate mortgage structure. The mortgage rate is fixed unless the individual refinances the loan.

The key intuition of the model is as follows. The fixed costs and fixed rate mortgage structure generate heterogeneity in the pass-through of monetary policy to the interest rate payments of households because individuals can vary in their refinancing and new borrowing decisions. Individuals with larger loan sizes and with longer durations are more likely to refinance or enter a new loan when interest rates decline because the interest savings rise with loan size and duration while some components of the adjustment costs remain fixed. In the model, young people have larger loan sizes and longer durations and hence a higher propensity to refinance and enter new loans.

Moreover, the young are more likely to be against their short-term liquidity constraints, as they are more likely to borrow against higher expected future income growth. As a result, refinancing leads to interest savings and home equity extraction that relieves them from their short-term constraints. In the presence of transaction costs, there are individuals who are against their short-term constraints but have not yet adjusted their long-term mortgage assets by refinancing because the benefit of doing so may be less than the fixed cost of adjustment. This is similar to the hand-to-mouth individuals in Kaplan and Violante (2014). When interest rates fall sufficiently, this increases the incentive to refinance. For these individuals, it leads to large consumption responses because it can relieve them from their short-term constraints.

I use the model to quantify the relative importance of different transmission mechanisms of monetary policy. The model is useful for separating the refinancing channel from other potential mechanisms, such as income volatility and liquidity constraints, which may be correlated with the household's loan adjustment decisions. I also use the model to study how the aggregate and heterogeneous effects of monetary policy differ between fixed and variable rate mortgage systems.

4.1 Setup

Environment The economy is populated by a continuum of households indexed by j. Agents live for a maximum of T periods. Each period, an agent who is aged a survives to the next period with probability π_a. Agents work for the first T_y periods and retire thereafter.

Assets Agents can choose to hold three types of assets: (i) saving via one-period assets s_{jat} at an interest rate of r_t, with a short-term borrowing constraint $s_{jat} \geq -\underline{s}$, (ii) holding a long-term mortgage b_{jat} at a fixed rate of R_{jat}, and (iii) purchasing a unit of housing at price p_t. Housing can be either owned, or rented at price p_t^r. Owned housing stock depreciates at a rate of δ each period.

Following Campbell and Cocco (2003) and Kaplan, Moll and Violante (2018), I assume the mortgage is amortized over the life of the agent.[11] The duration of a new loan for an agent aged a is $d(a) = T - a$, with a current mortgage rate of R_{ja0}. The loan balance b evolves as follows:

$$b_{j,a+1,t+1} = b_{jat}(1 + R_{ja0}) - M_{ja0},$$

where the initial amount borrowed b_{ja0} and the mortgage payment M_{ja0} satisfy:

$$b_{ja0} = M_{ja0} \left[\sum_{k=1}^{d(a)} \frac{1}{(1 + R_{ja0})^k} \right]. \tag{5}$$

Following the literature, I assume that households pay transaction costs when they purchase a new home or when they refinance an existing mortgage, denoted by F^{new} and F^{refi}, respectively. When a household moves or refinances, it enters into a new contract, and the mortgage rate is reset to the current market rate. The mortgage rate can be expressed recursively as

$$R_{j,a+1,t+1} = r_{t+1}^{d(a+1)} \cdot 1(\text{refi})_{t+1} + R_{jat} \cdot [1 - 1(\text{refi})_{t+1}], \tag{6}$$

where the variable $1(\text{refi})_{t+1}$ equals one if the agent refinances in period $t+1$ and zero otherwise.[12] The household can choose a new balance, subject to a minimum equity requirement:

$$b_{jat} \leq (1 - \phi) p_t h_{jat},$$

where ϕ is the minimum down payment or equity that must be held in the house.

[11] This assumption is motivated by the empirical observation that the loan durations decline with age (as seen in Table 2). In addition, the assumption significantly reduces the computational burden because I do not need an extra state variable to track loan duration separately from age.

[12] If I include a mortgage payment-to-income constraint, as in Greenwald (2018), this would amplify the heterogeneous results even more. This is because income changes more for the young following interest rate shocks and they are the ones who are more likely to be against their payment-to-income constraint.

Similar to the approach taken by papers in the literature (e.g., Hurst et al. (2016), Kaplan, Moll and Violante (2018), Chen, Michaux and Roussanov (2020)), and others), I abstract from other durable goods besides housing (such as auto purchases and furniture). This decision reduces the computational burden of the model while still capturing the largest component of households' durable assets holdings (housing). Other non-housing durable goods account for a larger share of younger households' consumption basket, while services account for a larger share of older households' expenditure. If these additional durables are modeled, I would expect the heterogeneity in consumption response to monetary shocks by age to be even more pronounced in the model, given that durables are more responsive to interest rate changes than non-durables Cloyne, Ferreira and Surico (2020) and that these are mostly consumed by younger households.

Income Each period t, a working agent of age a receives an exogenous income y_{jat}:

$$\log(y_{jat}) = \chi_a + \eta_{jat} + \phi_a(y_t) \tag{7}$$

where χ_a is deterministic; η_{jat} is idiosyncratic, with $\eta_{jat} = \rho_\eta \eta_{j,a-1,t-1} + \psi_{jt}$ where ψ_{jt} is an i.i.d. shock drawn each period from $N(0, \sigma_\eta^2)$; and $\phi_a(y_t)$ captures age-specific fluctuations to income that arise from aggregate shocks to the aggregate income in the economy (the y_t process is described below). When the household is retired, income is given by a social security transfer, which is a function of income in the last working-age period, as modeled in Guvenen and Smith (2014).

The idiosyncratic income shocks are important for at least two reasons. First, the idiosyncratic shocks generate a dispersion in household income within age groups. This makes it possible to compare, across age groups, their different propensities to refinance existing loans, as well as the extensive margin of switching from renting into owning a home after interest rate shocks. Second, the idiosyncratic shocks are important for generating the life-cycle savings patterns in the data by creating a precautionary savings motive. As shown in a number of papers, including Krueger and Perri (2006), the idiosyncratic income component creates a precautionary savings motive, which helps to more closely match the rising profile of savings (decline in debt) over the lifecycle that is observed in the data. Both of these factors are important for generating the heterogeneous consumption responses by age following interest rate shocks (discussed further in Section 6).

Aggregate shocks to the economy In addition to idiosyncratic income shocks, households also face exogenous aggregate shocks. The vector S_t of aggregate variables includes the log of real aggregate income $\log y_t$, the log of real house prices $\log p_t$, and the one-period interest rate r_t. I assume the dynamics of S_t are given by

$$S_t = A_0 + A_1 S_{t-1} + u_t, \tag{8}$$

where u_t is the residual, which is normally-distributed with mean 0 and variance-covariance V. The specification of the aggregate process follows the approach in Hurst et al. (2016), Kaplan, Moll and Violante (2018), Chen, Michaux and Roussanov (2020)), and others.

The aggregate state variables affect the mortgage rates and rental rates. The current market mortgage rate with a duration of d periods is modeled as a function of the aggregate state variables:

$$r_t^d = f^d(S_t). \tag{9}$$

The function f^d is duration-specific. This captures, in a reduced-form way, changes in term premia and risk premia that arise from shocks to the aggregate state of the economy. The rental rate is modeled as a function of the aggregate state of the economy:

$$\log(p_t^r) = f^{pr}(S_t). \tag{10}$$

4.2 Recursive formulation

For notational clarity, I drop the agent and age indices in the household's problem below. I assume agents derive per-period utility from consumption and housing services:

$$u(c, h) = \frac{\left(c^\alpha \cdot h^{1-\alpha}\right)^{1-\sigma} - 1}{1-\sigma}.$$

Housing can be rented or owned.[13] Each period, households choose whether to (i) rent, (ii) purchase a new home, (iii) own a home and refinance their existing mortgage, or (iv) own a home and not refinance their existing mortgage. Households also choose their consumption, savings in liquid one-period bonds, and mortgage debt. The household problem is solved recursively (Appendix H describes the model computation).

Denote the household's state variables by $z = \{a, S, y, \text{assets}\}$, where a denotes age, S and y are the aggregate state and idiosyncratic labor income realizations, respectively, and assets is a vector of start-of-period holdings of short-term assets (s), housing owned (h^{own}), mortgage balance (b)

[13] This specification of utility between housing and non-durable consumption is common in the literature (e.g., Piazzesi, Schneider and Tuzel (2007) and Davis and Van Nieuwerburgh (2015)). Using CEX data, Aguiar and Hurst (2013) find that the share of expenditure that households allocate to housing out of total expenditure is roughly invariant to the level of household income and the level of household expenditure.

and the fixed rate on any existing mortgage (R). The value function can be written as

$$V(z) = \max\left\{V(z)^{\text{rent}}, V(z)^{\text{purchase}}, V(z)^{\text{own \& refi}}, V(z)^{\text{own \& no refi}}\right\}. \tag{11}$$

If the household decides to rent, it faces the following value function:

$$\begin{aligned} V(z)^{\text{rent}} &= \max_{c,h^{\text{rent}},s'} u\left(c, h^{\text{rent}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' + p^r h^{\text{rent}} &= y + (1-\delta)ph^{\text{own}} + (1+r)s - b(1+R) \\ h^{'\text{own}} &= b' = 0, \quad s' \geq -\underline{s} \end{aligned} \tag{12}$$

and equations (7)-(10) for income and aggregate state processes, mortgage yields and rental rate.

If the household decides to purchase a new home, it faces the following value function:

$$\begin{aligned} V(z)^{\text{purchase}} &= \max_{c,s',h'^{\text{own}},b'} u\left(c, h'^{\text{own}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' + ph'^{\text{own}} - b' &= y + (1-\delta)ph^{\text{own}} + (1+r)s - b(1+R) - F^{\text{new}} \\ b' &\leq (1-\phi)ph'^{\text{own}}, \quad s' \geq -\underline{s}, \\ R' &= r^d \end{aligned} \tag{13}$$

and equations (7)-(10) for income and aggregate state processes, mortgage yields, and rental rate. The variable F^{new} is the transaction cost of purchasing a new home, which is a function of the size of the home. The functional form and calibration of F^{new} is described in Section 4.3.

