Transmission of Monetary Policy to Consumption and Population Aging*

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Abstract

This paper assesses the effects of demographic changes on the transmission of monetary policy to consumption. First, I empirically estimate age-specific consumption responses to rate shocks. Consumption of younger people is more responsive and explains most of the aggregate response. The response is driven by 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. The mortgage channel accounts for a sizable share of the young-old difference in response. Under an older demographic structure, aggregate consumption is less responsive to monetary policy shocks.

Keywords: Age structure; consumption; monetary policy; refinancing.

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1 Introduction

Most industrialized countries are currently undergoing a sustained process of population aging, which is projected to continue through this century. In Japan, for instance, individuals aged over 60 now account for 30 percent of the population. The share of the population aged over 60 is three times what it was in 1970, and is expected to continue rising to over 40 percent by 2050.[1] Similarly, in the U.S., the share of the population aged over 60 is expected to rise from 18 percent to 28 percent by 2050. While there has been substantial literature looking at the implications for Social Security and fiscal policy, there has been much less study of the implications for monetary policy.[2] Understanding the relationship between demographics and monetary policy is important for the setting of optimal monetary policy.

Assessing the effects of changes in monetary policy across demographic groups is also relevant for distinguishing between different macro models and frictions in the economy. There exists competing models, each emphasizing different channels and embodying different policy implications. An important reason for focusing on monetary policy shocks is that different models respond differently to these shocks.[3] Moreover, the availability of high-frequency data on Federal Funds futures from 1989 onwards means that exogenous monetary policy shocks can be more convincingly identified. The availability of the high-frequency data has lead to a resurgence of papers using the data to assess the nature of the monetary transmission mechanism.[4]

In this paper, I contribute towards existing literature in three ways: (i) by quantifying the response of consumption to monetary policy shocks by age, (ii) by examining which channels can explain the heterogeneity and sensitivity of consumption to changes in monetary policy, and (iii) by quantifying how the aggregate consumption response will change as the population ages. To do so, I provide empirical analysis using household-level micro data, and document new consumption and loan adjustment facts. I then develop a model that accounts for these empirical facts.

To empirically estimate the response of consumption to monetary policy shocks, I identify interest rate shocks using high-frequency data on Federal Funds futures and long-term interest rates. I estimate the response of consumption to monetary policy shocks using two sources of micro household-level expenditure: the U.S. Consumer Expenditure Survey (CEX) on all categories of spending, and the Nielsen Homescan data on food expenditure. I then provide evidence of the importance of the mortgage refinancing and new borrowing channel. I supplement the CEX analysis

[1]The projections are from the United Nations.

[2]See e.g. Auerbach and Kotlikoff (1985), Auerbach et al. (1989), Ríos-Rull (2001), and Abel (2003).

[3]Using monetary policy shocks as a means of distinguishing between models and frictions is in the spirit of Lucas (1980). Papers that have applied this idea include Christiano, Eichenbaum and Evans (1997), Gali (1997) who studies the effects of technology shocks, and Rotemberg and Woodford (1992) and Ramey and Shapiro (1997) who study the effects of shocks to government purchases.

[4]E.g. Gertler and Karadi (2015), Gorodnichenko and Weber (2015), and Nakamura and Steinsson (2015).

with Freddie Mac mortgage data to estimate loan adjustment propensities.

My four main empirical findings are as follows. First, I find that expansionary monetary policy shocks lead to significantly lower mortgage rates. These expansionary shocks have large and persistent effects on consumption. Second, the consumption elasticity of young people (those aged under 35 years) is about double that of the average person in the economy. Moveover, the consumption response of young people to monetary policy shocks accounts for two-thirds of the aggregate consumption response. The finding that consumption elasticities decline with age is consistent with regional variations in monetary policy effects. Specifically, states with a higher share of older population have a smaller consumption response to interest rate shocks than younger states.

Third, the response of consumption is driven by homeowners. There is no statistically significant consumption response for renters. The large response of homeowners is predominately due to households who adjust their loans following interest rate shocks. The adjustment decision reflects both the intensive margin of homeowners refinancing, and the extensive margin of households entering into a new loan. I find that the consumption of homeowners who adjust their loans after expansionary shocks rises significantly more than that of homeowners who do not adjust their loan.

Fourth, a higher fraction of young people adjust their loans after expansionary monetary policy shocks, compared with older people. The higher fraction accounts for the larger consumption response of young people to monetary policy shocks. Moreover, I find that the household's propensity to adjust their loan rises with loan duration. In the data, young people have much larger loan sizes and longer duration than middle aged or older people. Individuals take out a mortgage to purchase their home, which is then paid down. Naturally, older people have lower balances as they have paid down more of their mortgages than young people.

I develop a household model of mortgages and housing that generates the empirical findings. The features of model are: an uninsurable labor income risk, a life-cycle savings motive, and a fixed-rate mortgage structure. Individuals pay a fixed cost to adjust their long-term assets, which includes their housing and their fixed-rate mortgage.[5] The interest rate on the mortgage is fixed unless the individual pays a cost to adjust their loan.

The key intuition behind the model is as follows. The fixed-rate mortgage structure generates heterogeneity in the pass-through of monetary policy to the interest payments of households, 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. Consistent with the data, the model implies that younger people have larger loans than older people, as they borrow against higher expected

[5] My model builds on models of liquid and illiquid assets, such as Alvarez, Guiso and Lippi (2012), Alvarez and Lippi (2009), Abel, Eberly and Panageas (2009), Kaplan and Violante (2014), and Berger et al. (2015).

future income. Therefore, young people also have a higher propensity to adjust their loans relative to older people. 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 adjust their loans and short-term liquidity constraints, which can generate large consumption responses in the aggregate.

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 home-ownership rates, and declining debt holdings over the life-cycle. The model also generates aggregate and household-age conditioned responses to a monetary policy shock that are statistically indistinguishable from the analog moments in the data.

I use the model to quantify the importance of the loan adjustment channel for explaining the difference in the consumption responses between young and old people to interest rate shocks. I use the model to separate the refinancing and new lending channel from other channels, such as labor income volatility and liquidity constraints. Distinguishing between the factors affecting consumption is relevant for assessing whether the same shock will be more or less effective under different macroeconomic conditions.[6]

I quantify the role of the refinancing channel by shutting down the refinancing decision and re-estimating the model under a variable rate mortgage structure, without any fixed costs. I find that the difference between the consumption response of young and old people declines by about 50 percent under the model with a variable mortgage structure. So according to my model, the refinancing channel accounts for 40 percent of the difference in the consumption response of younger and older people. The remaining is accounted for by the standard income and substitution effects, wealth effects and other channels, which have been emphasized in existing literature on the redistributive effects of monetary policy.[7] The model has two implications. First, it implies that a shift in demographics can reduce the aggregate consumption responses to monetary policy shocks, because the loan adjustment channel becomes weaker. Second, it implies that in response to monetary policy shocks, economies with predominately fixed rate mortgages have lower aggregate consumption responses, but higher cross-sectional heterogeneity by age compared with economies with mostly variable rate mortgages. The cross-sectional heterogeneity arises from heterogeneity in refinancing propensities and the flow-on effects to consumption.

The paper is structured as follows. Section 2 describes the data. Sections 3 and 4 discusses the empirical methodology and the empirical results. Section 5 sets up the model and Section 6

[6]Using the data alone, it is not possible to completely rule out the role of other potential mechanisms, such as income volatility and liquidity constraints, which may be correlated with the household's loan adjustment decisions. One reason is the CEX data has sparsely populated information on holdings of short-term financial assets, which is relevant for understanding how liquidity constraints interact with loan adjustment decisions.

[7]E.g. Adam and Zhu (forthcoming), Auclert (2015), Doepke, Schneider and Selezneva (2015), Meh and Terajima (2011), Sterk and Tenreyo (2015), Doepke and Schneider (2006*b*) and Doepke and Schneider (2006*a*).

discusses the model results. Section 7 concludes.

Related literature

This paper contributes towards 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), Cochrane and Piazessi (n.d.), Hamilton (2008), Nakamura and Steinsson (2015) and others, show that monetary shocks can have significant effects on long-term yields through affecting market expectations about the future path of interest rates and/or affecting risk premia. These studies focus on asset price effects. In this paper, I showing that these changes in long-term rates can also affect real variables, in particular 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.[8] For instance, Keys et al. (2014) and Di Maggio, Kermani and Ramcharan (2014) exploit the change in the outstanding auto loan balance following anticipated rate resets on adjustable rate mortgages. Cloyne, Ferreira and Surico (2015) examine consumption responses in the U.S. and the U.K. of outright homeowners and mortgagees. This paper differs from these studies by examining the individual's decision to change their rates, while the other papers focus on the consumption effect taking as given the rate change. 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 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 (2015). His analysis abstracts from refinancing. In this paper, I show that refinancing decisions over the life-cycle can also matter for aggregate consumption responses, and generate differences in economies that vary with the demographic structure.

On the theoretical front, papers such as Garriga and Sustek (2017), Greenwald (2017), and Hedlund and Ozkan (2017) also study monetary transmission to the mortgage market. However, these papers assume a representative borrower and generally abstracts from life-cycle features of borrowers. Beraja and Vavra (2017) uses a model closer to this paper. Since their paper focuses on the interactions between regional house prices and the ability to refinance, it abstracts from rental decisions and amount of home equity extraction amount by assuming all households own a house and extract all home equity if they refinance. In this paper, since I focus on the heterogeneity

[8]E.g. Keys et al. (2014), Di Maggio, Kermani and Ramcharan (2014), Auclert (2015) and Cloyne, Ferreira and Surico (2015). Coibion, Gorodnichenko and Hong (2015) also quantify the effect on consumption inequality, while Kaplan, Moll and Violante (2016) look at the heterogeneous effects on labor income.

in the refinancing transmission over the life-cycle, it turns out to be important to incorporate endogenous rental decisions and amount of home equity extraction. In doing so, the model generates greater mortgage adjustment for the young (both because of a move from renting to home owning, and from refinancing existing mortgages), and greater home equity extraction, relative to older households. Both of these features contribute towards larger transmission interest rate shocks to younger households, who have higher propensities to spend the additional cash on consumption. This is helps generate large aggregate and cross-sectional responses by age, seen in the data. Guren and McQuade (2017) also studies heterogeneous responses to monetary policy shocks, but focuses on implications for alternative mortgage designs rather than changes in demographics.

