Population Aging and the Transmission of Monetary Policy to Consumption*

Arlene Wong[†]

December 28, 2015

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Abstract

This paper assesses the effects of demographic changes on the transmission of monetary policy to consumption. First, I provide empirical estimates of age-specific consumption elasticities to interest rate shocks. The consumption of young people is significantly more responsive to interest rate shocks than the old, and explains most of the aggregate response. The consumption responses are driven by homeowners who refinance or enter new loans after interest rate declines. Second, I develop a life-cycle model that explains these empirical facts. The model features fixed-rate mortgages, with fixed costs to refinance and enter into a new loan. I find that young people have a higher propensity to adjust their loans, because the fixed costs are spread over a larger loan size, relative to older individuals. Quantitatively, the loan adjustment channel accounts for a sizable share of the difference in consumption elasticities between young and old individuals. Under an older demographic structure, the model predicts a significantly lower aggregate consumption response to monetary policy shocks.

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

*I am indebted to Matthias Doepke, Martin Eichenbaum, Aviv Nevo, and Sergio Rebelo for their continuing guidance and support. I am very thankful to David Berger, Nir Jaimovich, Alejandro Justiniano, and Giorgio Primiceri for useful discussions. I also wish to thank Luigi Bocola, Michael Chu, Laura Doval, Yana Gallen, and Guido Lorenzoni for helpful comments. This research was funded by a cooperative agreement between the USDA/ERS and Northwestern University, but the views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Agriculture.

†Correspondence: Department of Economics, Northwestern University, 2001 Sheridan Rd, Evanston, IL 60208. Email: arlene.wong@u.northwestern.edu. Web: http://sites.northwestern.edu/awo760.

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 of (i) and (ii) 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 address (ii) and (iii).

To empirically estimate the response of consumption to monetary policy shocks, I iden-

[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]Some recent examples include Gertler and Karadi (2015), Gorodnichenko and Weber (2015), and Nakamura and Steinsson (2015).

tify 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 with Freddie Mac mortgage data to estimate loan adjustment propensities.

My five main empirical findings are as follows. First, I find that expansionary monetary policy shocks lead to significantly lower mortgage rates. Second, these expansionary shocks have large and persistent effects on consumption. Third, across a broad range of consumption categories, the consumption elasticity of young people (those aged under 35 years) is 2-3 times higher than 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.

Fourth, the response of consumption to monetary policy shocks 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 extensive margin of homeowners refinancing, and the intensive margin of homeowners 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.

Fifth, 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 size. In the data, young people have much larger loan sizes 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 partial equilibrium life-cycle model 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 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. The reason is that interest savings rise with loan size, while the cost of adjustment is fixed. Consistent with the data, the model implies that young people have larger loans than older people. As a result, young people also have a higher propensity to adjust their loans relative to older people.

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 perform two exercises. First, I 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] Second, I analyze the effects of demographic changes on the aggregate response of consumption to monetary policy shocks. I use the structural model to take into account the response of household's consumption and investment decisions to changes in the demographic structure.

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 40 percent under the model with a variable mortgage structure. So according

[5]My model 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 Berger et al. (2015).

[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.

to my model, the refinancing channel accounts for 40 percent of the difference in the consumption response of younger and older people. The remaining 60 percent is accounted for by the standard income and substitution effects, and the Fisher channel, which have been emphasized in existing literature on the redistributive effects of monetary policy.[7]

I also use the model to perform a second experiment to quantify how the aggregate response of consumption to monetary policy shocks changes as the population ages. I quantify the aggregate consumption responses under the demographic structures of Florida and California. I consider Florida and California, since these two states provide a wide bound on the range of the old-to-young ratios across the U.S. states. I re-estimate the model using state-specific processes for house prices and income, controlling for various non-demographic factors (including local area housing supply elasticity and sectoral composition). My analysis implies that if the share of old to young in the U.S. rises by 50% (as is expected by 2035), then the aggregate consumption response to an interest rate shock will fall by 26-35%.

The paper is structured as follows. Section 2 describes the data, and section 3 outlines the empirical methodology. Section 4 discusses the empirical results. Section 5 sets up the model, and section 6 describes the calibration process. Section 7 discusses the results of the two experiments in the model. Section 8 concludes.