If the household decides to refinance an existing mortgage and not move, is solves:

$$\begin{aligned} V(z)^{\text{own \& refi}} &= \max_{c,s',b'} u\left(c, h'^{\text{own}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' - b' &= y + (1+r)s - b(1+R) - F^{\text{refi}} \\ b' &\leq (1-\phi)ph'^{\text{own}}, \quad s' \geq -\underline{s}, \\ R' &= r^d, \\ h'^{\text{own}} &= h^{\text{own}}(1-\delta) \end{aligned} \tag{14}$$

and equations (7)-(10) for income and aggregate state processes, mortgage yields, and rental rate. The variable F^{refi} is the transaction cost of refinancing. The functional form and calibration of F^{refi} is described in Section 4.3.

If the household decides not refinance an existing mortgage and not move, it solves:

$$
\begin{aligned}
V(z)^{\text{own \& no refi}} &= \max_{c,s'} u\left(c, h^{\text{own}}(1-\delta)\right) + E\left[V(z')\right] \qquad (15)\\
\text{s.t. } c + s' &= y + (1+r)s - M \\
b' &= b(1+R) - M, \quad s' \geq -\underline{s}, \\
R' &= R, \\
h'^{\text{own}} &= (1-\delta)^{\text{own}},
\end{aligned}
$$

and equations (7)-(10) for income and aggregate state processes, mortgage yields, and rental rate. The mortgage payment M follows equation (5).

The problem for a retired household is identical, except that social security benefits replace labor earnings. Upon death, the agent bequeaths total net wealth $W = (1-\delta)ph^{\text{own}} + (1+r)s$. The bequest parameter is denoted by B, which gives bequest utility $B\left(W_{jat} - 1\right)^{1-\sigma}/(1-\sigma)$.

In deciding to rent or own a home, households consider the user cost of housing relative to rental costs (see Dìaz and Luengo-Prado (2012) for a review of the literature on the user cost of owning a home). The user cost of owning a home depends on the savings from not paying rent, the expected real rate of housing appreciation net of depreciation, and the opportunity cost of down payment. Households are more likely to own a home if: (i) house prices are expected to appreciate in the future; (ii) rental costs rise relative to current house prices; and (iii) the interest rate declines because the cost of financing and the opportunity cost of the down payment are lower.

4.3 Model Calibration

Demographics and preferences The model period is annual. Households work for 40 years and are retired for up to 20 years. Agents face age-dependent survival probabilities, given by the US actuarial life-expectancy tables and assume a maximum age of $T = 85$.[14] I interpret the first period of life as 25 years of age and initialize the model by these agents' assets and income to match the distribution of ages 20 to 29 households in the 2004 Survey of Consumer Finances (SCF).

The discount rate β, the utility parameter α, and the bequest parameter B are calibrated to target key moments of the savings and asset-holding profiles. These moments include the average homeownership rate of 70 per cent,[15], ratio of liquid wealth to income for working-age individuals, and the share of wealth held by older households (aged 65+) of 20 percent from the SCF data in

[14] I use the male survival probabilities from the 2000 Social Security Administration actuarial life tables. The share of the population over age 85 was less than 1.5 percent in 2000.

[15] The long-run average homeownership rate is around 65-66 percent.

2007. These targets yield $\beta = 0.962$, $\alpha = 0.88$, and a bequest motive of B around 2 (comparable to Cocco, Gomes and Maenhout (2005)).

Transaction costs The household pays transaction costs if they make a home purchase or if they refinance. I consider different transaction costs for these two decisions.

For refinancing costs, I consider $F^{\text{refi}} = F_f^{\text{refi}} + F_v^{\text{refi}} \cdot b'$, where F_v^{refi} is the variable cost that scales with the size of the mortgage and F_f^{refi} denotes the fixed costs. In reality, refinancing costs typically contain a fixed component of around $2,000, comprising appraisal, inspection, and attorney review and closing fees (Federal Reserve Board online refinancing guide[16]). In addition, there may also be a component that scales with the size of the mortgage, where this variable component can range from 0 to 3 percent of the loan principal for the origination fee. However, for many lenders, it is not uncommon to waive the variable fees (i.e., set to be 0 per cent). Besides these fees to lenders, there may also be other costs such as time costs associated with appraisal of the home and filing the application, which may not necessarily scale with the size of the mortgage.

I calibrate the fixed and variable refinancing costs to match the average annual refinancing rate of 5 percent (Freddie Mac Single Family Loan-Level data set), and the correlation between the refinancing probability and the size of the mortgage balance. The use of fixed costs to match refinancing patterns is not new to this paper (e.g., this approach is also taken in Berger et al. (2018)). The calibrated fixed cost of refinancing is about $2,100, which is in line with the range of costs described in the Federal Reserve Board's online refinancing guide. The calibrated variable component turns out to be small, close to 0.005 percent (equivalent to $10 for a $200,000 loan). Given this, for simplicity I set the variable component to zero for my baseline results. The small size of the variable cost suggests that the fixed costs are the predominant source of the refinancing cost. Intuitively, one reason for the small size is that it proxies not just for lender-related costs but also for other pecuniary and non-pecuniary expenses that do not necessarily scale with the size of the mortgage. The small size of the variable coefficient is also consistent with the fact that it is not uncommon for lenders to waive these variable fees.[17]

For new purchases, I follow Dìaz and Luengo-Prado (2012), Berger et al. (2018), and Berger and Vavra (2019) in setting the transaction cost as a function of the value of the home. Specifically, I assume $F^{\text{new}} = 0.05 \cdot ph^{\text{own}}$. The typical fee charged by real estate brokers in the US economy is around 2-5 percent (Zillow home guide (2018)).[18]

[16] The Federal Reserve Board online refinancing guide is found at https://www.federalreserve.gov/pubs/refinancings/

[17] I have also experimented with alternative transaction costs. These alternative specifications include: (i) a common fixed adjustment cost for both moving and refinancing of around $5,000 (to match the average loan adjustment rate, in previous versions of this paper) and (ii) a small variable cost component of 0.005 percent for refinancing. Both approaches yield declining refinancing propensities and consumption semi-elasticities with age.

[18] The Zillow home guide can be viewed at https://www.zillow.com/sellers-guide/closing-costs-for-sellers/.

In Section 5, I show that given the model calibration, the model generates distributions of total wealth and liquid wealth holdings across households that resemble the empirical distributions.

Income I follow Floden and Lindé (2001) in exogenously setting the idiosyncratic income process terms $\rho_\eta = 0.91$ and $\sigma_\eta = 0.21$ to match the annual persistence and standard deviation of residual earnings in the Panel Study of Income Dynamics. The process is discretized with two states using the Tauchen (1986) method. I set the deterministic age-specific vector χ_a equal to the average log earnings for each age from Guvenen et al. (2015).[19] I set the parameter ϕ_a based on the correlation between real aggregate income per capita and age-specific earnings in the Current Population Survey (CPS). Table 13 shows that the earnings of young workers fluctuate more with aggregate income than the earnings of middle-aged workers, consistent with the literature (e.g., Jaimovich and Siu (2009), Ríos-Rull (1996), and others).

Table 13: Income Exposure to Aggregate Activity by Age

Age group	25-34	35-44	45-54	55-64
ϕ_a	4.582	1.603	3.574	0.307

Notes: This table shows the estimated coefficient obtained from a regression of the log earnings growth of each group on log growth in aggregate income per capita interacted with an indicator function for the 10-year age ranges, controlling for age-education-gender fixed effects, quarterly seasonality, and a linear time trend. The regression is based on quarterly CPS data over 1982-2007.

Aggregate variables The parameters on the aggregate variables (income, house prices, and short-term interest rate) in equation (8) are exogenously set based on estimated coefficients from a reduced-form quarterly VAR over the period 1984-2007. The data on income and interest rates are obtained from the Federal Reserve Board. Table 14 gives the coefficients for the aggregate processes. The aggregate processes are discretized with 18 states using the Tauchen (1986) method.

Table 14: Coefficients for the Aggregate Processes

Variables	$\log y_t$	$\log p_t$	r_t
$\log y_{t-1}$	0.9200	0.2857	-0.6344
$\log p_{t-1}$	0.002	0.9827	0.9629
r_{t-1}	-0.0001	-0.0013	0.9173
constant	-0.0097	-4.5682	0.0930

Notes: This table shows the estimated coefficients for equation (8). The variables $\log y_t$, $\log p_t$, and r_t denote the log income per capita, log house prices, and the three-month interest rate, respectively. See text for more detail.

[19] See Table 4 in Guvenen et al. (2015), estimated from a regression of earnings of individuals on a full set of age and cohort dummies using a long panel of administrative data.

I model the mortgage yield curve as a linear function of the current aggregate short-term interest rate and aggregate economic activity. This specification allows me to capture, in a reduced-form way, changes in term premia and risk premia arising from shocks to the aggregate economy without introducing additional states into the computation of the model. Formally, I specify

$$r_t^d = a_0^d + a_1^d r_t + a_2^d \log y_t, \tag{16}$$

where r_t^d denotes the mortgage rate of duration d, r_t denotes the short-term interest rate, and y_t denotes real per-capita aggregate income. I estimate equation (16) for the 30-, 15-, and 1-year real mortgage rates. I deflate the nominal mortgage rate using the break-even inflation rate implied from Treasury inflation-protected bonds (TIPS).[20] I then interpolate the mortgage rates with durations between 30 years, 15 years and 1 year. Coefficients are in Table 15.

I set the housing depreciation rate δ to 3 percent to match the average ratio of residential investment to the residential stock in US Bureau of Economic Analysis data. I set $\phi = 0.2$ so that households are required to have a minimum 20 percent down payment, in line with Landvoigt, Piazzesi and Schneider (2015) and others. The short-term asset borrowing constraint is set to 0.