Second, the model developed in this paper is most closely related to the transaction cost models in the literature that distinguish between liquid and illiquid assets. In these models, the presence of fixed costs of adjustment for illiquid assets generates lumpy adjustments of asset portfolios.[9] My framework builds on these models with liquid and illiquid assets by incorporating a number of additional features, which are important for generating the heterogenous age-specific consumption responses to interest rate shocks. These features include a uninsurable labor income risk, a life-cycle savings motive, and a fixed-rate mortgage structure. This provides a natural environment to quantitatively analyze monetary policy and demographic changes.

Lastly, this paper contributes to the literature that looks at the impact of demographics changes on capital accumulation, labor markets and asset pricing. A number of studies examine the implications for the setting of optimal fiscal policy.[10] A related set of papers have also shown the implications of population aging for aggregate labor market volatility,[11] and the implications of long-term structural changes on the natural rate of interest. This paper focuses instead on non-permanent interest rate shocks, such as monetary policy shocks, and the interactions with demographics, which has received less attention in the literature.[12]

2 Data

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 U.S.

[9] Recent examples are Alvarez, Guiso and Lippi (2012), Alvarez and Lippi (2009), Abel, Eberly and Panageas (2009), Kaplan and Violante (2014), and others.

[10] See e.g. Auerbach and Kotlikoff (1985), Auerbach et al. (1989), Ríos-Rull (2001), and Abel (2003).

[11] These papers include Clark and Summers (1980), Ríos-Rull (1996), and Jaimovich and Siu (2009).

[12] The few studies that explore this issue include Fujiwara and Teranishi (2008), Kara and von Thadden (2010), Iman (2013), and Juselius and Takás (2015). My paper differs in two ways. First, I model monetary policy shocks as changes to the short-term interest rate, rather than inflation shocks. Secondly, I model fixed-rate mortgages, rather than assuming a one-period variable structure. This allows for refinancing and mortgage decisions.

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 BLS and the National Income and Product Accounts (NIPA) 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.[13] See Appendix A details on the construction of the categories, and discussion of robustness around measurement issues.

I complement the analysis with a second data set on household expenditure from Nielsen Homescan.[14] The data set includes information on all food purchased and brought into the home by a large number of households over 1999-2010 from 52 geographically dispersed markets (each roughly corresponding to a Metropolitan Statistical Area) and nine regional areas. In total, I use data from 112,837 households who report purchases for at least 10 months. The data has detailed prices and quantities of purchased items. An item is at the Universal Product Code (UPC) level. The data set contains demographic information about the household panelist, updated annually. Appendix A describes the data in more detail.

The empirical findings based on the Homescan data complement the results from the CEX data along three dimensions. First, consumers can remain in the sample for longer than five quarters, unlike in the CEX Survey. This creates a longer panel to track household consumption. Consumers are in the sample for an average of eight consecutive quarters. Second, while the Homescan data covers food expenditures only, it provides information on prices and quantities at a detailed UPC level, which is unavailable in the CEX survey. This allows for the construction of age-specific price deflators, to show that the empirical findings are robust to any potential inflation differences across age groups. Appendix C describes the construction of the age-specific price indices in more detail. Third, the broad geographic coverage of the Homescan data allows me to examine differential responses in consumption to monetary policy shocks across states (see Appendix I).[15]

Mortgage data

I obtain household-level data on mortgages from two sources: the CEX survey and the Freddie Mac Single Family Loan-Level data. I use the CEX detailed expenditure files on owned living quarters and other owned real estate, and mortgages, over the sample period is 1990-2007. The

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[13] I start the sample in 1989 since the monetary policy shocks that I identify (described in more detail below) are based on Federal Funds futures contracts, which were traded from 1989 onwards. I stop the sample in 2007 to abstract from issues surrounding the zero lower bound on interest rates.

[14] The data were obtained from the USDA and used as part of a cooperative agreement between the USDA/ERS and Northwestern University. Similar data are available for academic research from the Kilts-Nielsen Data Center.

[15] While the CEX Survey samples households across the U.S., the BLS cautions against analysis at a regional level as the sample was not constructed to be representative of consumption at the local level.

Freddie Mac Single Family Loan-Level data is a loan-level panel data of all 30-year mortgages securitized by Freddie Mac.[16] In total, there are approximately 17 million loans in the sample period 2000-2007. See Appendix A for more detail.

The Freddie Mac data 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.

3 Empirical methodology

In this section, I discuss the identification of the monetary policy shocks and the procedure for estimating the responses to the shocks. Specifically, I examine the responses of: (i) mortgage rates, (ii) consumption elasticities, and (iii) propensities to refinance or enter into new loans.

3.1 Identifying monetary policy shocks

In order to estimate the response of consumption and mortgage adjustment propensities to monetary policy shocks, it is crucial to identify exogenous shocks to monetary policy. I use high-frequency data on the Federal Funds futures contracts.[17] Federal Funds futures contracts have been traded since 1989. The rate on the contracts reflects the market expectations of the average effective Federal Funds rate during that month. It therefore provides a market-based measure of the anticipated path of the Federal Funds rate. I consider two types of shocks: current month shocks, and a measure of long-term path shocks (discussed below).

About eight times a year, the Federal Reserve announces any changes to its Federal Funds rate in a scheduled FOMC press release. In addition, there are also inter-meeting announcements, which occur between the scheduled meetings. To identify the exogenous part of the announced changes in monetary policy, I examine changes in the traded rate on the federal Funds futures in a narrow window around the FOMC press releases. I obtain the times and dates of the FOMC press releases from Gorodnichenko and Weber (2015), and the Board of Governors of the Federal Reserve system

[16] This data can be obtained from Freddie Mac (link here).

[17] Other papers that also use high-frequency data include Kuttner (2001), Cochrane and Piazessi (2002), Rigobon and Brian (2004), Nakamura and Steinsson (2015), Gertler and Karadi (2015), and Gorodnichenko and Weber (2015).

website. Data on Federal Funds futures are from Gorodnichenko and Weber (2015) and Gürkaynak, Sack and Swanson (2005).[18]

We can think about a monetary policy shock both in terms of a shock to rates in the current period and to the future path of the Federal Reserve's actions (i.e., a shock to the slope of the yield curve). First, I define a current period 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 when the FOMC issues an 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.

Following Gorodnichenko and Weber (2015), Nakamura and Steinsson (2015), and others, I consider a 60 minute time window around the announcement that starts $\triangle^- = 15$ minutes before the announcement.[19] By examining a narrow window around the announcement, this ensures that the only relevant shock during that time period (if any) was the monetary policy shock.[20] The key identifying assumption is that there are no other factors that occurred within the window around the FOMC announcement that moved the Fed Funds futures contracts. This includes other economic and financial news, and movements in the risk premium.[21]

Following Cochrane and Piazessi (2002) and others, I aggregate up the identified shocks to obtain a quarterly measure of the monetary policy shock.[22] This results in 64 estimated monetary policy shocks over 1990-2007.[23] The average monetary policy shock is approximately 0. Two

[18] I stop the sample in 2007 to abstract from issues surrounding the zero-lower bound.

[19] For robustness, I also considered identifying policy shocks based on an even tighter window of 40 minutes (30 minutes after and 10 minutes before the press release), as well as a looser window based on the close of business the day before and day of the announcement. I also considered alternative identification strategies, such as employing the Romer and Romer monetary policy shocks, which are based on narrative information.

[20] The futures contracts incorporate all publicly available information at the beginning of the window. Therefore the public information will not show up as spurious variation in the monetary shock.

[21] One concern that we might have with the identification scheme is that the Federal Reserve Bank may have private information about aggregate economic conditions that are correlated with household consumption, which are not reflected in the futures contracts. The measured monetary policy shock would then be a combination of the true shock and some error that is correlated with consumption. I consider the potential measurement error in three ways. First, in the Appendix E, I consider regressing consumption on forwards of the monetary policy shocks. If the shocks are exogenous, then current consumption should not respond to future shocks. I show that the estimated coefficients are statistically insignificant. Second, I also consider other identification assumptions, including the Cholesky decomposition of the residuals, and the narrative approach in Romer and Romer, to show that the results are qualitatively robust across different assumptions. Finally, I note in the case where the error is additive (i.e. the measured shock equals the true shock plus the error) and the correlation between the error and consumption is the same across each age group, then the estimated age-specific heterogeneous elasticities will be unbiased, even if the level of the elasticities is biased.

[22] Cochrane and Piazessi (2002) aggregate up daily shocks to obtain a monthly shock series.

[23] I exclude the rate cut of September 17, 2001, which is the first trading day after the terrorist attacks of September

standard deviations of the quarterly shock is 25-35 basis points (depending on the window that the shock is measured over).[24] The largest expansionary shock is 48 basis points, in the fourth quarter of 1991. One-third of the shocks are between 10-50 basis points (in absolute values).