Related literature

This paper contributes towards four main strands of literature. First, it relates 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.[8] A related set of papers have also shown the implications of population aging for aggregate labor market volatility,[9] and the implications of long-term structural changes on the natural rate of interest.[10] 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.[11]

[7]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*).

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

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

[10]See for example, Eggertsson and Mehrotra (2014).

[11]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 from these studies in two ways. First, I model monetary policy shocks as changes to the short-term interest rate, rather than inflation shocks. Secondly, I incorporate fixed-rate mortgages into the life-cycle model, rather than assuming a one-period

The second strand of literature studies the redistributive effects of monetary policy. Recent empirical work has combined sectoral and household data to document how nominal positions of households and unhedged interest positions can induce redistributive effects following permanent shocks to inflation,[12] or transitory shocks to interest rates.[13] In this paper, I consider an alternative and distinct channel - the refinancing and new mortgage channel - and document the importance of this channel for generating heterogeneous effects across households to short-term interest rate shocks.

Third, this paper adds to the literature that studies the relationship between consumption, mortgage refinancing and homeownership decisions. These papers have focused on the response of consumption and borrowing to house price shocks.[14] These papers show that refinancing decisions and liquidity constraints can generate large responses to housing wealth shocks.[15] This paper contributes to this literature, by focusing on the response to interest rate shocks, and the interaction with demographics.

Lastly, 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.[16] 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.

variable structure. This allows for refinancing and mortgage decisions which are important in the U.S.

[12]See Doepke, Schneider and Selezneva (2015) and Doepke and Schneider (2006*a*) for the U.S., Meh and Terajima (2011) for Canada, Adam and Zhu (forthcoming) for the Euro Zone, and Sterk and Tenreyo (2015) for the U.K.

[13]See for example, Keys et al. (2014), Di Maggio, Kermani and Ramcharan (2014), Auclert (2015) and Cloyne, Ferreira and Surico (2015).

[14]Examples include the empirical work of Khandani, Lo and Merton (2013), Bhutta and Keys (2015), Mian, Sufi and Trebbi (2014), Mian and Sufi (2014), Campbell and Cocco (2007), and Hurst and Stafford (2004). There have also been quantitative studies that examine these empirical findings in the context of house price shocks, such as Gorea and Midrigan (2015), Berger et al. (2015), Kaplan, Mitman and Violante (2015) and Chen, Michaux and Roussanov (2013).

[15]Other papers that look at the relationship between refinancing and debt constraints also include Beraja et al. (2015) and Agarwal et al. (2015).

[16] Recent examples are Alvarez, Guiso and Lippi (2012), Alvarez and Lippi (2009), Abel, Eberly and Panageas (2009), Kaplan and Violante (2014), and Berger et al. (2015).

2 Consumption and Mortgage Data

Consumer Expenditure Survey

I use data from the CEX interview sample, which has been conducted continuously by the Bureau of Labor Statistics (BLS) since 1980. The CEX interview survey is a rotating panel of households that are selected to be representative of the U.S. 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.[17] See Appendix A details on the construction of the categories, and discussion of robustness around measurement issues.

Nielsen Homescan

I complement the analysis with a second data set on household expenditure from Nielsen Homescan.[18] 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

[17] 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.

[18] 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.

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 B 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.[19] These results are presented in Appendix E.

Mortgage data

I obtain household-level data on mortgages from two sources: the CEX survey and the Freddie Mac Single Family Loan-Level data. See Appendix A for more detail on the construction of the variables and description of the data.

I use the CEX detailed expenditure files on owned living quarters and other owned real estate, and mortgages, over the sample period is 1993-2007. Some of the variables are unavailable prior to 1993, and therefore I focus on the period starting from 1993. Using the mortgage starting date, I construct a loan-adjustment binary variable that equals one if the loan is a new transaction and zero otherwise. I combine these files with the data on consumption and demographic in the CEX interview surveys.

The Freddie Mac Single Family Loan-Level data is a loan-level panel data of all 30-year mortgages securitized by Freddie Mac.[20] In total, there are approximately 17 million loans in the sample period 2000-2007. I construct a loan-adjustment binary variable that equals one if the loan is a new transaction and zero otherwise.

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, and delinquency status. 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.