The rental rate is assumed to depend on the aggregate state of the economy, as follows:

$$\log(p_t^r) = \alpha_0 + \alpha_1 r_t + \alpha_2 \log y_t + \alpha_3 \log p_t. \tag{17}$$

I estimate equation (17) using the national house price, rent indices are from the Federal Housing Finance Agency and the OECD Analytical House Price Database. See column (IV) of Table 15 for the regression coefficients.

Table 15: Real Mortgage Rates, House Prices, and Rental Rates

Variables	30-year rate (I)	15-year rate (II)	1-year rate (III)	$\log\left(p_t^R\right)$ (IV)
$\log(y_t)$	-3.475	-2.272	12.030	0.843
r_t	0.334	0.392	0.415	-0.002
$\log(p_t)$				-0.022
constant	5.526	4.885	0.581	3.187

Notes: This table shows the estimated processes for real mortgage rates and rental rates from equations (16)-(17). The 1988-2007 data are from the Freddie Mac, Fannie Mae Primary Mortgage Market Survey, the Federal Housing Finance Agency, and the OECD Analytical House Price Database.

An alternative approach to modeling the price dynamics would be to define a term structure that relates the mortgage yield curve to expectations about the paths of both the nominal interest rates

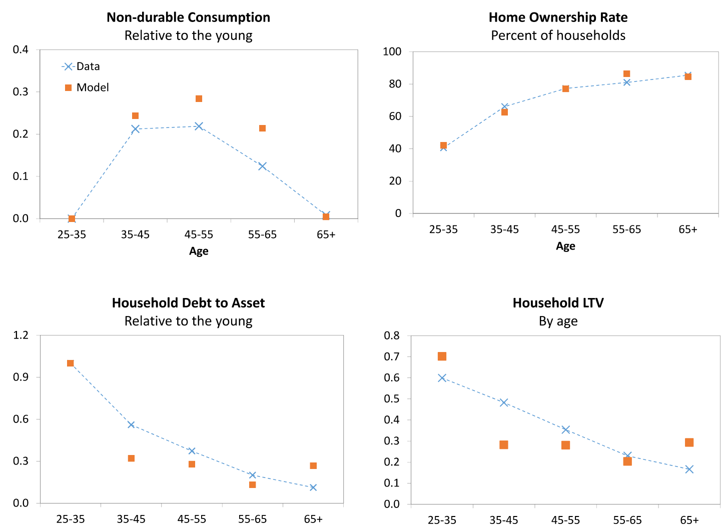
[20] These data are available from the Federal Reserve Bank. TIPS were first issued in 1997, but the market was initially illiquid (as discussed in Nakamura and Steinsson (2018)). Therefore, I use data from 2003 onward to avoid relying on data from the period when TIPS liquidity was limited.

and inflation, and a no-arbitrage condition within the housing market. I find that the dynamics over time and the impulse response functions of interest rates to monetary policy shocks match better under the current approach based on an empirical estimation of equation (16). In Appendix I, I provide evidence that the specification in equations (16) and (17) generate good approximations to the actual mortgage rate, house prices, and rental dynamics in the data.

5 Model Fit

Figure 1 shows the life-cycle profiles in the model compared to the data from the 2004 SCF and the CEX. The model captures the hump-shaped profile of consumption, the rise in the homeownership rate, and the decline in the debt-to-asset and loan-to-valuation ratios.

Figure 1: Life-cycle Consumption and Asset Profiles: Model vs Data



Notes: This figure depicts four key life-cycle moments in the model (orange) and CEX and SCF data (blue) by age.

In addition, the model generates the distribution of net wealth and distribution of liquid assets. Table 16 shows the distributions by age groups. The rows with the heading "Aggregate" give the share of total wealth held by the young, middle and old households. I further split households in terms of the bottom quartile (p0-25), the middle group (p25-75), and top quartile (p75-100) of the distribution of net wealth. For instance, column 1 of Table 16 shows that old households hold about 24 percent of aggregate net wealth. Old households in the 25th-75th percentiles of the wealth distribution hold about 13 percent of aggregate net wealth in total. Old households in the top quartile (p75-100) of the wealth distribution hold about 11 percent of aggregate net wealth in total.

Similarly, column 3 of Table 16 shows that old households hold about 36 percent of liquid assets in aggregate. Old households who are in the bottom quartile (p0-25) of the wealth distribution hold about 3 percent of liquid assets in total, while those in the 25th-75th percentiles of the wealth distribution hold about 2 percent of liquid assets in total. Old households who are in the top quartile (p75-100) of the wealth distribution hold about 31 percent of liquid assets in total.

Comparing columns 1 to 2 and columns 3 to 4 of Table 16, we can see that the distributions of both total net wealth and liquid asset holdings by age and wealth distribution are broadly consistent with the empirical SCF estimates. Net wealth in the SCF is defined as the difference between the assets and liabilities of the household. Net liquid assets in the SCF include transaction accounts and deposits less any credit card balances and other lines of credit.

Table 16: Wealth Distribution by Age and Percentiles of Wealth

		Share of aggregate net wealth		Share of aggregate liquid assets	
		Model	Data	Model	Data
Young	**Aggregate**	**0.04**	**0.05**	**0.03**	**0.03**
	p0-25	0.00	0.00	0.02	0.00
	p25-75	0.01	0.01	0.01	0.00
	p75-100	0.03	0.03	0.00	0.05
Middle	**Aggregate**	**0.72**	**0.76**	**0.62**	**0.68**
	p0-25	0.01	0.00	0.05	-0.01
	p25-75	0.27	0.43	0.01	0.41
	p75-100	0.43	0.33	0.56	0.34
Old	**Aggregate**	**0.24**	**0.20**	**0.36**	**0.29**
	p0-25	0.00	0.00	0.03	0.00
	p25-75	0.13	0.13	0.02	0.10
	p75-100	0.11	0.07	0.31	0.11

Notes: This table shows the distribution of net wealth and distribution of liquid assets by age, and in terms of the bottom quartile (p0-25), the middle group (p25-75), and the top quartile (p75-100) of the distribution of net wealth. Columns 1 and 3 are derived from the model. Columns 2 and 4 are from the SCF.

6 Monetary Policy Experiment

I use the model to interpret the heterogeneous empirical findings in Section 3 and to understand the transmission mechanism of monetary policy to consumption.

Recall the aggregate state variables were $S_t = [\log y_t, \log p_t, r_t]$, which followed the process $S_t = A_0 + A_1 \cdot S_{t-1} + u_t$. A monetary policy shock ϵ_t affects the residuals u_t in the following way: $u_t = \Gamma(\epsilon_t) + \psi_t$ where ψ_t denotes all other non-monetary policy shocks (i.e., house price and aggregate income shocks). Consistent with the data estimation described in Section 3, I regress the residuals u_t on the Federal Funds futures shocks (identified in Section 2).[21] The parameter coefficients are presented in Table 17.

Given the coefficients on the VAR, Figure 2 shows the pass-through to the short-term interest rate, aggregate income, and prices after a 1 ppt expansionary monetary policy shock. The short-term interest rate declines on impact, while house price growth and the price-to-rent ratio both rise over the first year. Since the parameters on the aggregate variables were set based on empirically estimated processes, the dynamics resemble the time series and impulse response functions to monetary policy shocks observed in the data. This allows me to then examine the consumption, refinancing, and homeownership responses to a realistic monetary policy shock.

Table 17: Monetary policy shock coefficients

	$u_t^{\log y_t}$	$u_t^{\log p_t}$	$u_t^{r_t}$
Γ	0.006	0.004	0.648
	(0.003)	(0.008)	(0.393)

Notes: This table shows the contemporaneous effect of monetary policy shocks on the aggregate variables. The variables $u_t^{\log y_t}$, $u_t^{\log p_t}$, and $u_t^{r_t}$ denote the residuals from the regression corresponding to the equation with the dependent variables of log income per capita, log house prices, and the 3-month interest rate, respectively. The Γ coefficients are estimated using high-frequency Federal Funds futures shocks. Standard errors are in parentheses.

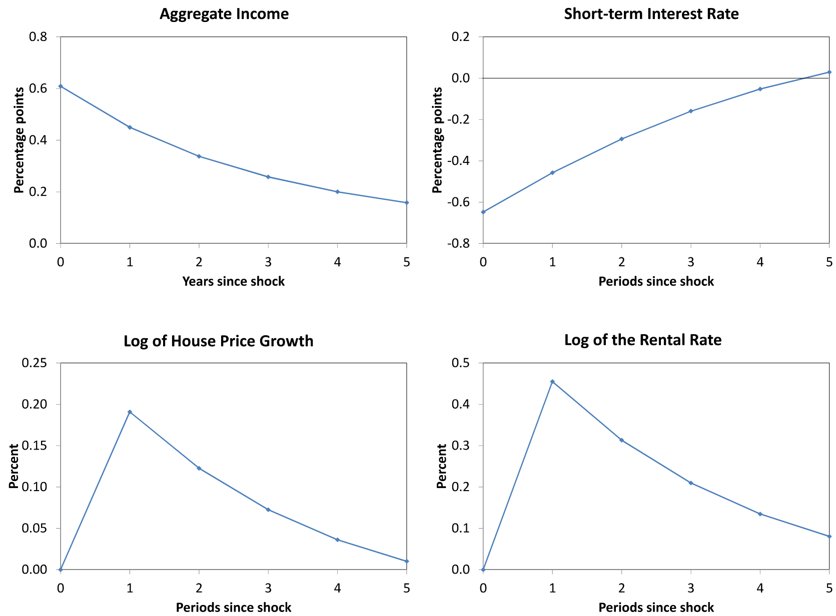
6.1 Heterogeneity Response to Monetary Policy

I now show that the heterogeneous consumption and loan adjustment responses in the model are consistent with the data.

Model-Implied Heterogeneous Responses to Monetary Policy To directly compare the model to the data, I simulate a panel of households in response to the monetary shock. I then estimate the change in log consumption over the year after the shock and the share of loans that adjusted over the year. This is comparable to regression specification (2), which controls for features outside of the model (such as family structure formation) that are less likely to be relevant at high frequencies.