As I will show below, these current period shocks can potentially have persistent effects on long-term rates and consumption. This can occur when the current period shocks change expectations about the Federal Reserve's future path of rates set in addition to interest rates in the current period. To isolate out the shock to the path of rates, the literature has also considered monetary policy shocks to "forward guidance". This refers to the Central Bank's ability to affect both the current short term rate and the future expected path of short term rates.[25] One approach to assess the importance of forward guidance, put forth by Gürkaynak, Sack and Swanson (2005) (GSS), is to decompose the futures surprises 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 procedure is based on a principal components analysis to extract two factors from a panel of changes in the 3, 6, 9 and 12 month ahead futures on 3-month Eurodollar deposits and OIS rates.[26]

3.2 Estimating consumption elasticities

I first estimate the response of consumption to interest rate shocks. I do so by combining the data on the Federal Funds futures contracts with household-level consumption data from the Consumer Expenditure Survey and Nielsen Homescan, separately. Using the monetary policy shock series, I estimate how consumption responds to interest rate shocks:

$$\triangle \ln C_{ht} = b_0 + \sum_{k=1}^{K} \beta_k \cdot \epsilon_{t-k}^{-} + \sum_{k=1}^{K} \gamma_k \cdot \epsilon_{t-k}^{+} + \lambda_{s(t)} + \alpha X_{ht} + \nu_{ht}. \tag{2}$$

C_{ht} denotes real consumption for household h in quarter t. I estimate the regression for the change in consumption, denoted by $\triangle \ln C_{ht} = \ln C_{ht} - \ln C_{h,t-1}$. $\lambda_{s(t)}$ denotes seasonality fixed effects. X_{ht} denotes household-level controls: changes in family size, the number of children, and marital status over the quarter, and household-specific interview fixed effects.[27] I cluster the standard errors

11, 2001, to abstract from potential noise in the rates caused by the event.

[24]The quarterly shock includes shocks that occur at inter-meeting policy moves. The inter-meeting shocks are much larger in magnitude than the scheduled meeting announcement shocks. For instance, a 1 standard deviation on the inter-meeting announcement shock is 24-32 basis points over 1994-2008.

[25] Recent studies that examine the role of forward guidance in affecting aggregate outcomes include McKay, Nakamura and Steinsson (2015), Gilchrist, López-Salido and Zakrajšek (2015), Justiniano et al. (2012) and others.

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

[27]I control for these changes in household size in order to obtain a measure of the individual's response, which maps most closely to standard macro models that do not model household formation separately.

by time, to capture the fact that there may be correlations across households in their changes in consumption since the monetary policy shocks are aggregate.[28]

I denote expansionary and contractionary monetary policy shocks by ϵ^-_{t-k} and ϵ^+_{t-k}, respectively. The expansionary shock $\epsilon^-_{t-k} = \min(\epsilon_{t-k}, 0)$, and the contractionary shock $\epsilon^+_{t-k} = \max(\epsilon_{t-k}, 0)$. I estimate the effects of positive and negative shocks on consumption separately to allow for differences in the response of consumption to the sign of monetary policy shocks. This specification is motivated by a number of potential mechanisms that may have asymmetric effects for rises and declines in interest rates, such as asymmetric borrowing constraints and refinancing decisions.[29] The β_k and γ_k coefficients give the change in the growth rate of consumption in period $t+k$ given a one percentage point expansionary and contractionary monetary policy shock, respectively, at time t. The consumption elasticity T periods after an expansionary shock is given by:

$$\frac{\partial \ln C_{h,t+T}}{\partial \epsilon^-_t} = \sum_{k=1}^{T} \frac{\partial \triangle \ln C_{h,t+k}}{\partial \epsilon^-_t} = \sum_{k=1}^{T} \beta_k. \tag{3}$$

Similarly, the consumption elasticity to a contractionary shock after T periods is given by

$$\frac{\partial \ln C_{h,t+T}}{\partial \epsilon^+_t} = \sum_{k=1}^{T} \frac{\partial \triangle \ln C_{h,t+k}}{\partial \epsilon^+_t} = \sum_{k=1}^{T} \gamma_k. \tag{4}$$

Equations 3 and 4 give the change in the conditional expectations of consumption after T periods, given a monetary policy shock at time t.

To explore heterogeneity in consumption responses over the life-cycle, I further condition on the age of the head of household. Formally, I estimate:

$$\begin{aligned} \triangle \ln C_{ht} = b_0 &+ \sum_{k=1}^{K} \beta^a_k \cdot \epsilon^-_{t-k} \cdot \text{Age}_{h,t-k} \\ &+ \sum_{k=1}^{K} \gamma^a_k \cdot \epsilon^+_{t-k} \cdot \text{Age}_{h,t-k} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \end{aligned} \tag{5}$$

X_{ht} denotes household-level controls, which include changes over the quarter in employment status, marital status and family composition. I control for seasonality and household-specific interview fixed effects. Age_{ht} is a vector of age-group dummies referring to the age of the household head.

[28] I also considered clustering by age group, to capture the potential correlations in consumption across the life-cycle. Clustering by age group gave tighter standard errors than clustering by time period.

[29] Not allowing for potential asymmetry would potentially downward bias the estimates towards zero in, for instance, cases where households respond to interest rate declines but not interest rate rises. I also considered other non-linearities and functional forms, such as by size of the shock. However, I did not find the non-linearities to be statistically significant. Part of the reason for this could be that the sample of shocks is relatively short and there magnitude of shocks is not dispersed enough to precisely identify non-linearities with size.

In the base results, I define young individuals as those aged 25-35 years, as this is the primary age range for first-time home purchases. Middle aged is defined as 36-64 years, and old individuals are those between ages 65 and 75.[30] Defining age groups in this way captures any differential consumption response to interest rate shocks that may be related to home-ownership decisions.[31] I also consider narrower groups based on 10-year age ranges using the Nielsen Homescan data, which has a larger number of households.[32]

3.3 Estimating the effects on mortgage rates and loan adjustments

One reason why the consumption response of young and old people differ is that they can vary in their decision to adjust their loans after interest rate shocks. Under fixed rate mortgage contracts, the nominal interest rate resets only if the households enters a new loan or refinances an existing mortgage. The household can also borrow more without increasing their interest payments under a lower mortgage rate (i.e. cash-out refinancing), which boosts their consumption.[33]

I first estimate the change in mortgage rates to monetary policy shocks. Formally, I estimate the change in the mortgage rate following a monetary policy shock based on the regression:[34]

$$\triangle R_t = b_0 + \sum_{k=1}^{K} \beta_k \cdot \epsilon^-_{t-k} + \sum_{k=1}^{K} \gamma_k \cdot \epsilon^+_{t-k} + \eta_t. \tag{6}$$

$\triangle R_t$ denotes the change in the average mortgage rate in quarter t; ϵ_t denotes the monetary policy shock at date t, and η_t denotes the residual. I consider two types of monetary policy shocks: surprises in the current monthly rate, and surprises in the path of the futures rate.[35]

I then examine the propensity of the household to enter a new home loan or refinance their existing loan into the lower mortgage rate, after an expansionary monetary policy shock. Formally,

[30] The broad age ranges also ensures that there is a sufficient number of households to reliably estimate age-specific responses using the CEX data set.

[31] This follows the approach of Hurst et al. (2015) who examine the effect of GSE policies on the young, middle age and old households.

[32] We can also omit one of the age groups interacted with the shocks. We can then include time fixed effects to capture any aggregate time-varying factors. The results are robust this specification, consistent with the assumption that the shocks are exogenous to aggregate factors affecting the differences in consumption response by age.

[33] For instance, Mian and Sufi (2014) and Mian, Rao and Sufi (2013) exploit county-level variations in house price elasticities to show that cash-out refinancing by households can lead to increases in consumption. Hurst and Stafford (2004) also show that households refinance existing mortgages to smooth consumption when faced with income shocks.

[34] The regression specification follows the high-frequency identification literature, which estimates the changes in asset returns in the period after the shock. Some recent examples include Gertler and Karadi (2015), Gorodnichenko and Weber (2015), and Nakamura and Steinsson (2015).

[35] The path shock is based on the GSS decomposition.

I estimate a linear probability model of loan adjustment:[36]

$$P_{ht} = b_0 + \sum_{k=1}^{K} \beta_k^a \cdot \epsilon_{t-k}^- \cdot \text{Age}_{h,t-k} + \sum_{k=1}^{K} \gamma_k^a \cdot \epsilon_{t-k}^+ \cdot \text{Age}_{h,t-k} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \tag{7}$$

P_{ht} is an indicator equal to one if household h adjusts their loan in quarter t. The monetary policy shocks are denoted by ϵ_{t-k}^+ and ϵ_{t-k}^-. X_{ht} denotes household-level controls: changes over the quarter in employment status, marital status and family composition. $\lambda_{s(t)}$ denotes seasonality fixed effects. Age_{ht} is a vector of age-group dummies (25-35, 36-64, and 65+) referring to the age of the household head. The variable of interest is β_k^a, which effect of a 1 percentage point expansionary shock on the loan adjustment propensity for people in age group a. Equation 7 is estimated using the CEX detailed expenditure data.

In addition to the age-specific propensities, I also explore the relationship between loan size and loan adjustment propensities (in appendix H).

4 Empirical Results

My four main empirical results are: (1) expansionary monetary policy shocks have large and persistent effects on consumption; (2) the aggregate consumption response is driven by the response of young people, which is significantly larger than that of older people; (3) the consumption response of homeowners who adjust their loans after monetary policy shocks is significantly larger than that of renters and homeowners that do not adjust their loans; and (4) young people have a higher propensity to adjust their loans following interest rate shocks, which contributes towards their higher consumption elasticity. The heterogeneity highlights the correlation between loan adjustment decisions and spending propensities by age for understanding aggregate consumption responses. My empirical findings then motivate the set-up of the theoretical model, which is used to understand the monetary transmission mechanism.

4.1 The Consumption Response

Table show the aggregate response overall. We can observe large, significant responses to expansionary monetary policy shocks.[37] The magnitudes of the consumption response based on the CEX data are within the ranges to elasticity estimates in the literature, which are based on aggregate

[36] Alternative specifications include probit and logit regressions.

[37] In the appendix, I provide estimates on consumption response regressed on forwards of the monetary policy shock. This provides a useful test of the exogeneity of the measured shock. Appendix Table **??** confirms that consumption does not have a statistically significant response to future monetary shocks.

output data.[38] The estimates are larger for total expenditure (durables and non-durables) than non-durables, reflecting larger responses of durable expenditures. The response to contractionary monetary policy shocks is statistically indistinguishable from zero.[39] Given the clear evidence of the expansionary effects on consumption, I focus the discussion on the heterogeneous consumption responses to expansionary interest rate shocks.