I also obtain data on mortgage rates from the Freddie Mac Mortgage Rate Survey. Since April 1971, Freddie Mac has surveyed lenders across the nation weekly to determine the average 30-year fixed-rate mortgage rate. In 1984, the 1-year adjustable mortgage rate was added to the survey. The 15-year fixed-rate mortgage rate was included beginning in 1991.

[19]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.

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

3 Empirical methodology

In this section, I discuss the identification of the monetary policy shocks. I then describe 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 at lower mortgage rates.

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.[21] 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.

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 website. Data on Federal Funds futures are from Gorodnichenko and Weber (2015) for the sample period 1994-2007.[22] I also obtain identified shocks prior to 1994 from Gürkaynak, Sack and Swanson (2005).

The monetary policy shock is computed 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

[21]The use of high-frequency data follows the approach of Kuttner (2001), Rigobon and Brian (2004), Nakamura and Steinsson (2015), Gertler and Karadi (2015), Gorodnichenko and Weber (2015), and others.

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

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) and Nakamura and Steinsson (2015), I consider a 60 minute time window around the announcement that starts $\triangle^{-} = 15$ minutes before the announcement.[23] 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. 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.

I sum up the identified shocks to obtain a quarterly measure of the monetary policy shock.[24] This results in 64 estimated monetary policy shocks over 1990-2007. The average monetary policy shock is approximately 0. Two standard deviations of the quarterly shock is 25-35 basis points (depending on the window that the shock is measured over).[25] The largest expansionary shock is 48 basis points, which occurred in the fourth quarter of 1991. One-third of the shocks are between 10-50 basis points (in absolute values).

I also considered 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. The role of forward guidance has become more important in the recent period, with interest rates at the zero lower bound.[26] 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.[27] In

[23]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. The results are qualitatively robust to the different definitions, and are available upon request.

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

[25]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.

[26] 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.

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

Appendix D, I examine the heterogeneity in consumption responses to the path shocks.

In the following section, I focus on the consumption response to the identified shocks to the short-term interest rate, based on the high-frequency futures data. However, the results are robust to considering other identification schemes for monetary policy shocks. These identification schemes include the Cholesky decomposition of the residuals, and the narrative approach in Romer and Romer.

3.2 Estimating the response of mortgage rates

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:[28]

$$\triangle R_t = \alpha + \beta \epsilon_t + \eta_t. \tag{2}$$

$\triangle R_t$ denotes the change in the mortgage rate on new loans. I examine the 30-year and 15-year fixed mortgage rates, and the 1-year adjustable mortgage rate. Following Gertler and Karadi (2015), I examine the change in the mortgage rates in the two-week period after the monetary policy shock.[29] I estimate Equation 2 over the period 1991-2007. 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.[30]

The coefficient β gives the change in the mortgage rate due to a 1 percentage point monetary policy shock. The coefficient is consistently estimated under the identifying assumption that the monetary policy shock ϵ_t is uncorrelated with the residual η_t. The exogeneity assumption is plausible, given the narrow window that is used to measure the monetary policy shock.[31]

[28] 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).

[29] The two-week period takes into account the fact the mortgage contracts are less liquid than other types of assets (such as government bonds). I also examined the change in the mortgage rate over a one-week period instead, and find similar results.

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

[31] The narrow window ensures that the only relevant shock in the time-period is the FOMC announcement.

3.3 Estimating consumption elasticities

I then 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 apply the following empirical specification to estimate how consumption responds to interest rate shocks:

$$\triangle \ln C_{ht} = b_0 + \sum_{k=1}^{K} \beta_k \cdot \epsilon_{t-k}^{-} + \sum_{k=1}^{K} \gamma_k \cdot \epsilon_{t-k}^{+} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \tag{3}$$

C_{ht} denotes real consumption for household h in quarter t. I estimate the regression for the change in consumption, denoted by $\triangle \ln C_{ht} = \ln C_{ht} - \ln C_{h,t-1}$.[32] X_{ht} denotes household-level controls: the age of the head of household, changes in family size, employment status, and marital status over the quarter, and household-specific interview fixed effects. $\lambda_{s(t)}$ denotes seasonality fixed effects.

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.