[21] Empirically, the Federal Funds futures shocks give a measure of the true monetary policy shock plus some measurement noise, $\epsilon_t^{\text{true}} + \text{noise}_t$. Under the assumption that the noise component is uncorrelated with non-monetary policy shocks, then the regression will give consistent estimates of the coefficients in $\mathrm{E}u_t = \Gamma(\epsilon_t) + \psi_t$. As in Gertler and Karadi (2015), this structure does not impose any timing restrictions on the effects of monetary policy and non-monetary policy shocks.

Figure 2: Response to an Expansionary Monetary Policy Shock



Notes: This figure depicts the annual impulse response functions for aggregate income, the short-term interest rate, the log of house price growth, and the log of the rental rate (implied by equation (17)).

Table 18 column (I) shows the empirical estimates from Section 3.1.[22] The model-implied responses are given in column (II). Consistent with the empirical moments, the young respond more than the middle-aged and the old. Relative to the empirical point estimates, the model-implied responses for the middle-age group are larger and the responses are lower for the young. It is worth noting, however, that the model responses are within the standard errors of the empirical estimates and are statistically indistinguishable from the empirical point estimates.

Idiosyncratic factors outside of the model may be contributing to the consumption responses of the young and middle-aged in the data. For instance, differential time preferences (as discussed in Cohen et al. (2020)) could also contribute toward the consumption responses in the data. If young individuals are more impatient than middle-aged individuals, this could lead to larger consumption responses of the young in the data and smaller consumption responses of the middle-aged relative to the model, which assumes a single discount factor. If heterogeneous discount factors were included, the refinancing channel could potentially be even more important for generating cross-sectional difference because the cash-flow savings would lead to more immediate consumption responses for the young relative to the middle-aged.

[22]The empirical estimates in Section 3.1 are based on quarterly regressions. These estimates are used to compute the consumption responses over a one-year period following a monetary shock. These empirical moments are comparable to the model-based moments.

Table 18: Heterogeneous responses to monetary policy by age

	Consumption response		Share of home-owners that adjusted	
	Data	Model	Data	Model
	(I)	(II)	(III)	(IV)
Young				
Coefficient	**2.36**	**1.22**	**0.33**	**0.26**
Standard error	(1.08)		(0.05)	
P-value	0.03		0.02	
Middle				
Coefficient	**0.25**	**0.85**	**0.05**	**0.10**
Standard error	(0.81)		(0.02)	
P-value	0.76		0.11	
Old				
Coefficient	**0.17**	**0.23**	**0.05**	**0.05**
Standard error	(1.38)		(0.00)	
P-value	0.90		0.01	

Notes: Columns (I) and (II) show the differences between age groups in their average semi-elasticities of consumption with respect to a 1 sd monetary policy shock. Column (I) gives the empirical estimates from Table 5. Columns (III) and (IV) show the total share of homeowners that adjusted over the year (baseline share plus the marginal response to the monetary policy shock). Column (III) gives the empirical estimates from Table 11.

The model also implies that young homeowners than old homeowners are more likely to adjust their loans after a monetary shock. The total share that adjusts their loans is broadly consistent (column (IV)) with the suggestive evidence from the empirical patterns documented in section 3.3 (reproduced in column (III)). In the model, refinancing rather than new home purchases is the predominant driver of loan adjustments after monetary policy shocks. This is consistent with evidence using Freddie Mac data (Appendix B.2, Table 22).

One important reason why young people have a higher propensity to refinance is the presence of fixed costs for refinancing. In deciding to adjust an existing mortgage or not, households compare the extra utility that they gain from lower interest payments net of paying a fixed cost of adjustment, relative to their existing utility (formalized in equation (11) in the model.) The benefit of adjusting the loan, in the form of lower interest payments, rises with loan size and duration, while the costs remain fixed. The refinancing channel does not exist in standard models with variable mortgages. In these models, interest rate shocks pass through to all mortgages.

The model provides insight into the large consumption responses of younger people. In the presence of fixed transaction costs, there are individuals who do not always choose to refinance their mortgage to access their home equity despite being against their short-term constraints (as in Kaplan and Violante (2014)). However, when there is a large enough monetary policy shock, they have an additional incentive to pay the transaction cost to adjust their assets and liabilities because they can reset their mortgage to a lower rate. These individuals would be classified as "wealthy hand-to-mouth" households (as in Kaplan, Violante and Weidner (2014) and Kaplan and Violante (2014)). In the model, a larger portion of young homeowners are short-term liquidity constrained, but not against their long-term mortgage constraint. Among young homeowners, 87 percent were short-term constrained but were not against the long-term mortgage loan-to-valuation ratio (LTV) (Table 19). This compares to 17 percent of old homeowners.[23]

Table 19: Share of households by short-term constraints and LTVs

	Not LT constrained		LT constrained		Total
	ST constrained	Not ST constrained	ST constrained	Not ST constrained	
Young	87.3%	7.1%	5.7%	0.0%	100.0%
Middle	55.5%	44.0%	0.2%	0.4%	100.0%
Old	16.8%	82.6%	0.0%	0.6%	100.0%

Notes: This table reports the joint distribution of homeowners in terms of their short-term (ST) liquidity constraint status and low and high loan-to-valuation ratios, within each age group. An individual who is short-term constrained is against the one-period borrowing constraint for the short-term asset s. An individual who is long-term constrained is against the mortgage loan-to-valuation constraint for his/her mortgage b.

Since the young are more likely to refinance and more likely to be against their short-term constraints, there is a positive correlation of 0.3 between those who adjust their loans and those with low liquidity. The decision to refinance leads to additional available cash in terms of lower interest payments and higher mortgage balance (home equity extraction). The correlation between those who are short-term constrained and the decision to extract home equity is 0.3. The average increase in mortgage balance is around $1,100 after an expansionary monetary policy shock, above a baseline average extraction of $6,600 when refinancing (broadly consistent with Bhutta and Keys (2016)). Those who are against their short-term liquidity constraints spend all of their additional cash (i.e., a marginal propensity to consume of 1). As a result, the correlation between those who adjust their loans and those with liquidity constraints leads to larger consumption responses in the aggregate and in the cross-sectional heterogeneity by age. This result relates to Auclert (2019), who highlights the importance of the correlation between unhedged interest exposure and marginal propensities to consume for understanding aggregate consumption responses. The analysis here differs in that it highlights the loan adjustment decisions by age.

Prepayment penalties can potentially undo the refinancing incentives for fixed rate loans if they are large enough because they reduce the net savings from lower interest payments. In the US, however, it is relatively uncommon for lenders to have prepayment penalties. Less than 2 percent of

[23] I split households in terms of LTV greater than or less than 70 percent in order to consider ranges in which-households can withdraw non-negligible home-equity up to the maximum LTV limit of 80 per cent.

prime borrowers have prepayment penalties (Mayer, Piskorski and Tchistyi (2013)). Moreover, under the 2010 Dodd-Frank Wall Street Reform and Consumer Protection Act, prepayment penalties were prohibited for most residential mortgage loans. From 2002 onward, Freddie Mac also placed restrictions on the purchases on prime and subprime loans with prepayments. This differs from other counties, such as Australia, where prepayment penalties on fixed rate mortgages are common and sizable.[24]

Role of the Refinancing Channel for the Transmission of Monetary Policy

Understanding the monetary transmission mechanism is crucial for the conduct of monetary policy. The counterfactual exercise of moving from fixed to variable rate mortgages isolates out the refinancing decision from other general equilibrium channels, such as changes in labor income and changes in household wealth from asset price movements.

First, I examine how important the refinancing channel is for explaining the cross-sectional and aggregate consumption responses to monetary policy shocks, relative to other channels. To quantify the importance of the refinancing channel, I perform the following exercise. I hold fixed the calibrated parameters on the utility functions but change the mortgage market to a variable rate structure. This means that the mortgage rate changes for all households following an interest rate shock.[25] I solve for the households' new optimal decisions for consumption, housing, renting, mortgage balance, and savings. Table 20, panel A, column (V) shows the consumption responses under a variable rate mortgage structure. Column (I) reproduces the baseline results from Table 18, which assumes a fixed rate mortgage structure. Panel B gives the percentage difference between columns (V) and (I).

I find that the difference between the consumption responses of young and old people declines by about 45 percent under the model with a variable mortgage structure (panel B, column (V)). So, according to my model, the refinancing channel accounts for 45 percent of the difference in the consumption responses of young and old people. The decline in heterogeneity by age is consistent with the uneven pass-through of mortgage rates by age in a fixed rate structure, with younger households more likely to refinance than older households after a monetary policy shock. In contrast, in a variable mortgage rate structure, the rate changes automatically and passes through to all households.

At the same time, the aggregate consumption response is about 1.5 times larger under a variable rate structure than under a fixed rate structure (consistent with theoretical studies such as

[24]See Freddie Mac perspectives article (2017) for a discussion of prepayment penalties in the US.

[25]This is equivalent to a mortgage market with zero refinancing transaction costs when interest rates decline. All households adjust their mortgages when interest rates decline because they have positive savings and there is no cost to refinance. Hence, there is full pass-through of the expansionary monetary shock to mortgages.

Table 20: Decomposition of Semi-Elasticity of Consumption to Monetary Policy Shocks

	Fixed rate mortgage				Variable rate mortgage
	Overall	No Δ income	No Δ house prices	Role of mortgage balances	
	(I)	(II)	(III)	(IV)	(V)
Panel A: Consumption response					
Young	1.22	0.84	1.15	1.03	1.82
Middle	0.85	0.31	0.75	0.56	1.77
Old	0.23	0.24	0.41	0.23	1.28
Aggregate	**0.72**	**0.33**	**0.62**	**0.53**	**1.75**
Young-Old	0.99	0.60	0.75	0.79	0.54
Middle-Old	0.62	0.07	0.34	0.33	0.49
Young-Middle	0.37	0.53	0.40	0.47	0.05
Average difference	**0.66**	**0.40**	**0.50**	**0.53**	**0.36**
Panel B: % relative to (I)					
Aggregate level		-0.54	-0.14	-0.27	1.43
Average difference		-0.40	-0.25	-0.20	-0.46

Notes: This table reports the consumption responses for different specifications. Column (I) shows the overall baseline results. Column (II) assumes that aggregate income remains unchanged after the monetary policy shock. Column (III) assumes that house prices remain unchanged after the monetary policy shock. Column (IV) adjusts the loan balance distribution so that homeowners have the same average mortgage as the middle-aged. Column (V) assumes that mortgage rate changes pass through automatically to existing mortgages. Panel B gives the percentage difference of the results relative to the baseline results in column (I). See text for more detail.