Total consumption elasticities by age

My second empirical result is that the response of consumption of young people is significantly larger than that of older individuals, and accounts for most of the aggregate response. This finding is seen in Table 2, which summarizes average annual responses of consumption to an expansionary monetary policy shock by age. Young people adjust their non-durable consumption by around 1-2 percentage points more than middle aged and older people. The consumption elasticity of the young is about twice as large as the average elasticity. The difference between the response of the young to the response of the middle and the old is statistically significant and lasts for about 1-2 years (Figure 1).[40] In contrast, the consumption responses of the middle and the old are statistically indistinguishable from each other. The decline in the consumption elasticities by age is also observed if households are partitioned into finer age groupings using the larger panel of households in the Nielsen Homescan data (Table 2).[41] Consumption elasticities decline by age, from an annual elasticity of 1.31 percent to 0.28 percent.[42] The finding that the decline in consumption elasticities by age is more pronounced for durables than non-durables.

The finding that consumption elasticities decline with age is also robust to different measures of monetary policy shocks. The previous results were based on a measure of the current period shock over the quarter. In Appendix Figure **??** , I show the consumption responses to long-term measures of a monetary policy shock, such the long-term "path" shock, based on the GSS decomposition. I find that the heterogeneity in consumption responses is more pronounced for long-term shocks than the quarterly shocks. This may reflect the greater persistency of the long-term path shock

[38] see for instance Barakchian and Crower (2013), Romer and Romer (2004), and Cloyne and Surico (2015).

[39] The wide standard errors reflect, in part, the smaller number of contractionary shocks that occurred during the sample period. There were 20 contractionary shocks during the sample period, which is less than half of the number of expansionary shocks.

[40] As mentioned above, the heterogeneous results are for expansionary monetary policy shocks. I focus the discussion on the expansionary shocks because the sample period has large number of shocks, while there are relatively few contractionary shocks which makes it difficult to precisely estimate the responses empirically. In the appendix, I provide estimates of the differences in consumption responses by age groups for contractionary shocks. The differences in responses are statistically insignificant. I come back to the interpretation of the contractionary shocks in the quantitative model section.

[41] I do not look at finer age groupings for the CEX data due to sample size considerations. Since the Nielsen data has a larger number of households in each period, I explore finer age groupings with this data.

[42] In Section 1.1 of the online Appendix, I show robustness of the results to different age group definitions. The age-specific results also distinct from cohort effects – the latter refers to the birth cohort. The finding that the young respond more than the old holds even after controlling for cohort fixed effects interacted with the monetary policy shocks. The estimated elasticities are depicted in the Appendix Table **??**.

on interest rates. Similar results can be seen with other measures of long-term shocks, such as the change in the two-year Treasury rate.

Contribution to aggregate consumption response

Given the heterogeneity of consumption responses by age and the large projected demographic shifts in the population structure, a natural question to ask is how much each age group contributes to the aggregate consumption response. I compute the percentage point and percent contributions of each age group to the aggregate elasticity in Table 3 columns (III) and (IV), respectively. Each age group's percentage point contribution is computed as the product of the age group's consumption elasticity (I) and its share of overall consumption (II).

Younger people drive the majority of the aggregate consumption response. The consumption response of young people accounts for 70 percent of the aggregate consumption response. The large contribution reflects the fact that they have a consumption elasticity that is about twice as high as the average person. In comparison, the consumption response of the middle aged to a monetary policy shock account for 30 percent of the aggregate total consumption elasticity. Older individuals do not contribute very much towards the aggregate consumption response.

The differences in elasticities imply that shifts in demographics can potentially have noticeable effects on the aggregate consumption response. A simple exercise that changes the population weights to the 2060 U.N. projected distribution (and thus column II), holding fixed the consumption elasticities, would imply a decline of 10-20 percent in the aggregate response to a same-sized monetary policy shock, depending on the assumption about fertility. This exercise, however, ignores the fact that the household's consumption elasticities may also change, as they re-optimize their consumption and savings profiles under a older population structure and longer life-expectancy. Therefore, I develop a theoretical framework that endogenizes the consumption and savings decisions, to estimate the impact of demographics on the aggregate transmission to consumption.

4.2 Loan adjustment decisions

In this section, I provide evidence that loan adjustment decisions (related to housing purchases and refinancing of existing mortgages) are important for explaining the variations in consumption responses by age. The monetary transmission depends on: (i) the pass-through to mortgage rates, which in turn depends on whether the household refinances or enters a new mortgage at the current rate, and (ii) the fraction of mortgage or rental savings that the household chooses to consume. Recent studies have focused on the latter, taking as given a change in the individual's mortgage rate.[43] This paper builds on these studies by examining the individual's decision to change their

[43] For instance, Di Maggio et al (2016) and Keys et al (2016) exploit the change in the outstanding auto loan balance following anticipated rate resets on adjustable rate mortgages to measure the consumption response.

rates (i), and how this correlates with the propensity to spend (ii). I highlight a novel feature of 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. The correlation between spending coefficients and refinancing decisions is a specific form of the correlation explored in Auclert (2016).

I first provide some summary statistics on housing and mortgages over the life-cycle. Second, I then show that monetary policy shocks do affect long-term mortgage rates, consistent with existing literature. Third, I show that the consumption response of homeowners who adjust their loans following monetary policy shocks is significantly larger than that of renters and homeowners who do not adjust their loans (my third empirical result). I provide evidence that young people have a higher propensity to adjust their loans following interest rate shocks, which boosts their consumption relative to the old. In the Appendix, I also provide empirical evidence on the response of labor income to the monetary policy shocks. The magnitudes are smaller than that of consumption, which suggests that labor income differences alone cannot fully explain the heterogeneity in the data. In the model section, I then quantify the importance of the housing and mortgage channel, relative to other channels, for explaining the empirical heterogeneity in consumption responses.

Housing and mortgage characteristics by age

Some well-known life-cycle characteristics can be observed in Table 4. First, the home-ownership rate rises significantly with age, from 48% for young people to 78% for older individuals. In comparison, the fraction of households with a mortgage is much lower for the old (22%), relative to the middle (54%) and young (43%), reflecting the fact that a large share of older homeowners have paid off their mortgages.

Second, the median loan size and duration is significantly larger for young people, and declines with age as households pay down their loan over time. The median loan size of young people is 1.8 times the loan size of older individuals, and 11 years longer in duration. Younger people also have a higher credit utilization on their short-term credit, which is consistent with existing studies that highlight the correlation between age and liquidity constraints.

Lastly, the majority of U.S. mortgages are at fixed rates, with little difference in the share of fixed-rate mortgages across the age groups. This suggests that the heterogeneity in age-specific consumption responses is not driven by differences in the types of loans by age.

Response of mortgage rates

I find that monetary policy shocks significantly affect mortgage rates. Table 5 decomposes the effect of the monetary policy shock into two components: surprises in the current quarterly rate (columns I), and surprises in the path of the futures rate (columns II).[44] These results are

[44]The decomposition is based on the GSS target and path shocks, described in Section 3.

consistent with Gertler and Karadi (2015) and Hamilton (2008), who also document significant effects of monetary policy shocks on long-term rates.[45]

One concern that we might have is that the pass-through may be capturing slow-moving declines in the mortgage rates since the 1990s. If the policy shocks are not truly exogenous and the size of the shocks are positively correlated with the trend decline in mortgage rates, then the estimated pass-through may be biased upwards. To allow for this possibility, all regressions include year indicator variables to control for possible trend effects. The results are also qualitatively robust to other non-linear specifications of the trend, such as quadratic year effects.

Consumption elasticities and loan adjustment decisions

A key characteristic of fixed-rate mortgages is that the interest rate is fixed over the life of the loan. This means that monetary policy shocks only affect the household's nominal interest rate if they decide to adjust their loan by entering a new mortgage or refinancing an existing loan. If the household is not at their borrowing constraint, they can also increase the amount borrowed without changing their mortgage payments, when interest rates decline.[46]

I explore the implications of the household's loan adjustment decision for consumption. To do so, I divide 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) households that are renters. I define a loan adjustment as a new mortgage transaction, due to new borrowing or refinancing of existing loans. For each of these sub-samples, I estimate the consumption elasticities to interest rate shocks (based on Equation 5).

My third empirical result is that homeowners increase their consumption following an expansionary monetary policy shock, while the consumption response of renters is statistically insignificant (Table 6). Individuals who adjust their loans increase their consumption by about 5 percentage points (about \$120 per quarter) more than the response of those that do not adjust their loans.

My forth empirical result is that there is a higher fraction of the young households who adjust their loans after expansionary monetary policy shocks within the first year (annual fraction of 38%, relative to 12% and 7% for middle aged and old people, respectively, Table 7).[47] This highlights a novel feature of the mechanism – that is, those who adjust their loans tend to be younger in age. These younger individuals on average have higher consumption elasticities and have a much higher level of short-term credit utilization.

[45] These studies show that short-term shocks can affect long-term yields through changing expectations and/or through risk premia. See Gertler and Karadi (2015) for a more detailed discussion.

[46] The notion of cash-out refinancing and the implications for consumption are also discussed in Mian and Sufi (2014) and Mian, Rao and Sufi (2013).

[47] These propensities are estimated based on Equation 7 using the CEX data over the sample period 1993-2007.

In the Appendix, I show using the Freddie Mac data, that households with larger loan sizes have higher loan adjustment propensities after interest rate declines. In the data, young people that have larger loan sizes. This is seen in the median loan size statistics in Table 4. The reason is that individuals take out a mortgage to purchase their home, which is paid down over time. Older people have lower loan balances since part or all of the loan has already been paid down.

The empirical results contribute to the literature that highlight an important role of mortgages for the monetary transmission to consumption.[48] While Keys et al. (2014) and Di Maggio, Kermani and Ramcharan (2014) examine the response to an 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 than 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.