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

$$\frac{\partial \ln C_{h,t+T}}{\partial \epsilon_t^{-}} = \sum_{k=1}^{T} \frac{\partial \triangle \ln C_{h,t+k}}{\partial \epsilon_t^{-}} = \sum_{k=1}^{T} \beta_k. \tag{4}$$

[32] Estimating the regression in consumption differences removes the household fixed effect, and any strong (unit-root) persistence in the residuals. I also estimated the regressions on the level of log consumption for robustness, and find similar point estimates. The standard errors under the levels regression is tighter.

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

$$\frac{\partial \ln C_{h,t+T}}{\partial \epsilon_t^+} = \sum_{k=1}^{T} \frac{\partial \triangle \ln C_{h,t+k}}{\partial \epsilon_t^+} = \sum_{k=1}^{T} \gamma_k. \tag{5}$$

Equations 4 and 5 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:

$$\begin{aligned}\triangle \ln C_{ht} = b_0 &+ \sum_{k=1}^{K} \beta_k^a \cdot \epsilon_{t-k}^- \cdot \text{Age}_{h,t-k} \\ &+ \sum_{k=1}^{K} \gamma_k^a \cdot \epsilon_{t-k}^+ \cdot \text{Age}_{h,t-k} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}.\end{aligned} \tag{6}$$

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. 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.[33] Defining age groups in this way captures any differential consumption response to interest rate shocks that may be related to home-ownership decisions.[34] I also consider narrower groups based on 10-year age ranges using the Nielsen Homescan data, which has a larger number of households.

An alternative approach to estimating the consumption response by age is to interact the monetary policy shocks with a continuous variable of age. The continuous age variable means that the household can have a different marginal consumption response for each age. This differs from the previous specification in Equation 6, which interacted with 3 age groups and therefore estimates an average response within the age group.

[33] 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.

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

Formally, I estimate

$$\triangle \ln C_{ht} = b_0 + \sum_{k=1}^{K} \beta_k \cdot \epsilon^-_{t-k} + \sum_{k=1}^{K} \gamma_k \cdot \epsilon^+_{t-k} + \sum_{k=1}^{K} \theta^-_k \cdot \epsilon^-_{t-k} \cdot \text{age}_{h,t-k} + \sum_{k=1}^{K} \theta^+_k \cdot \epsilon^+_{t-k} \cdot \text{age}_{h,t-k}$$
$$+ \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht} \quad (7)$$

where age_{ht} a continuous variable of the head of household's age. C_{ht} denotes the real consumption for household h in quarter t. X_{ht} denotes household-level controls: age of the head of household, changes in family size, employment status, and marital status over the quarter, and household-specific interview fixed effects. $\lambda_{s(t)}$ denotes seasonality fixed effects.

θ^+_k gives the effect of a 1 year increase in age on the response of the growth rate of consumption T periods after an expansionary monetary policy shock. The conditional expected response of consumption is given

$$\sum_k \beta_k + \theta^-_k.\text{age}_{h,t-k}$$

3.4 Estimating the loan adjustment propensities

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 on the fixed-rate mortgage only resets 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.[35]

I 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.

[35] 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.

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

$$P_{ht} = b_0 + \sum_{k=1}^{K} \beta_k^a \cdot \epsilon_{t-k}^{-} \cdot \mathrm{Age}_{h,t-k} + \sum_{k=1}^{K} \gamma_k^a \cdot \epsilon_{t-k}^{+} \cdot \mathrm{Age}_{h,t-k} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \tag{8}$$

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 8 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. The CEX does not have a continuous time panel of loan size. Therefore, I use the Freddie Mac Single Family Loan-Level Data to estimate the relationship between loan size and the probability of loan adjustment. Formally, I estimate

$$P_{ht} = b_0 + \sum_{k=1}^{K} \beta_k^a \cdot \epsilon_{t-k}^{-} + \sum_{k=1}^{K} \gamma_k^a \epsilon_{t-k}^{+} \cdot + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \tag{9}$$

X_{ht} denotes controls: loan age, credit score, indicator variables for MSA, and debt-to-income ratios.

4 Empirical results

My five main empirical results are: (1) expansionary monetary policy shocks lead to much lower mortgage rates; (2) these expansionary shocks have large and persistent effects on consumption; (3) the aggregate consumption response is driven by the response of young people, which is significantly larger than that of older people; (4) within age groups, 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;

[36] Alternative specifications include probit and logit regressions. The results are similar under the different approaches.

and (5) young people have a higher propensity to adjust their loans following interest rate shocks, which accounts for their higher consumption elasticity. The higher loan adjustment propensity can be explained by their larger loan sizes.