Auclert (2019) and Garriga, Kydland and Sustek (2017) and empirical work in Di Maggio et al. (2017)). How consumption changes when we move from having fixed to variable rate mortgages is a priori ambiguous. On the one hand, the covariance between those who experience changes in their mortgage rates and those with short-term constraints declines when we move from a fixed rate to a variable rate mortgage structure, since interest rates change automatically and pass through to all mortgages. This decline in the covariance dampens the cross-sectional differences in consumption responses across households as well as the aggregate response. On the other hand, a larger number of households now have lower mortgage payments following expansionary monetary policy shocks. Quantitatively, the latter effect dominates, and we can see in panel B, column (V) that the aggregate consumption response is larger under a variable rate structure.

I show that the effect of the refinancing channel on the consumption responses by age is at least as large as the effect from changes in aggregate income and changes in house prices following monetary policy shocks. Changes in aggregate income after monetary shocks boost the response of consumption. In addition, the income effect can also vary in terms of its effect on consumption by age because young and old workers have different exposures to fluctuations in aggregate income (described in Section 4.3). To explore the role of changes in aggregate income, I recompute the consumption responses assuming that the monetary shock has no effect on aggregate income (Table 20, column (II)). In panel B, a comparison of column (II) and the baseline results in (I) shows that the aggregate consumption response declines by about 54 percent and age-specific heterogeneity declines by 40 percent. This implies that income effects are an important channel, accounting for almost half of the transmission of monetary consumption in the aggregate and in the cross-section (consistent with Kaplan, Moll and Violante (2018) and Cloyne, Ferreira and Surico (2020)).

Column (III) also considers the effects of changes in house prices after monetary policy shocks. The wealth of an individual increases when house prices appreciate. Households can choose to consume out of that wealth (see, for instance, Berger et al. (2018), Stroebel and Vavra (2019), and Mian and Sufi (2014)). For instance, households may extract equity from their home by increasing their mortgage balance (see, e.g., Mian and Sufi (2014) and Bhutta and Keys (2016)). Column (III) shows the consumption responses if house prices do not change in response to monetary policy shocks. This differs from column (I) where house prices rise slightly (Figure 2). When house prices do not change, aggregate consumption is about 15 percent lower and heterogeneity by age declines by 25 percent (panel B, column (III)). This implies that the effect of changes in aggregate house prices after monetary shocks on consumption declines with age (consistent with declining elasticities in Berger et al. (2018)).

Lastly, column (IV) examines the role of mortgage balances over the life cycle for the aggregate and cross-sectional responses. The mortgage balances of homeowners decline on average by age. Larger mortgage balances mean that the dollar value of interest payment savings and the incentive to refinance is greater in the presence of transaction costs. To examine the role of life-cycle mortgage balances for the transmission of monetary policy, I adjust the loan balance distribution so that all individuals have the same average loan balance as the average middle-age loan balance prior to the monetary policy shock. This exercise therefore removes the life-cycle profile of mortgage balances. I then compute the consumption responses to an expansionary monetary shock. Comparing column (IV) to column (I), we can see that the aggregate consumption response declines by 27 percent and the average cross-sectional difference between the age groups also declines by 20 percent. This suggests that life-cycle mortgage borrowing profiles explain about 20-27 percent of the aggregate and cross-sectional consumption responses. The decomposition also allows us to understand the role of heterogeneous mortgage balances for the refinancing channel. The latter is relevant for understanding potential changes in the transmission of monetary policy over time, given the substantial rise in US household mortgage debt over time.

Overall, these results imply that the refinancing response generates heterogeneity in consumption responses, similar to the effects from the income channel and at least as important as the wealth effects from changes in house prices. These results imply that the mortgage structure is an important channel for generating large aggregate consumption effects, as well as for understanding the cross-sectional dispersion in consumption responses to changes in monetary policy.

In the counterfactual above, I focus on isolating the role of the refinancing decision and the effect of having transaction costs in fixed rate mortgage markets for the transmission of monetary policy. Specifically, my counterfactual involves a scenario in which mortgage rates adjust automatically with no transaction costs. It is worth noting that there may be additional yield curve effects associated with moving from long-term to short-term mortgage structures. This yield curve effect arises because the pass-through to short-term mortgage rates is larger in magnitude than the pass-through to long-term mortgage rates. Including the yield curve effect is therefore likely to amplify my results on the effect of moving from a fixed rate to a variable rate market structure, as it can lead to larger cash-flow effects for constrained households that previously chose to refinance under a fixed rate mortgage structure. Guren, Krishnamurthy and McQuade (2021) is a related paper that examines the yield curve effect for stabilizing housing crises.

7 Conclusion

What is the role of the refinancing and mortgage market structure for the transmission of monetary policy to consumption in the aggregate and in the cross section? This paper first provides new suggestive evidence, using micro household-level data, that young people are more responsive than old individuals to interest rate shocks. The consumption elasticities of young people are larger than that of the average person and matter for the aggregate response. The consumption responses are driven by homeowners with mortgage transactions. I find that young people have a higher propensity to adjust their loans following interest rate declines, which can account for their higher consumption elasticities.

The second contribution of this paper is to develop a life-cycle model with fixed transaction costs and a fixed rate mortgage structure that is able to generate the empirical heterogeneity. The fixed rate mortgage structure is key to generating heterogeneity in the transmission of monetary policy to interest income because there is variation across households in their decision to refinance their mortgage. In the model, individuals with larger loan sizes have a higher propensity to adjust their loans after interest rate declines because the benefit of refinancing rises with loan size and duration, but some costs of adjustment are fixed. These individuals are disproportionately younger, reflecting life-cycle incentives to hold larger-sized loans when young in order to borrow against higher expected future income.

I use the model to quantify the importance of the mortgage channel for explaining the consumption responses of the young and old to interest rate shocks. I find that it explains a sizable fraction of the total age-specific heterogeneity and highlights the role of refinancing for monetary transmission. These results imply that the structure of the mortgage market is important for understanding monetary policy transmission.

The cross-sectional results by age provide insight into why the refinancing channel matters for the aggregate response. The fixed rate mortgage structure generates heterogeneity in the pass-through of monetary policy to the mortgage balances and payments because individuals vary in their refinancing and new borrowing decisions. Individuals with larger loan sizes are more likely to adjust their loans when interest rates decline because interest savings rise with loan size, while the cost of adjustment is fixed. In the model, consistent with the data, younger people have larger loans than older people, as they borrow against higher expected future income. Therefore, young people also have a higher propensity to adjust their loans when rates decline. At the same time, younger people are also more likely to be short-term liquidity constrained. As a result, there is a positive correlation between those who decide to refinance and short-term liquidity constraints, which can generate large consumption responses in the aggregate.

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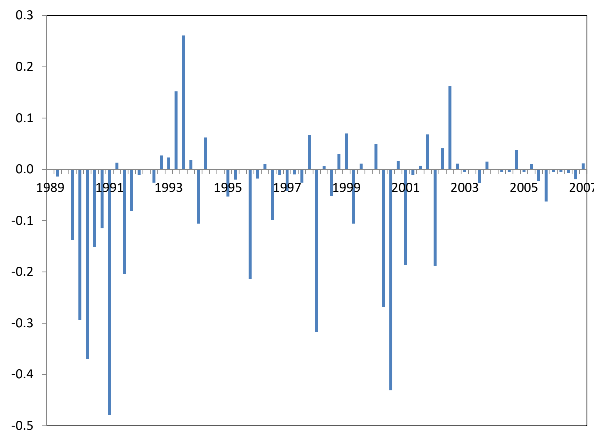
Appendix

A Monetary policy shocks

Figure 3 depicts the time series of the shocks.

Figure 3: Monetary Policy Shocks



Notes: This table shows the time series of the quarterly shocks. See text for more details.

B Data

B.1 CEX Data

I obtain the micro data on the US Consumer Expenditure survey (CEX) from the Inter-university Consortium for Political and Social Research (ICPSR) at the University of Michigan and from the Bureau of Labor Statistics (BLS). The survey is conducted on a quarterly basis by the BLS for the main purpose of constructing the consumer price index weights. The unit of survey is the household level, and each household is interviewed by the BLS once per quarter, for at most five consecutive quarters. While expenditure is reported at the household level, demographics are reported for individuals. These include age, income, education attainment, family size, and year of birth of the head of household.

Data are collected on expenditures at a detailed level for non-durable and durable goods and for services. Similar to Krueger and Perri (2006), I define non-durable expenditure to include food, alcohol and tobacco, gasoline and other fuel, and clothing. Services expenditure covers household utilities, household operations, service charges, recreational services, public transportation, personal care services, health care, and education, and excludes housing. Durable goods expenditure includes spending on vehicles, housing furnishings, and recreational equipment. Each category of expenditure is deflated using the BLS consumer price indices.

Following Aguiar and Hurst (2013), Coibion et al. (2017), and others, I restrict the sample to ensure that the data are comparable over time. Specifically, I restrict the sample to include only households in which the head of household is between 25 and 75 years old (inclusive). To reliably estimate cohort effects, I include only households who are born between 1914 and 1973 inclusive, to ensure that each cohort has at least 10 years of data. The sample includes only households who report expenditures in all four quarters of the survey, and with non-zero food expenditure. Only urban households are included in the sample, since the BLS did not interview rural households prior to 1983. I also restrict households with complete income reports, and with at least three monthly observations per quarter. This leaves 235,933 households in total over the period 1980-2007.