Regional variations in responses and local area demographics

As robustness to the household-level analysis, I also examined variations in consumption responses and age-specific demographics across MSA regions in Appendix I using the Nielsen data. Specifically, I show that local area consumption in regions with a higher old-to-young ratios change by less in response to monetary policy shocks than states with lower old-to-young ratios.

5 Model

In this section, I build a household model of housing and mortgage decisions that is able to generate the key empirical results in Section 4, and use it to draw inferences for the national economy. 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.[49]

The model contains two key features. First, individuals pay a fixed cost to adjust their long-term assets.[50] Fixed 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 their loan. The balance of the loan is amortized over the life of the individual.

[48] See, for instance, Keys et al. (2014) Di Maggio, Kermani and Ramcharan (2014), Cloyne, Ferreira and Surico (2015), and Beraja and Vavra (2017).

[49] The latter is important for generating age-specific consumption responses to interest rate shocks.

[50] This builds on the recent work that models liquid and illiquid assets separately, such as Alvarez, Guiso and Lippi (2012), Alvarez and Lippi (2009), Abel, Eberly and Panageas (2009), Kaplan and Violante (2014), and others.

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 the adjustment costs are fixed. In the model, young people have larger loan sizes and longer durations, and therefore have 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. As discussed more below, in the presence of fixed costs, there exists 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 the mechanisms that generate the heterogenous responses. The structural 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. My data alone is not sufficiently rich to completely rule out other potential mechanisms that affect consumption. For instance, the CEX data has sparsely information on short-term financial asset holdings and does not have high frequency labor income data. Distinguishing between the factors affecting consumption is relevant for assessing whether the same shock will be more or less effective under different macroeconomic conditions. In the Appendix, I also use the model to quantify the potential effects of demographic shifts on the aggregate consumption response to monetary policy shocks.

5.1 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. They work for the first T_y periods, and retire thereafter.

Assets Agents can choose to hold three types of assets: (i) saving via a 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 rent at price p^r_t. Owned housing stock depreciates at a rate of δ each period.

I assume the mortgage is amortized over the life of the agent.[51] The duration of a new loan for an agent aged a is $d(a) = T - a$. The fixed rate $R_{ja0} = r_t^{d(a)}$, the current market mortgage rate with a $d(a)$ duration. The loan balance b evolves as

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

where the initial amount borrowed b_{ja0} and the mortgage payment M_{ja0} satisfies[52]

$$b_{ja0} = M_{ja0} \left[\sum_{k=1}^{d(a)} \frac{1}{(1 + R_{ja0})^k} \right]. \tag{8}$$

While the stock of rental housing can be freely adjusted each period, I assume a lump-sum transaction cost of F applies when the household enters a new loan or refinances an existing mortgage. Upon refinancing, the mortgage rate is reset and the household can also choose a new mortgage 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. If the loan is refinanced, the new fixed rate is the current market mortgage rate in that period. The mortgage rate can be expressed recursively as

$$R_{j,a+1,t+1} = r_{t+1}^{d(a+1)} \cdot 1(\text{refi})_{t+1} + R_{jat} \cdot [1 - 1(\text{refi})_{t+1}] \tag{9}$$

where the variable $1(\text{refi})_{t+1}$ equals one if the agent refinances in period $t+1$ and zero otherwise.[53]

[51] Papers, such as Campbell and Cocco (2003) and Kaplan, Mitman and Violante (2015), also assume loan amortization of the life of the agent. This assumption is motivated by the empirical observation that the loan durations decline with age. 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.

[52] Note, at each point in time, the duration of the loan is known given the age of the person, since the loan is amortized over their life. Thus, the constant mortgage payment M_{jat} is known, given the balance and mortgage rate. It can be computed, based on Equation 8, as

$$M_{jat} = b_{jat} \left[\sum_{k=1}^{d(a)} \frac{1}{(1 + R_{jat})^k} \right]^{-1}$$

[53] If we also include a mortgage payment-to-income constraint, as in Greenwald (2017), this would amplify the heterogeneous results even more. This is because the 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.

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

$$\log(y_{jat}) = \chi_a + \eta_{jat} + \phi_a(y_t) \tag{10}$$

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 $N(0, \sigma_\eta^2)$;[54] 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).

Aggregate shocks to the economy In addition to idiosyncratic income shocks, households also face exogenous aggregate shocks. The vector S_t of aggregate variables include log of real aggregate income $\log y_t$, 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[56]

$$S_t = A_0 + A_1 S_{t-1} + u_t \tag{11}$$

where u_t is the residual, which is normally-distributed with mean 0 and variance-covariance V.

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:

$$r_t^d = f^d(S_t) \tag{12}$$

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

$$\log(p_t^r) = f^{pr}(S_t) \tag{13}$$

5.2 Recursive formulation

For notational clarify, I drop the agent and age indices when describing the household's problem. Each period, households choose whether (i) to rent, (ii) to continue owning their same home and

[54]The idiosyncratic income shocks are important for at least two reasons. First, the idiosyncratic shocks generate a dispersion of households income within age groups. This makes it is 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.[55] Both of these factors are important for generating the heterogeneous consumption responses by age following interest rate shocks (discussed further in Section 7).

[56]This follows the approach in a number of models, including Hurst et al. (2015), Kaplan, Mitman and Violante (2015) and Chen, Michaux and Roussanov (2013), who also specify an AR(1) process of the economy.

not adjust any existing mortgage, or (iii) to adjust their mortgage and housing stock. The adjusters include those homeowners who went from being renters to a homeowner and those who were homeowners in both periods. Households also choose their consumption, savings in liquid one-period bonds, and mortgage debt.[57] 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.[58]

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

$$V(z) = \max\left\{V(z)^{\text{rent}}, V(z)^{\text{own \& no-adjust}}, V(z)^{\text{own \& adjust}}\right\} \tag{14}$$

$$\begin{aligned} V(z)^{\text{rent}} &= \max_{c, h^{\text{rent}}, s'} u\left(c, h^{\text{rent}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' + p^r h^{\text{rent}} &= y + (1-\delta) p h^{\text{own}} + (1+r)s - b(1+R) \\ h'^{\text{own}} &= b' = 0, \quad s' \geq -\underline{s} \end{aligned} \tag{15}$$

and Equations 11-13 for income and aggregate state processes, mortgage yields and rental rate.

$$\begin{aligned} V(z)^{\text{own \& no-adjust}} &= \max_{c, s'} u\left(c, h^{\text{own}}(1-\delta)\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' &= y + (1+r)s - M \\ b' &= b(1+R) - M, \quad s' \geq -\underline{s}, \quad R' = R \end{aligned} \tag{16}$$

and Equations 11-13 for income and aggregate state processes, mortgage yields and rental rate. The mortgage payment M follows Equation 8.

$$\begin{aligned} V(z)^{\text{own \& adjust}} &= \max_{c, s', h'^{\text{own}}, b'} u\left(c, h'^{\text{own}}\right) + E\left[V(z')\right] \\ \text{s.t. } c + s' + p h'^{\text{own}} - b' + F &= y + (1-\delta) p h^{\text{own}} + (1+r)s - b(1+R) \\ b' &\leq (1-\phi) p h'^{\text{own}}, \quad s' \geq -\underline{s}, \quad R' = r^d \end{aligned} \tag{17}$$

and Equations 11-13 for income and aggregate state processes, mortgage yields and rental rate. F is the fixed cost of adjusting the loan.

The problem for a retired household is identical, except that social security benefits replace

[57] The household problem is solved recursively. Section 1.3 of the online appendix describes the model computation.

[58] In the model, I focus on owner-occupied decisions and abstract from housing investment decisions by assuming that households cannot both rent and own a house.

labor earnings. Upon death, the agent bequeathes total net wealth $W = (1-\delta)ph^{\text{own}} + (1+r)s$ which gives utility $B\left(W_{jat} - 1\right)^{1-\sigma} / (1-\sigma)$. B is the bequest utility parameter.

5.3 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 U.S. actuarial life-expectancy tables and assume a maximum age of $T = 85$.[59] 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 SCF. I set $\sigma = 2$ and I follow Cocco, Gomes and Maenhout (2005) in setting the bequest parameter $B = 2$.

The discount rate β and the utility parameter α are estimated to target the homeownership rate and the total (non-retirement) wealth to income ratio for the working age of 2.3 from the SCF data in 2007. These targets yield $\beta = 0.962$ and $\alpha = 0.88$. The fixed cost of transaction F is calibrated to target the average annual fraction of loans that are refinanced. I use the Freddie Mac pool of mortgages to obtain a quarterly refinancing fraction of 4.5 percent over 1999-2007.[60] This yields a transaction cost of approximately $F = \$5K$, which is approximately 2.8 percent of the median house price in the model. I interpret the fixed costs as inclusive of both monetary and non-monetary costs involved in refinancing a mortgage or entering a new loan. I initialize households in the model to match the distribution of income, liquid wealth net of debt, and housing for 25- to 30-year-old households in the SCF.

Income I follow Floden and Lindén (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 PSID. The process is discretized with two states using the Tauchen method. I set the deterministic age-specific vector χ_a equal to the average log earnings for each age from Guvenen et al. (2015).[61] I set the parameter ϕ_a based on the correlation between real aggregate income per capita and age-specific earnings in the CPS (see the Appendix for more detail). Table 8 shows a higher exposure of the earnings for young workers relative to the middle aged workers.[62]

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

[60] The data is from the Freddie Mac Single Family Loan-Level database, 1999-2014.

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

[62] The findings are consistent with Jaimovich and Siu (2009), Ríos-Rull (1996) and others, who show that younger and older workers have relatively higher cyclical volatility in hours worked than the middle aged workers.

Aggregate variables The parameters on the aggregate variables (income, house prices and short-term interest rate) in Equation 11 are exogenously set based on estimated coefficients from a reduced-form quarterly VAR of these variables over the period 1984-2007.[63] Table 9 gives the coefficient estimates and the variance-covariance matrix of the residuals u_t. These residuals are multi-normal with mean 0 and variance-covariance V. The aggregate processes are discretized with 18 states using the Tauchen method.