4.1 Response of mortgage rates

My first empirical result is that monetary policy shocks significantly affect mortgage rates. A monetary policy shock reduces the 30-year, 15-year and 1-year mortgage rates by 50-60 basis points. Table 1 decomposes the total effect of the monetary policy shock into two components: surprises in the current monthly rate, and surprises in the path of the futures rate.[37] The path shocks, in particular, have large effects on the 30-year mortgage rate. These results are consistent with Gertler and Karadi (2015), who also document significant effects of monetary policy shocks on long-term yields. Monetary policy shocks can therefore have large effects on a household's mortgage payments.

4.2 Consumption elasticities

My second empirical result is that expansionary monetary policy shocks have large and persistent effects on consumption, over the sample period 1990-2007. In this section, I document the estimated elasticities of consumption to interest rate shocks.

The left panel of Figure 1 shows clear evidence of statistically significant and persistent effects of expansionary monetary policy shocks on consumption. Figure 1 plots the the estimated impulse response functions of total consumption to a one-standard deviation monetary policy shock. The 90^{th} percent confidence interval is represented by the dashed lines. Total consumption rises to a peak of 1.7 percent in response to an expansionary monetary policy shock. The average annual consumption elasticity over the first year is 1.2 percent, and the effect on consumption persists for over two years.

The right panel of Figure 1 shows that consumption falls to a trough of 1.1 percent at five quarters after an initial contractionary shock. However, the effect is statistically insignificant. The wide standard errors reflect the smaller number of contractionary shocks that occurred during the sample period.[38]

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

[38] There were 20 contractionary shocks during the sample period, which is less than half of the number of expansionary shocks.

Given the clear evidence of the expansionary effects on consumption, I focus the discussion on the heterogeneous consumption responses to expansionary interest rate shocks.[39]

Total consumption elasticities by age

My third empirical result is that the response of consumption of young people is significantly larger than that of older individuals, and account for most of the aggregate response. This finding is seen in Figure 2, which shows the consumption responses by age over time, and Table 2, which summarizes average annual responses of consumption to an expansionary monetary policy shock by age. Total consumption of young people rises by an average of 2.4 percent over the year. In comparison, the average consumption responses of middle aged and older people are 0.8 percent and 0.4 percent, respectively.

Figure 3 depicts the difference in the consumption response of young people relative to that of middle aged and older individuals. Young people adjust their consumption by 0.5-2.5 percentage points more than middle aged and older people. The difference is statistically significant and persists over time.

The higher elasticity of young people to an interest rate shock is consistent with the estimated marginal effect of age on the consumption elasticity (based on Equation 7). Figure 4 shows that the annual consumption response of a household declines by 5 basis points for every one-year increase in the age of the head of household. This implies that, for instance, the consumption response of a 25 year old is 2 percentage points higher than that of a 65 year old.[40] The effect of age on the consumption response is statistically significant. 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, starting from an annual elasticity of 1.04 percent for young people to 0.01 percent for older people. In Section 1.1 of the online Appendix, I show robustness of the results to different age group definitions.

The finding that consumption elasticities decline with age is broad-based across consumption categories. Table 2 shows the consumption elasticities by type of good. The difference in consumption response of young people relative to older people is most pronounced for

[39] The age-specific consumption responses to contractionary shocks are presented in the Appendix C. I further discuss the interpretation of the contractionary shocks using the quantitative model in Section 7.

[40] This is computed as 5 basis points $\times$ 40.

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

durable goods. Young people are also the only group that adjust their non-durable goods consumption after an expansionary monetary policy shock.

Figure 5 splits the categories down further. This shows a decline in life-cycle elasticities to interest rate shocks across almost all consumption categories. These categories include: apparel, housing, vehicles, gasoline, entertainment, food, healthcare, and personal care. The young-old difference is most pronounced for durables consumption, such as apparel, housing and vehicles.