The CEX data have some well-documented measurement errors.[26] Over time, total spending measured by the CEX has fallen relative to the national income and product accounts (NIPA) measure. Moreover, the discrepancy has differed by consumption category. I approach this measurement issue in three ways. First, I note that this discrepancy will not affect the interpretations of the age-specific estimated results in this paper if the discrepancy in reporting is uniform across the age groups. That is, the comparison of old and young households will not be affected, even though the levels of expenditure are mismeasured. Second, for robustness, I recompute age-specific elasticities for consumption categories where has been little deterioration in the ratio of the CEX spending to NIPA spending over the past two decades.[27]

B.2 Mortgage data

I use the CEX detailed expenditure files on owned living quarters and other owned real estate and mortgages over the sample period of 1993-2007. Some of the variables are unavailable prior to 1993, and therefore I focus on the period starting from 1993. I obtain the data from the BLS for the period 1996-2007 and from the ICPSR at the University of Michigan for the period 1993-1995. I focus on loans related to owner-occupied housing. This is based on the observations with a property code equal to 100, which denotes “The home in which you (your CU) currently live(s).”

To identify a loan adjustment (new loan for purchase or on an existing property) in the sample, I first obtain the starting year and month of the transaction. Using the mortgage starting date, I construct a loan-adjustment binary variable that equals one if the starting date equals the current observation date. It is equal to zero otherwise, signaling an existing loan. I do not include in the sample any observations with original balances in the bottom 1 percent of the sample, to abstract from possible home equity lines of credit.

The loan adjustment variable that I define includes new loan transactions for new housing purchases, as well as refinancing of loans on existing homes. I do not separate the two transactions, since the CEX data do not provide a link between the mortgage and the address of the home to distinguish between new purchases and refinancing. Therefore, I focus the analysis on the overall loan adjustment propensities.

The second data source that I use to examine loan adjustment propensities is the Freddie Mac Single Family Loan-Level data. This data set is loan-level panel data of all 30-year mortgages securitized by Freddie Mac. I merge the loan origination data file (with loan characteristic information, such as the original leverage ratios and credit scores) with the monthly panel performance data files. I keep only non-delinquent loans and loans with positive balances. I deflate the current loan

[26]For a discussion of these issues, see, for example, Aguiar and Hurst (2013) and Aguiar and Bils (2015).

[27]These categories include food at home, food away from home, rent and utility, and cable and satellite television and radio services.

balances using the BLS price index to obtain a measure of real loan balances, as at 1983. In total, there are approximately 17 million housing loans in the sample period of 2000-2007.

I identify a loan adjustment as all loans that enter the sample in the quarter, with a recorded purpose of "no cash-out refinance." Since the dataset is a loan-level panel, I focus on the loan adjustments that are from "no cash-out" refinancing. These are transactions that are unlikely to involve a change in the loan balance on existing loans. This allows me to examine the correlations between loan adjustment propensities and loan size prior to the adjustment, without confounding any possible effects of loan balance increases from "cash-out" activity. However, the results are also robust to considering "cash-out" refinancing. Kirkman, Justiniano and Wong (2015) examines other types of loan adjustments (cash-out refinancing and new homeownership) using the Equifax household-panel data. Since the Equifax data are at a household-level, we observe the loan balance immediately prior to the loan adjustment for all types of loan adjustments.

In Table 21, I compare the unconditional share of loans that adjust each quarter (panel A) and the propensity to adjust loans following monetary shocks (panel B) implied by different datasets: the CEX data, Freddie Mac data, and CoreLogic loan data. Specifically, panel B of Table 21 estimates equation (4), which regresses an indicator equal to one a loan adjustment in quarter t on lags of the monetary policy shocks. Panel B reports the marginal responses in loan adjustment over the year to a 1 percentage point monetary policy shock. We can see in Table 21 that the unconditional and conditional moments are not statistically different across the data sets.

Table 21: Loan adjustments across different data sets

	CEX	**Core-Logic**	**Freddie Mac**	**CEX**	**Core-Logic**	**Freddie Mac**
	1995-2007	1995-2007	1995-2007	1999-2007	1999-2007	1999-2007
	(I)	(II)	(III)	(IV)	(V)	(VI)
Unconditional share of loans that adjust over the year:						
Mean	0.21	0.21	n.a.	0.18	0.23	0.15
Standard deviation	(0.03)	(0.04)	n.a.	(0.02)	(0.05)	(0.08)
Marginal propensity to adjust loans over the year after shock:						
Coefficient	0.06	0.09	n.a.	0.10	0.16	0.07
Standard error	(0.01)	(0.09)	n.a.	(0.03)	(0.10)	(0.02)
P-value	0.01	0.33	n.a.	0.10	0.12	0.01

Notes: This table displays the unconditional share of loans that adjust each year and the propensity to adjust loans following monetary shocks implied by different data sets: the CEX data, Freddie Mac data, and CoreLogic loan data.

There is insufficient information in the CEX to separate loan adjustments in refinances versus new housing purchases. However, it is possible to examine the responses of these two margins in the Freddie Mac loan-level data. Column (I) of Table 22 reproduces the overall response to a monetary shock, from either refinancing or new purchases, equivalent to column (VI) of Table 21. Columns (II) and (III) show the coefficients from separately estimated the response of refinancing and new purchases. As we can see, the majority of the loan adjustments to monetary policy shocks are refinances. The responses of refinances to monetary policy shocks are statistically significant at a 1 percent level. In comparison, new purchases account for a smaller share of the loan adjustment response and are statistically insignificant at a 10 percent level.

Table 22: Refinancing and new purchases

	Total	**Refinancing**	**New Purchases**
Coefficient	0.07	0.05	0.02
Standard error	(0.02)	(0.01)	(0.02)
P-value	0.010	0.001	0.317

Notes: This table shows the share of loans that adjust following monetary shocks, split by new purchases and refinancing. The data are from Freddie Mac.

C Loan adjustment by loan size

In this section, I examine the relationship between loan size and loan adjustment propensities using the Freddie Mac Loan Performance data, over the sample period 1999-2007. Specifically, I sort loans into deciles. I estimate a probit model of a new loan regressed on lags of the monetary policy shock interacted with the loan size decile. The positive correlation between loan size and loan adjustment propensities is seen in Table 23.[28] The table presents the loan adjustment propensities within the year of an expansionary monetary policy shock, by loan decile. Formally, I estimate equation (4) by deciles. The propensity to adjust the loan rises with loan size, ranging from 10 percent in the bottom decile to 48 percent in the top decile. Table 23 shows that the propensity to adjust rises with loan size.

Table 23: Loan Adjustment Behavior by Loan Size

Loan size decile	Propensity to adjust	Loan size decile	Propensity to adjust
1	0.101***	6	0.279***
	(0.001)		(0.001)
2	0.168***	7	0.286***
	(0.001)		(0.001)
3	0.234***	8	0.307***
	(0.001)		(0.001)
4	0.228***	9	0.316***
	(0.001)		(0.001)
5	0.253***	10	0.479***
	(0.001)		(0.002)

Notes: This table shows the average annual propensity to adjust a loan (given the household owns a home) by deciles of loan size. The numbers 1 and 10 denote the smallest and largest 10 percent of loans in the loan size distribution, respectively. The standard errors are in parentheses and the 1, 5, and 10 percent significance levels are denoted by $***$, $**$, and $*$ respectively. The propensities are estimated using the Freddie Mac Loan Performance micro data, which spans 2000-2007. See text for more details.

[28] As discussed in Section 2, I focus on no cash-out refinancing loan adjustments when looking at loan balances, since loan balances are tracked over time at the loan-panel level rather than at the household level. However, the results are also robust to the inclusion of “cash-out” refinancing. Kirkman, Justiniano and Wong (2015) examines other types of loan adjustments (cash-out refinancing and new homeownership) using the Equifax panel data.

D Robustness

Alternative windows for defining loan adjustment For robustness, I consider different time horizons for defining a change in loan status. In the baseline, households are classified as "Adjusters" if they are a homeowner and had a loan status change within quarter t. Below, I consider classifying households as "Adjusters" if they have a loan status change within the past t to $t+k$ quarters.

Table 24 reports average consumption responses over the year following a monetary policy shock across the three mortgage and homeownership groups. The columns differ in terms of the time horizons for defining a change in loan status, ranging from t to $t-2$. The results are not statistically different across the different definitions.

Table 24: Consumption Responses by Housing and Mortgage Decisions

Window of adjustment	Past year	Past 3 qtrs	Past 2 qtrs
	(I)	(II)	(III)
Adjust Loan			
Coefficient	4.02	3.83	3.26
Standard error	(2.18)	(2.13)	(2.07)
P-value	0.07	0.08	0.12
Do not adjust loan			
Coefficient	0.08	-0.03	-0.14
Standard error	(0.49)	(0.48)	(0.46)
P-value	0.88	0.95	0.77
Renters			
Coefficient	0.44	0.24	0.21
Standard error	(0.39)	(0.36)	(0.33)
P-value	0.26	0.51	0.52
Recession fixed effects	Yes	Yes	Yes

Notes: This table shows the average semi-elasticity of consumption responses to a one standard deviation expansionary monetary policy shock over the year, based on equation (3). The households are stratified by those who adjusted their loans, those who did not adjust their loans and those who remained renters within the window. Columns (I)-(III) differ in terms of the window in which the adjustment is measured. For example, Column (I) classifies households into the group that adjusts their loans if there was a loan adjustment within the year. Column (II) classifies households into the group that adjusts their loans if there was a loan adjustment within the past three quarters. Column (III) classifies households into the group that adjusts their loans if there was a loan adjustment within the past two quarters. The standard errors and corresponding p-values for the coefficients are computed using the delta method. See text for more detail.