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 and risk premia arising from shocks to the aggregate economy, without introducing additional states into the computation of the model. Formally, I specify

$$r_t^d = a_0 + a_1 r_t + a_2 \log y_t \tag{18}$$

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 18 for the 30-year, 15-year and 1-year real mortgage rates. I deflate the nominal mortgage rate using the break-even inflation rate implied from Treasury inflation protected bonds.[64] I then interpolate the mortgage rates with durations between 30, 15 and 1 year.[65] Coefficients are in Table 10.[66]

I set the housing depreciation rate δ to 3 percent to match the average ratio of residential investment to the residential stock in BEA data. I set $\phi = 0.2$ so that households are required to have a minimum 20 percent down-payment, in line with Keys et al. (2014), Landvoigt, Piazzesi and Schneider (2015) and many others. The short-term asset borrowing constraint is set to 0. The house price-to-rent ratio is assumed to depend on the aggregate state of the economy:

$$\log(p_t^r) = \alpha_0 + \alpha_1 r_t + \alpha_2 \log y_t + \alpha_3 \log p_t \tag{19}$$

I estimate Equation 19 using the national house price and rent indices obtained from the Dallas Federal Reserve. See Column (III) of Table 10 for the regression coefficients.[67]

[63]The data on income and interest rates are obtained from the Federal Reserve Board.

[64]These data are available on the Feds website at http://www.federalreserve.gov/pubs/feds/2008/200805/200805abs.html. TIPS were first issued in 1997, but the market was initially illiquid (as discussed in Nakamura and Steinsson (2015)). Therefore I use data from 2003 onwards to avoid relying on data from the period when TIPS liquidity was limited.

[65]I assume the yield curve beyond 30 years is flat, consistent with the flattening of the yield curve in the data.

[66]An alternative approach would be to define a term structure that relates the mortgage yield curve to expectations about the paths of both the nominal interest rates and inflation. 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, and therefore define the relationship based on empirically estimation of Equation 18. In Section 1.4 of the online appendix, I provide evidence that the specification in Equation 18 is a good approximation of the actual mortgage rate dynamics.

[67]An alternative approach would be to specify the rental rate based on a no-arbitrage condition within the housing market. I find the dynamics of the house price to rent ratio match the data better under the current approach. In

6 Model Fit and Computational Experiments

Model Fit The estimated model fits key non-targeted life-cycle moments well. Figure 2 shows the life-cycle profiles in the model compared to the data from the 2004 U.S. Survey of Consumer Finances (SCF) asset profiles and consumption profiles. The model captures the hump-shaped profile of non-durable consumption, the rising profile of total wealth to income (reflecting the rise in housing wealth over the life cycle), and the decline in household debt holdings over the life-cycle.

Monetary Policy Experiment I use the model to quantify how much of the differences between the consumption responses of the young and old to expansionary monetary policy shocks is due to the refinancing and home-ownership channel. 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 allow the sign of the monetary policy shock to have a different contemporaneous effect on the aggregate variables, by assuming

$$u_t = \Gamma_0 + \Gamma^+ \epsilon_t^+ + \Gamma^- \epsilon_t^- + \psi_t \tag{20}$$

where $\epsilon_t^+ = \max(\epsilon_t, 0)$ and $\epsilon_t^- = \min(\epsilon_t, 0)$ denotes the expansionary and contractionary monetary policy shocks, respectively. I set the Γ parameters based on empirically estimated coefficients. Formally, I regress the residuals u_t on the Federal Funds futures shocks (identified in Section 2).[68] The parameter coefficients are presented in Table 11. Figure 3 shows the pass-through to the short-term interest rate, aggregate income, and prices after a 1ppt expansionary monetary policy shock. The short-term interest rate declines upon impact, aggregate income falls, while house price growth and the price-to-rent ratio 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 home-ownership responses to a realistic monetary policy shock.

Section 1.4 of the online appendix, I plot the predicted values of house prices and rental ratios in the data.

[68] 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 Equation 20. This assumption is plausible since the Federal Funds futures shocks were identified within a narrow window around the FOMC announcements, and so the only shock identified within that period are likely to be monetary policy shocks. See Section 3 for more discussion on the construction and identification of these shocks in the data. Note that 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 on the aggregate variables.

Consumption Responses I compute the consumption impulse response functions as the average percentage change in consumption under an interest rate shock, relative to the case with no shock. Formally, the impulse response function after k periods to a one-standard deviation expansionary shock at time t is computed as

$$IRF(k) = E_t[\ln C_{t+k}|\epsilon_t = -\sigma_\epsilon, \psi_t = 0] - E_t[\ln C_{t+k}|\epsilon_t = 0, \psi_t = 0].$$

Table 12 depicts the response of aggregate consumption to an expansionary shock and a contractionary shock in the model, and the estimated response from the data.[69] There is a pronounced and persistent effect of monetary policy shocks on aggregate consumption. Consumption rises by a peak of around 1.8 percent, which is statistically indistinguishable from the empirically estimated response functions.[70]

There is also significant heterogeneity underlying the aggregate consumption response to interest rate shocks. The model is also able to generate heterogeneous responses by age that are in line with the data. Figure 4 shows that young people adjust their consumption by more than old individuals. The model responses are statistically indistinguishable from the empirical estimates.

Heterogeneity in Refinancing and Homeownership Decisions The model is also able to generate the empirical finding that younger people are more likely to adjust their loans (either refinancing or entering new loans) than older people following an expansionary monetary policy shock. The average fraction of young people that adjust their loans over the year in the model is in line with the estimated responses in the data (Figure 5) and Table 13.

An important reason for why young people have a higher propensity to refinance is the presence of fixed costs of mortgage adjustments. In deciding to adjust an existing mortgage or not, the household compares 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 14 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.[71] The refinancing channel does not exist in standard models with variable mortgages. In these models, interest rate shocks pass through to all mortgages.[72]

Besides having a higher propensity to refinance (line 1 of Table 13), the young are also more likely to spend a greater share of the additional cash from savings on payments and any home

[69]The empirical impulses responses are from Section 4, cumulated to an annual frequency.

[70]These aggregate impulse response functions for consumption are not targeted in the model, and therefore provides a validation of the model specification.

[71]The intuition is that effectively the cost is spread out over a larger loan size and duration.

[72]A similar effect arises for homeownership decisions. The decision to become a new homeowner and therefore enter a new mortgage affects the payments paid on the housing services. Evidence of the increase in consumption following the switch from renter into homeownership is given in Agarwal et al. (2015).

equity extraction. The spending coefficient is around 0.8 percent, while the middle and old are less than 15 percent (Table 13). The implied dollar difference in consumption for those who refinance and those who do is about $2,600 over the year for the young. This highlights a correlation between those who are more likely to refinance (the young) and their propensity to spend, which contributes towards the overall aggregate consumption response to monetary policy shocks.

Another way of seeing how short-term liquidity constraints interacts with refinancing decisions by age is to examine the refinancing decisions across the distribution of short-term liquid wealth (Figure 6). The left panel shows that the fraction of loans refinanced declines as the household's liquid asset holdings rises, following an expansionary monetary policy shock. The right panel plots the average age of household by liquid asset holdings. The two panels highlight the correlation between refinancing decisions and potential propensity to spend out of additional income by age.

The model provides insight into the large consumption responses of younger people. In the model, there is a larger portion of young people who are short-term liquidity constrained, but not against their long-term mortgage constraint. In the presence of fixed transaction costs, these individuals do not always choose to refinance their mortgage to access their home equity by borrowing more via their mortgage balance. However, when interest rates decline, this boosts the incentive to adjust their loans, since loan adjustments lowers mortgage payments and releases home equity. The correlation between those who adjust their loans and those with liquidity constraints generates leads to large consumption responses in the aggregate that are consistent with the data. This relates to Auclert (2015), who highlights the importance of the correlation between unhedged interest exposures and marginal propensities to consume for the aggregate response. The analysis here differs in that it highlights the loan adjustment decision by age.

Of course, the refinancing channel is not the only difference in the model that drives why young respond more than the old. Other forces in the model include larger labor income variation of the young, life-cycle and substitution motives. In the next section, I formalize the quantitative importance of the refinancing channel relative to these other channels for the explaining the heterogeneous consumption responses across the age groups.

Importance of the Refinancing and Homeownership Channel How important is the refinancing and homeownership channel for explaining the young-old difference consumption response to interest rate shocks? To quantify the importance of this channel, I shut down the refinancing decision and fixed mortgage structure, and re-estimate the model a variable rate mortgage structure, while keeping the calibrated parameters on the utility functions the same. There are no fixed transaction costs for adjusting either housing or mortgages, and the mortgage rates change for all households following the interest rate shock. Variations in the consumption responses by age arise from the income and substitution, labor income, wealth and life-cycle effects.

Figure 7 shows the consumption responses for different age groups, relative to old individuals, following an expansionary interest rate shock.[73] The grey line depicts the empirically estimated consumption response, and the blue dots reflect the results of the full model with fixed-rate mortgages. The full model with refinancing closely matches the consumption responses estimated in the data, which were not targeted in the model. The dashed line shows the predictions for the model without fixed-rate mortgages and transaction costs.

The difference between the full model and the variable mortgage rate model represents the effect of the refinancing channel. Figure 7 shows that relative to the oldest age group, the response of the younger groups (< 35, $35-44$ years) is about 0.8-0.9 percent higher, and the response of the middle groups ($45-54$ and $55-64$) is about 0.7 and 0.3 percent higher, respectively. When we exclude refinancing (i.e. assuming a variable mortgage structure) the difference in consumption response, relative to the old, declines for all age groups. Overall, the heterogeneity declines by about 50%. This implies that the refinancing channel explains around a half of the different in consumption responses between young and old, in response to interest rate shocks. The remaining half percent is accounted for the income and substitution effects, labor, wealth and life-cycle effects, which have been emphasized in existing literature on the redistributive effects of monetary policy.[74]

While the cross-sectional heterogeneity in responses in the economy with variable structure declines, the aggregate consumption response is higher (consistent with Auclert (2015), Garriga and Sustek (2017), and others). The aggregate response to a monetary policy shock is about 2.8 times higher in the economy with variable rate mortgages compared with the fixed rate mortgages, while the cross-sectional heterogeneity is about 50% less.

Aggregate Responses under an Older Demographic Structure The previous section showed that the model is able to generate the patterns of consumption responses to interest rate shocks, estimated in Sections 3 and 4. It predicts that the consumption of young people are significantly more responsive than old individuals, and drive the majority of the aggregate consumption response to expansionary interest rate shocks. These results imply that under and older demographic structure, the aggregate consumption response to interest rate shocks will become more muted as the housing and mortgage channels becomes weaker.

A simple exercise in Section 4, which changed the population weights to the 2050 U.N. projected population distribution (and therefore column II) and held fixed the consumption elasticities, would

[73] I focus on explaining the expansionary shock response, since that is where the consumption heterogeneity by age is most pronounced.

[74] Some examples of recent empirical studies include Adam and Zhu (forthcoming), Auclert (2015), Doepke, Schneider and Selezneva (2015), Meh and Terajima (2011), Sterk and Tenreyo (2015), Doepke and Schneider (2006*b*) and Doepke and Schneider (2006*a*).

imply a decline of 18 percent in the aggregate response to a same-sized monetary policy shock. This exercise, however, ignores the fact that the household's consumption elasticities may also change, as they re-optimize their consumption and savings profiles under an older population structure.

Changes in demographic structures can potentially have general equilibrium effects on the response of aggregate variables to interest rate shocks. For instance, under an older demographic structure, the average consumption elasticities is likely to be lower due to the greater contribution of old individuals (who have smaller elasticities). The impact on hours and wages from an interest rate shock may then be lower due to a more muted demand response. The lower employment effect can then in turn dampen the impact on the consumption of the young and middle aged who are still working, further reducing the aggregate consumption response to the initial interest rate shock.[75]

I therefore the analysis using the projected 2050 population structure and probabilities of survival, allowing for individuals to reoptimize their entire savings, borrowing and consumption profiles. Under this economy, the aggregate consumption result is about 28% lower. The results are little changed if I allow for different retirement ages (i.e. allowing individuals to work longer to 75, rather than 65, since they now expect to live longer). These results imply that population aging can significantly dampen the transmission of monetary policy to aggregate consumption.

I interpret these results are a potential upper bound on the effects of demographics of transmission of monetary policy. In the model, I abstract from other potential changes in the economy, such as the level of the interest rate, which can then have effects on the aggregate savings rates and capital accumulation.[76] My set-up also abstracts from possible changes to social security and fiscal policy when faced with an aging population. These fiscal policy responses could have implications for the transmission of monetary policy if it changes the way people choose to save over their life. Another potential change would be if older households begin to engage more in reverse mortgages, which allow them to extract more home equity. These reverse mortgages are predominately at variable rates. If older households engaged more in these types of debt, this would increase the sensitivity of the older individuals to interest rate shocks, offsetting some of the decline in consumption responses arising from aging. This paper abstracts from these debt, as it currently accounts for a very small fraction of the mortgage market. A full general equilibrium model is needed to capture these effects, which I defer for future research. Nonetheless, this stylized exercise provides a useful indication of the qualitative effects of aging on the transmission of monetary policy to consumption. It is also useful for understanding the effects of demographics on regional variations in the effects

[75] An alternative approach is to use state-level processes and relate the differences in processes to the local demographic structure. For example, California and Florida are two extremes of the state age distribution. I can then quantify the aggregate consumption responses to a monetary policy under two different economies. By specifying state-specific processes for interest rates and income, the model captures, in a reduced form way, potential general equilibrium effects on the labor market and interest rates. This exercise yields qualitatively similar results.

[76] See Auerbach and Kotlikoff (1985), Auerbach et al. (1989) and Ríos-Rull (2001).

of monetary policy for today's transmission mechanism.

7 Conclusion

In this paper, I address the question of how changes in demographic structure affect the transmission of monetary policy shocks to consumption. First, this paper provides new empirical evidence, using two sources of micro household-level data, that young people are more responsive than old individuals to interest rate shocks. The consumption elasticities of young people are significantly larger than that of the average person, and drive most of the aggregate response. The consumption responses are driven by homeowners with mortgage transactions. I estimate 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 the costs of refinancing remain 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 perform two exercises. First, I quantify the importance of the mortgage channel for explaining the consumption responses of the young-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 population aging can significantly dampen the transmission of monetary policy to aggregate consumption.

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8 Figures and Tables

Table 1: Consumption Response to a Monetary Policy Shock

	Expansionary		**Contractionary**	
	First year	Second year	First year	Second year
Total	1.92	4.31	3.77	10.77
	[0.25, 3.59]	[0.4, 8.22]	[8.35, -0.8]	[23.31, -1.76]
Non-durables	1.06	1.43	0.20	-4.58
	[0, 2.13]	[-1.07, 3.935]	[-2.62, 3.03]	[-12.32, 3.15]

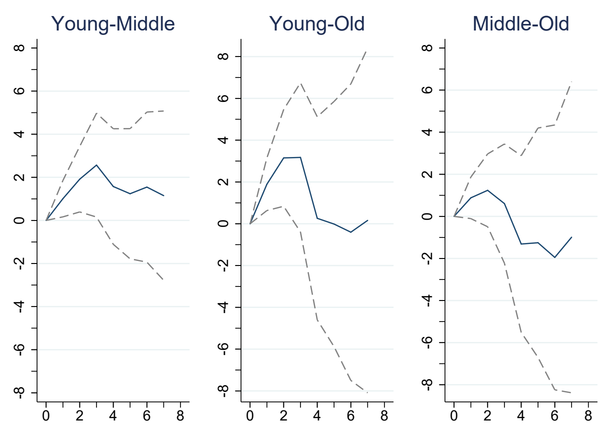
Notes: This table shows the annual elasticities of consumption to 1 standard deviation expansionary and contractionary monetary policy shocks. 80 percent confidence intervals are depicted in parentheses. The elasticities are estimated using the CEX data.

Table 2: Consumption Elasticities by Age

	Young 25-34		Middle 35-64		Old 65+
CEX data					
Total	4.59		0.79		-1.15
	[2.01 , 7.17]		[-1.44 , 3.02]		[-4.8 , 2.5]
Non-durables	2.24		0.47		0.12
	[0.67 , 3.82]		[-0.7 , 1.65]		[-1.83 , 2.07]
			Age groups		
	25-34	35-44	45-54	55-65	65+
Nielsen data					
Non-durables (food)	0.79	0.50	0.60	0.38	0.03
	[0.28, 1.31]	[0.21, 0.78]	[0.36, 0.83]	[0.14, 0.63]	[-0.23, 0.28]

Notes: This table shows the annual elasticities of consumption to a 1 standard deviation expansionary monetary policy shock, based on Equation 5. 80 percent confidence intervals are depicted in parentheses. The elasticities are estimated using the CEX data and the Nielsen Homescan data.

Figure 1: Difference in Consumption Response by Age Group



Notes: This figure depicts the differential impulse response function of non-durable consumption to a 1 standard deviation expansionary path shock for the young relative to the middle (left panel), young relative to the old (middle panel), and middle relative to the old (right panel). The dashed lines depict the 80 percent confidence intervals.

Table 3: Contribution by Age-group to Aggregate Consumption Elasticity

	Annual response	**Share of consumption**	**Contribution to total elasticity in ppt**	**Contribution to total elasticity % of total**
Current population				
Young	2.24	32%	0.72%	72%
Middle	0.47	57%	0.27%	27%
Old	0.12	11%	0.01%	1%
Average	**1.00**	**100%**	**1.00%**	**100%**
Population of 2060				
Young	2.24	24%	0.54%	66%
Middle	0.47	53%	0.25%	31%
Old	0.12	23%	0.03%	3%
Average	**0.82**	**100%**	**0.82%**	**100%**

Notes: This table shows the annual elasticities of consumption by age group in column (I). The elasticities are obtained by estimating Equation 5 separately for each consumption category using the CEX data. Column (II) shows each age group's the share of overall consumption within the consumption category. Column (III) and (IV) give the contribution of each age group to the total elasticity in percentage points and percent of total, respectively. Column (III) is computed based on the product of (I) and (II). (IV) is computed based on (III) divided by the total elasticity within each consumption category. The bottom panel shows a simple exercise that shifts the population to the U.N. projected 2060 population structure, holding all other factors constant (i.e. elasticities, the consumption per capita for each age group). See text for more detail.

Table 4: Homeownership and Mortgage Statistics

	Young 25-34	**Middle** 35-64	**Old** 65+
Homeownership rate	46%	72%	79%
Fraction with mortgages	42%	55%	23%
Median loan size	109,789	98,032	65,301
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.

Table 5: Response of Mortgage Rates to Monetary Policy Shocks

Policy shock	(I)	(II)
Current shock	0.392	
	[0.181 , 0.602]	
Long-term shock		0.243
		[0.031 , 0.454]
Trend controls	Yes	Yes
R squared	0.369	0.1123

Notes: This table shows change in the mortgage rates to a 1 percentage point monetary policy shock. The regressions are estimated over the available sample period 1999-2007 for the 30-year fixed mortgage rate from the Freddie Mac data. I consider two types of monetary policy shocks: the shock in the current quarter and the shock to the path of the Federal funds rate (the GSS path shock). Each row is based on a separate regression of the mortgage rate on the shock. 85% confidence intervals are in the parentheses.

Table 6: Annual Elasticities of Consumption

Adjust loan	Do not adjust loan	Renters
6.00	0.39	-0.68
[0.47 , 11.53]	[-1.57 , 2.36]	[-3.59 , 2.23]

Notes: This table shows the annual elasticities of non-durable consumption to a 1 standard deviation expansionary monetary policy shock, based on Equation 5. 80% confidence intervals are in the parentheses. The elasticities are estimated using the CEX data.