Inclusion of time fixed effects Table 25 shows the differential consumption responses to a one standard deviation expansionary monetary policy shock, based on equation (3) with including time fixed effects. The standard errors and corresponding p-values for the coefficients are computed using the delta method. The table is analogous to Table 8, which is estimated without time fixed effects. The estimated coefficients are statistically indistinguishable from the estimates in Table 8. Hence, the results are robust to including time fixed effects.

Table 26 shows the differential marginal propensities of households to have a loan-status change over the past year following an expansionary monetary policy shock. Time fixed effects are included in the regression. The table is analogous to Table 8, which is estimated without time fixed effects.

Table 25: Differential Consumption Responses by Age, Housing, and Mortgage Decisions

Young vs. Middle	All	Subset of households		
		Adjust loan	No adjust	Renters
Coefficient	2.64	-0.86	1.06	-2.93
Standard error	(1.32)	(7.81)	(1.82)	(1.98)
P-value	0.05	0.91	0.56	0.15
Time fixed effects	Yes	Yes	Yes	Yes
Income interactions	Yes	Yes	Yes	Yes
Education interactions	Yes	Yes	Yes	Yes

Notes: This table shows the differential consumption responses to a one standard deviation expansionary monetary policy shock, based on equation (3) with including time fixed effects. The standard errors and corresponding p-values for the coefficients are computed using the Delta method.

The estimated coefficients are statistically indistinguishable from the estimates in panel B of Table 10. Hence, the results are robust to including time fixed effects.

Table 26: Marginal Propensities to Change Loan Status, Conditional on an Expansionary Shock

Panel A: Extra propensity to adjust loan over the year after a shock	**Young**	**Middle**	**Old**
Coefficient	0.10	0.02	-0.03
Standard error	(0.01)	(0.02)	(0.02)
P-value	0.01	0.42	0.21
Panel B: Differential response	**Young - Middle**	**Young-Old**	**Middle-Old**
Coefficient	0.08	0.13	0.05
Standard error	(0.03)	(0.03)	(0.02)
P-value	0.12	0.04	0.08

Notes: The table shows the differential marginal propensities of households to have a loan-status change over the past year following an expansionary monetary policy shock. Time fixed effects are included in the regression. The standard errors and p-values are computed based on the delta method.

Table 26 shows the differential marginal propensities of households to have a loan-status change over the past year following an expansionary monetary policy shock. Time fixed effects are included in the regression. The table is analogous to Table 12, which is estimated without time fixed effects. The estimated coefficients are statistically indistinguishable from the estimates in Table 12. Hence, the results are robust to including time fixed effects.

Table 27: Marginal Propensities to Change Loan Status

Panel A: Baseline estimates, not controlling for (loan size)*shock	Young - Middle	Young-Old	Middle-Old
Coefficient	0.053	0.08	0.03
Standard error	(0.01)	(0.01)	(0.01)
P-value	0.01	0.03	0.16

Panel B: Differential response, controlling for (loan size)*shock	Young - Middle	Young-Old	Middle-Old
Coefficient	0.051	0.03	-0.02
Standard error	(0.005)	(0.02)	(0.02)
P-value	0.01	0.24	0.30

Notes: This table shows the differential marginal propensities of households to have a loan-status change in the past year, given an expansionary monetary policy shock. Panel A does not condition on loan size and its interaction with the monetary policy shocks. Panel B shows the differential responses in a specification that does condition on loan size and its interaction with the monetary policy shocks. The standard errors and p-values are computed based on the delta method. The regressions include time fixed effects.

E Consumption response to long-term shocks

The finding that consumption elasticities decline with age is robust to different measures of monetary policy shocks. The main results are based on a measure of the current period shock over the quarter.

I examine the consumption responses to long-term measures of a monetary policy shock. Specifically, I estimate regression specification (2) using the long-term "path" shock, based on the GSS decomposition described in Section 2. Table 28 reports the differences between the age groups in their average consumption responses over the year following a monetary policy shock. The coefficients are normalized to report the response to an expansionary monetary policy shock (i.e., a decline in rates). The p-values for the test of equality between the responses of the group are computed using the delta method. For example, a p-value of less than 0.1 would reject the null of equal consumption between age groups at a 10 percent significance level.

Consistent with the findings using the high-frequency shocks, the estimates using the path shocks also suggest that young people adjust their consumption more than the middle-aged and old households. Specifically, the young increase consumption by about 2.1 percentage points more than middle-aged, which is statistically significant at the 10 percent level. In comparison, the difference in consumption responses of the middle-aged and older households is statistically insignificant at a 10 percent level.

Table 28: Heterogeneous responses to monetary policy by age

	(I)	(II)	(III)
Young-Middle			
Coefficient	2.37	3.14	2.28
Standard error	(1.34)	(1.39)	(1.29)
P-value	0.08	0.03	0.09
Young-Old			
Coefficient	0.76	1.73	1.52
Standard error	(2.83)	(2.84)	(3.09)
P-value	0.79	0.55	0.63
Middle-Old			
Coefficient	-1.61	-1.41	-0.76
Standard error	(2.43)	(2.42)	(2.72)
P-value	0.51	0.56	0.78
Recession fixed effects	Yes		
Time fixed effects		Yes	Yes
Income interactions			Yes
Education interactions			Yes

Notes: This table shows the differences between age groups in their average semi-elasticities of consumption over the year, in response to a monetary policy shock. The estimates are based on equation (2). The standard errors and corresponding p-values for the coefficients are computed using the delta method. See text for more detail.

F Separating age from cohort effects

One concern we may have is whether the age-specific results reflect cohort effects rather than life-cycle factors. The cohort effects refer to the birth year of the individual. For instance, it might be, in principle, that individuals born more recently react more strongly to recent shocks than individuals born more in the past.[29] If so, we may mistakenly think that the stronger response of people born more recently is from a life-cycle effect related to age.

I reestimate equation (2) with additional controls for birth cohort group interacted with the monetary policy shocks. The cohort groups are defined based on 20-year groups, starting from 1930. I consider 20-year periods to ensure that there are sufficient households per cohort group.

Table 29 shows the average semi-elasticity of consumption over the year to a one standard deviation monetary policy shock by age. We can see suggestive evidence that the young respond more than the middle-aged and old, although the precision of the estimate is reduced once we include the additional interactions of cohorts with monetary shocks.

[29] This could be rationalized by theories in which expectations are updated based on a weighting of past life experiences. An older person has a longer period of time to average out the recent shock and may therefore respond less. This theory is a very different from the life-cycle effect.

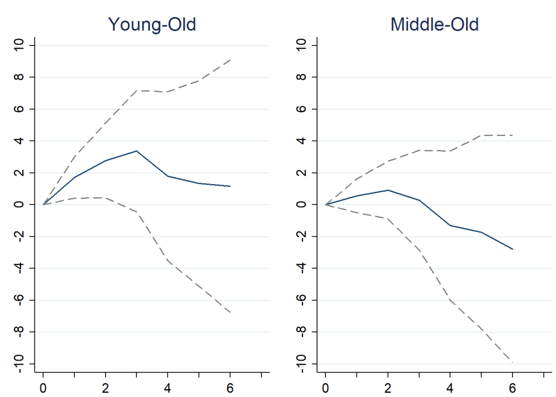
Table 29: Heterogeneous responses to monetary policy by age

	(I)	(II)	(III)
Young-Middle			
Coefficient	1.63	3.28	2.67
Standard error	(1.63)	(2.21)	(2.18)
P-value	0.32	0.14	0.23
Young-Old			
Coefficient	0.25	2.75	2.37
Standard error	(4.09)	(4.68)	(4.95)
P-value	0.95	0.56	0.64
Middle-Old			
Coefficient	-1.38	-0.52	-0.30
Standard error	(4.07)	(4.16)	(4.41)
P-value	0.74	0.90	0.95
Recession fixed effects	Yes		
Time fixed effects		Yes	Yes
Income interactions			Yes
Education interactions			Yes

Notes: This table shows the differences between age groups in their average semi-elasticities of consumption over the year, in response to a monetary policy shock. The estimates are based on equation (2). The standard errors and corresponding p-values for the coefficients are computed using the delta method. See text for more detail.

G Differential Consumption Responses by Quarter

Figure 4: Differential consumption responses by quarter



Notes: This figure depicts the differential consumption responses by group to a one-standard deviation expansionary monetary policy shock. The 10-percent confidence intervals are depicted by the dashed lines.

H Computational Appendix

In this section, I describe the solution to the quantitative model and its extensions. An agent j of age a at time t can hold three assets in the model: a liquid asset, s_{jat}, which has the interest rate r_t; housing, h^o_{jat}, which has an associated price p_t; and mortgage b_{jat}, which has an associated mortgage rate r_{jat}.

The household state vector is $z_{jat} \equiv (y_{jat}, S_t, \text{assets}_{jat})$, where S_t denotes the multivariate aggregate state vector $S_t = [\log y_t, \log p_t, r_t]$, y_{jat} denotes the idiosyncratic income, and assets_{jat} is the vector of incoming endogenous variables $\text{assets}_{jat} = \left[s_{jat}, h^o_{jat}, b_{jat}, r_{jat}\right]$. In the following equations, I drop the subscripts for ease of notation when describing the household's recursive problem.