Table 7: Loan Adjustment Behavior by Household Age

	Young 25-34	**Middle** 35-64	**Old** 65+
Propensity to adjust loan following shock	0.10	0.03	0.02
	[0.125 , 0.076]	[0.032 , 0.025]	[0.025 , 0.009]
Average annual fraction of households:			
- Own housing and adjust loan	0.375	0.114	0.067
- Own housing and do not adjust loan	0.089	0.605	0.719
- Renters	0.536	0.281	0.214

Notes: This table shows the average annual propensity to adjust a loan (given the household owns a home) by age. 80% confidence intervals are in parentheses. The elasticities are estimated using CEX data (1993-2007).

Table 8: 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 ϕ_a for each age group a from Equation 10. This is obtained from an 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. See text for more detail.

Table 9: Aggregate Processes: Coefficients

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 11. The variables $\log y_t$, $\log p_t$, and r_t denote the log income per capita, log house prices and the 3-month interest rate, respectively. See text for more detail.

Table 10: 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	3.093	0.843
r_t	0.334	0.392	0.415	-0.002
$\log(p_t)$				-0.022
constant	-0.030	-0.029	0.027	3.187

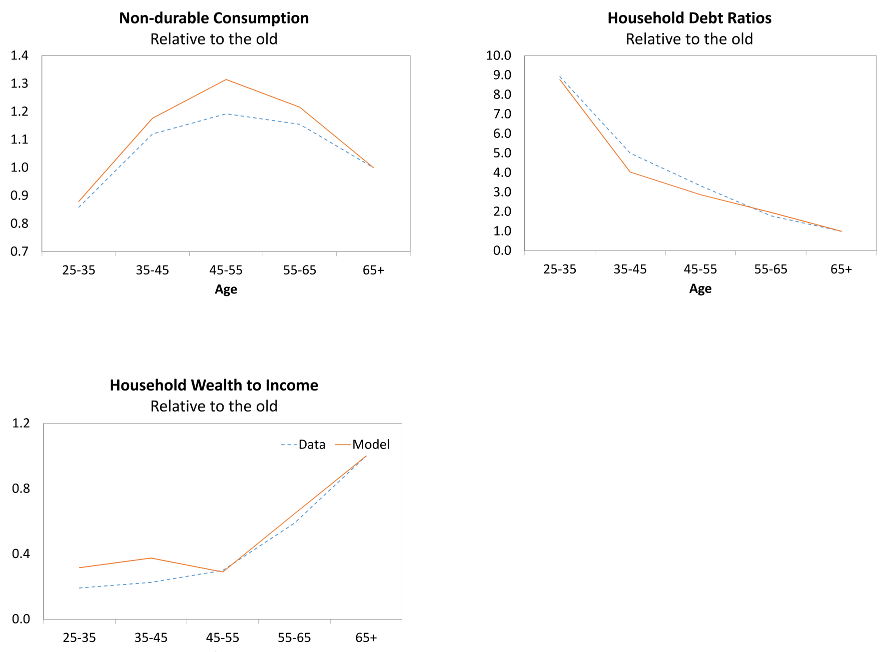
Notes: This table shows the estimated processes for real mortgage rates and rental rates from Equations 18-19. The 1988-2007 data are from the Federal Reserve Board, St Louis Federal Reserve Bank and Freddie Mac.

Table 11: Monetary policy shocks and aggregate variables

	$u_t^{\log y_t}$	$u_t^{\log p_t}$	$u_t^{r_t}$
Γ^-	0.006	0.004	0.648
Γ^+	0.001	-0.012	0.296

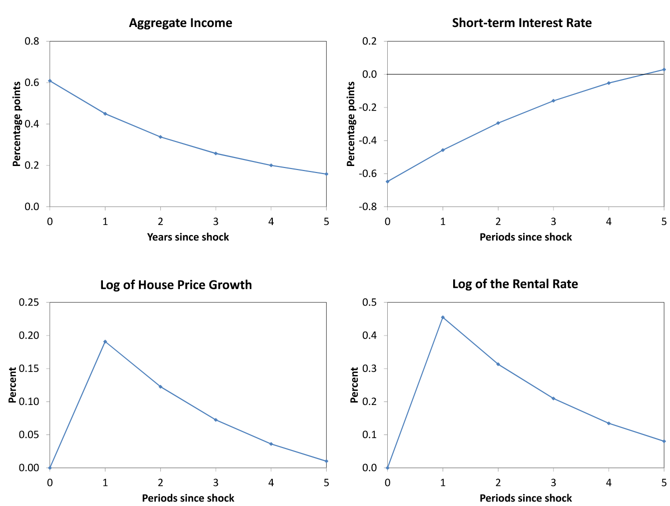
Notes: This table shows the contemporaneous effect of monetary policy shocks on the aggregate variables. The variables $u_t^{\log y_t}$, $u_t^{\log p_t}$, and $u_t^{r_t}$ denote the residuals from the regression corresponding to the equation with the dependent variables of log income per capita, log house prices and the 3-month interest rate, respectively. The Γ coefficients are from Equation 20, estimated using high-frequency Federal Funds futures shocks.

Figure 2: Life-cycle Consumption and Asset Profiles: Model vs Data



Notes: This figure depicts four key life-cycle moments by age group. Each panel plots both the model implied average moments (solid line) and the empirical moments (dashed line) from the CEX and the 2004 SCF.

Figure 3: Response to an Expansionary Monetary Policy Shock



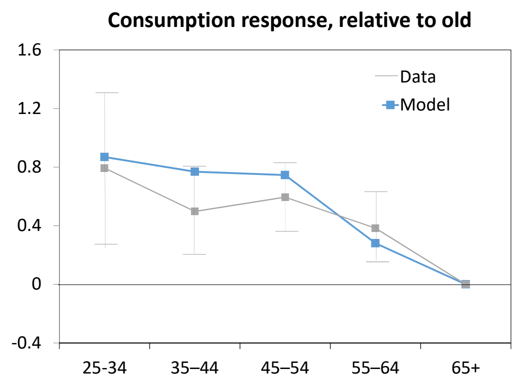
Notes: This figure depicts the annual impulse response functions for aggregate income, the short-term interest rate, log of house price growth, and log of house price to rent ratio.

Table 12: Response of Aggregate Consumption a Monetary Policy Shock

Source	Year 1	Year 2
Model	0.43	0.87
Data	1.06	1.43
	[0, 2.13]	[-1.07, 3.935]

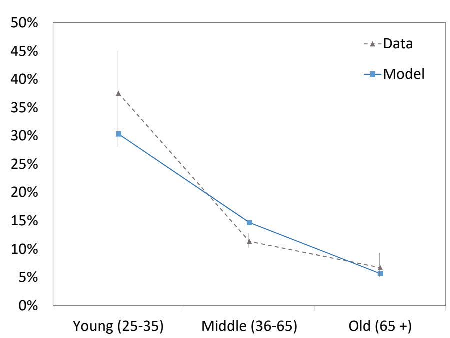
Notes: This table depicts the aggregate non-durable consumption response to a 1 standard deviation shock to monetary policy from the model and data. The 80 percent confidence intervals are in parentheses.

Figure 4: Age-specific Consumption Response to a Monetary Policy Shock



Notes: This figure depicts the model implied impulse response function of non-durable consumption by age group to a 1 standard deviation shock to monetary policy.

Figure 5: Age-specific Loan Adjustments to a Monetary Policy Shock



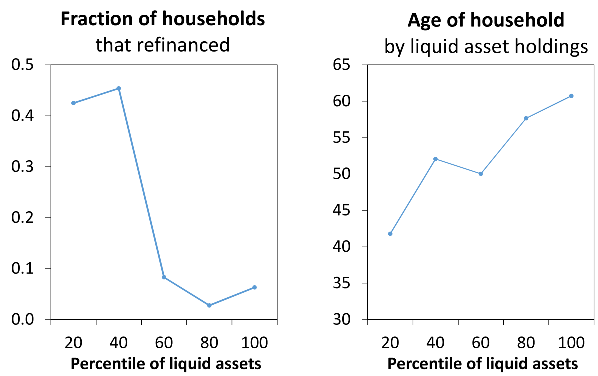
Notes: This figure depicts the fraction of loans refinanced and change in the homeownership rate by age group following a 1 standard deviation shock to monetary policy.

Table 13: Spending coefficients by age

	Young	Middle	Old
Share of households that refinanced over the year	0.304	0.147	0.057
Spending coefficient	0.798	0.185	0.107
Average difference in consumption for those who refi vs those who do not	$2,667	$318	$295

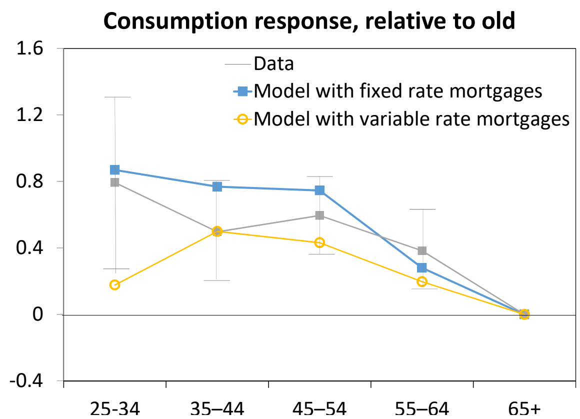
Notes: This shows the average share of all households that refinanced; the spending share of the extra refinanced amount; and the difference in consumption for those who refinanced and those did not.

Figure 6: Age-specific Consumption Response to a Monetary Policy Shock



Notes: The left panel shows the fraction of loans refinanced by liquid asset holdings, following a one standard deviation expansionary monetary policy shock. The right panel plots the average age of household by liquid asset holdings.

Figure 7: Decomposing the Effects of Monetary Policy on Consumption



Notes: This figure depicts consumption response to a 1 standard deviation shock for each age group relative to the old. The grey lines depict the empirical elasticities and 80% confidence intervals. The blue line is based on the full model with fixed-rate mortgages. The orange line is based on the model with variable rate mortgages.