When working, households solve

$$V(z) = \max \left\{ V(z)^{\text{rent}}, V(z)^{\text{purchase}}, V(z)^{\text{own \& refi}}, V(z)^{\text{own \& no refi}} \right\}.$$

The three value functions, for renters, new home purchasers, refinancing households, and non-refinancing households, are given by

$$\begin{aligned} V(z)^{\text{rent}} &= \max_{c, h^{\text{rent}}, s'} u\left(c, h^{\text{rent}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' + p^r h^{\text{rent}} &= y + (1-\delta) p h^{\text{own}} + (1+r)s - b(1+R) \\ h'^{\text{own}} &= b' = 0, \quad s' \geq -\underline{s}. \end{aligned}$$

$c(z) = y + (1-\delta) p h^{\text{own}} + (1+r)s - b(1+R) - s' - p^r h^{\text{rent}}$ is the associated consumption policy function for the renter. $s'(z)$ and $h^{\text{rent}}(z)$ are the associated liquid asset and rental housing policy functions, respectively.

$$\begin{aligned} V(z)^{\text{purchase}} &= \max_{c, s', h'^{\text{own}}, b'} u\left(c, h'^{\text{own}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' + p h'^{\text{own}} - b' &= y + (1-\delta) p h^{\text{own}} + (1+r)s - b(1+R) - F^{\text{new}} \\ b' &\leq (1-\phi) p h'^{\text{own}}, \quad s' \geq -\underline{s}, \quad R' = r^d, \end{aligned}$$

where $c(z) = y + (1-\delta) p h^{\text{own}} - p h'^{\text{own}} + (1+r)s - s' + b' - b(1+R) - F^{\text{new}}$ is the associated consumption policy function for the household that purchases a home, and $s'(z)$, $h^{\text{own}}(z)$ and $b'(z)$ are the associated liquid asset, housing owned, and mortgage policy functions, respectively.

$$\begin{aligned} V(z)^{\text{own \& refi}} &= \max_{c, s', b'} u\left(c, h'^{\text{own}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' - b' &= y + (1+r)s - b(1+R) - F^{\text{refi}} \\ b' &\leq (1-\phi) p h'^{\text{own}}, \quad s' \geq -\underline{s}, \quad R' = r^d \\ h'^{\text{own}} &= h^{\text{own}}(1-\delta), \end{aligned}$$

where $c(z) = y + (1+r)s - s' + b' - b(1+R) - F^{\text{refi}}$ is the consumption policy function for the refinancer, and $s'(z)$ and $b'(z)$ are the associated liquid asset and mortgage policy functions, respectively.

$$\begin{aligned} V(z)^{\text{own \& no refi}} &= \max_{c,s'} u\left(c, h^{\text{own}}(1-\delta)\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' &= y + (1+r)s - M \\ b' &= b(1+R) - M, \quad s' \geq -\underline{s}, \quad R' = R \\ h'^{\text{own}} &= b' = 0, \quad s' \geq -\underline{s} \\ M &= b\left[\sum_{k=1}^{d(a)} \frac{1}{(1+R)^k}\right]^{-1}, \end{aligned}$$

where $c(z) = y + (1+r)s - s' - M$ is the associated consumption policy function for the homeowner who does not refinance his existing mortgage, and $s'(z)$ is the associated liquid asset policy function.

The expected value function for each of these value functions above is taken over the aggregate shocks S, idiosyncratic shocks y, the probability of survival π, and the household's holdings of assets. The expectation is defined as

$$EV[V(z')] = \pi\beta \sum_{z'} \max\left\{V(z)^{\text{rent}}, V(z)^{\text{purchase}}, V(z)^{\text{own \& refi}}, V(z)^{\text{own \& no refi}}\right\} F\left(z'|z\right),$$

where $F\left(z'|z\right)$ is the probability associated with the evolutions of the aggregate and idiosyncratic income states.

The problem for a retired hosuehold is identical, except that retirement benefits replace labor earnings. At the time of death, hosueholds' continuation value is given by the bequest motive in the text.

To solve the model numerically, I proceed as follows. First, I reformulate the choice variables to rectangularize the problem and simplify computational issues that arise from the endogenous mortgage constraint. I reformulate the problem in terms of the leverage ratio, defined as

$$q_{jat} = b_{jat}/p_t h_{jat} \geq 0.$$

I then substitute the budget constraint into the utility function to eliminate consumption as a choice variable. The household's choice variables are therefore: (i) $s'(z)$ and $h^{\text{rent}}(z)$ for the renter; (ii)$s'(z)$, $h^{\text{own}}(z)$ and $q'(z)$ for the household that purchases a home; (iii) $s'(z)$ and $q'(z)$ for the refinancer; and (iv) $s'(z)$ for the household that does not choose to buy a home or refinance an existing mortgage.

I discretize the problem so it can be solved on the computer by first discretizing the idiosyncratic income variable y_{jat} and multivariate aggregate state vector $S_t = [\log y_t, \log p_t, r_t]$ using the algorithm of Tauchen (1986). Specifically, I use the Tauchen algorithm to obtain the grid points for the quarterly of S. I then simulate the quarterly process of S_t to get the annual probability transition matrix for S_t. I use 18 grids for S_t and four grids for y_{jat}. This gives the probability function $F(z'|z)$ that is used to compute the expected value functions in the next period, defined above.

As in Berger et al. (2018), I approximate the value functions ($V(z)^{\text{rent}}$, $V(z)^{\text{purchase}}$, $V(z)^{\text{own \& refi}}$, and $V(z)^{\text{own \& no refi}}$) as multilinear functions in the states, where $z_{jat} = [S_t, y_{jat}, \text{assets}_{jat}]$. There are four endogenous asset states, denoted by the vector $\text{assets}_{jat} = \left[s_{jat}, h^o_{jat}, b_{jat}, r_{jat}\right]$. I use 20 knots for h^o_{jat} and q_{jat} and 10 knots for s_{jat} and r_{jat}. The knots are spaced more closely together near the constraints for q_{jat} and s_{jat}. I assume multilinear interpolation of the value functions between the knots.

At age and at each choice (rent, purchase, refinance, and no refinance), I compute optimal policies using a Nelder-Meade algorithm. I compare the value functions for each of the four cases (to rent, to purchase a new home, to refinance, and to own a home and not adjust the mortgage) to generate the overall policy function. I proceed via backward induction from the final period of life. Given the non-linearity of the policy functions, I experimented with different initialized starting values to check the implied simulated impulse response functions.

To simulate the model, I initialize the cohorts to match the values of the SCF for young households (those younger than 35). Similar to the procedure in Berger et al. (2018), I first randomly split the sample into five income groups. Within each income group, I randomly allocate households into two groups, renters and homeowners, to match the SCF data. For homeowners, I assign them the median value of housing and mortgages within that same income bin. The model is simulated with a panel of $10,000$ households (100 cohorts) over their lifetimes.

To compute the impulse response functions of consumption to a monetary policy shock, I first simulate the consumption and asset profiles decisions for 100 different cohorts, with $1,000$ households in each cohort. Each cohort faces a different historical path for the state variables. Then, for each cohort, I compute the consumption choice for each household following a monetary policy shock. This involves feeding in the aggregate dynamics following the shock for house prices, rental rates, interest rates, mortgage rates, and income, and computing the consumption choices. I then compare the consumption response under the monetary policy shock to the consumption choice that would have occurred if the households faced the aggregate dynamics under no monetary policy shock. I aggregate across households within the same cohort, assuming the demographic profile of the economy, to compute the aggregate consumption response and take the average across cohorts.

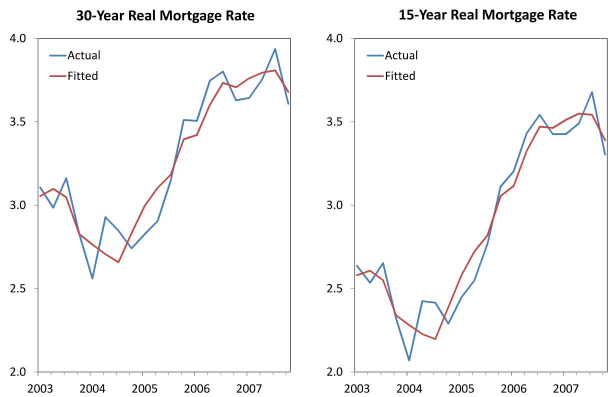
In Section 6, I consider the role of having variable rate mortgages for the transmission of monetary policy (Table 20, column (IV)). I assume that households with variable rate mortgages have their payments move one-for-one with the current mortgage rate. In other words, households now choose between three different options $V(z)^{\text{rent}}$, $V(z)^{\text{purchase}}$, and $V(z)^{\text{no purchase}}$, where $V(z)^{\text{purchase}}$ is identical to $V(z)^{\text{refi}}$ in the original problem except that there is no transaction cost associated with the change in mortgage. In this scenario, the household can still choose to not adjust its mortgage balance, but no longer has a choice to keep its mortgage rate unchanged when faced with aggregate policy shocks. This model introduces no new parameters. I keep the original utility parameters and purchasing transaction costs the same in this version of the model.

I Mortgage Rate, House Prices, and Rental Rates

In the model, I specify linear approximations of the mortgage yield curve, house prices, and rental rates as a function of aggregate state variables. The mortgage yield curve is a function of the short-term interest rate and aggregate employment. House prices and the house-price-to-rent ratios are a function of prior period house price, short-term interest rates, and aggregate employment. One advantage of specifying these processes in this way is that it generates plausible time series and impulse response function dynamics without adding additional state variables to the computation.

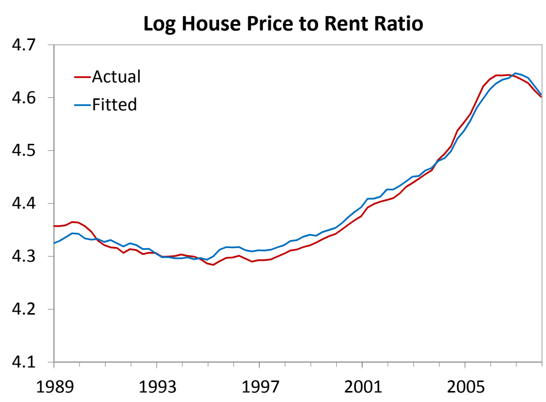
In this section, I provide evidence that the linear specifications are indeed good approximations to actual dynamics. Figure 5 shows that the predicted 30- and 15-year real mortgage rates closely fit the actual mortgage rates over time. Figure 6 also shows that the predicted and actual log house-price-to-rent ratios are similar over time.

Figure 5: Predicted and actual 30- and 15-year mortgage rates



Notes: This figure depicts the model-predicted and actual 30- and 15-year real mortgage rates.

Figure 6: Predicted and actual log house-price-to-rent ratio



Notes: This figure depicts the model-predicted and actual log house-price-to-rent ratio. The latter are from the Federal Housing Finance Agency and the OECD Analytical House Price Database.