Contribution to the aggregate consumption elasticity

I now ask what is the contribution of each group to the aggregate consumption response. The percentage point and percent contributions of each age group to the aggregate elasticity are given 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).[42]

I find that young people drive the majority of the aggregate consumption response to interest rate shocks. The consumption response of young people accounts for 65 percent of the aggregate response of total consumption. Young people account for 56 percent of the response in durables, and all of the response in non-durables. Their large contribution to the aggregate consumption response reflects the fact that they have a very high consumption elasticity relative to average person.

In comparison, the consumption response of the middle aged to a monetary policy shock account for 35 percent of the aggregate consumption elasticity. Older individuals do not contribute towards the aggregate consumption response.

4.3 The role of housing and mortgage 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. I summarize differences in homeownership rates and mortgage characteristics by age. I then examine the impact of loan adjustment on consumption.

[42] The average elasticity is set to zero for cases where the response is statistically insignificant. This provides a conservative estimate for the contribution of young people to the aggregate consumption response, since the point estimates of middle aged and old people are statistically insigificant and negative in many cases. Recomputing Table 3 using the (insigificant) point estimates of the middle aged and old therefore gives larger results for the contribution of the young to the aggregate response.

I show that within each age group, 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 fourth empirical result). Lastly, I show that young people have a higher propensity to adjust their loans following interest rate shocks, which boosts their consumption. The higher loan adjustment propensity can be explained by their larger loan sizes (my fifth empirical result).

Housing and mortgage characteristics by age

Some well-known life-cycle characteristics can be observed in Table 4. First, the homeownership 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.

Lastly, the majority of loans are at fixed rates in the U.S., and there is very little difference in the share of fixed-rate mortgages across the age groups. Moreover, while the share of fixed-rate mortgages fluctuates over time, the variation does not significantly differ by age group. This suggests that the heterogeneity in age-specific consumption responses is not driven by any differences in the share of loans at fixed rates across the age groups.

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.[43]

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,

[43] 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).

recorded in the CEX detailed mortgage and housing data, which arises due to new borrowing or refinancing of existing loans. For each of these sub-samples of households, I estimate the age-specific consumption elasticities to interest rate shocks (based on Equation 6).

My fourth empirical result is that homeowners increase their consumption following an expansionary monetary policy shock, while the consumption response of renters is statistically insignificant (Table 5). Moreover, most of the consumption response of households is accounted for by households that choose to adjust their loans. For instance, young individuals who adjust their loans increase their consumption by 6.5 per cent in response to an expansionary interest rate shock. This is about 3 times larger than the response of those that do not adjust their loans. A comparison across the age groups also shows that the effect of loan adjustment on consumption is most pronounced for young people. Young homeowners who adjust their loans increase their consumption by 6.5%. In comparison, the consumption of middle aged and older homeowners with loan adjustments increase by 5.3% and 3.6%, respectively.

Age-specific propensities to adjust loans

To understand the importance of the loan adjustment decision for the overall consumption response to interest rate shocks, we need to know the fraction of households that adjust their loans within each age group. Therefore, I estimate loan adjustment propensities using the CEX data and the Freddie Mac data.

My fifth empirical result is that there is a higher fraction of the young households who adjust their loans after expansionary monetary policy shocks. Table 6 that shows that young people have a much higher propensity to adjust their loans within a year of an expansionary monetary policy shock (39%, relative to 12% and 7% for middle aged and old people, respectively).[44] The higher fraction of young people who adjust their loans explains their higher consumption response to interest rate shocks.

One explanation for the higher loan adjustment propensities of young people is that they have larger loan sizes. Using the Freddie Mac data, I find evidence that households with larger loan sizes have higher loan adjustment propensities, following interest rate declines. In the data, it is the young 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

[44]These propensities are estimated based on Equation 8 using the CEX data over the sample period 1993-2007.

their home, which is paid down over time. Older people therefore have lower loan balances relative to young individuals since part or all of the loan has already been paid down.

The positive correlation between loan size and loan adjustment propensities is seen in Table 7.[45] The table presents the loan-adjustment propensities within the year of an expansionary monetary policy shock, by loan decile.[46] The propensity to adjust the loan rises with loan size, ranging from 10% in the bottom decile to 48% in the top decile.

4.4 An Alternative Approach: Regional Consumption Elasticities

The previous sections provided evidence of age-specific heterogeneity in consumption elasticities to monetary policy shocks using household-level analysis. An alternative approach to understanding the effect of demographics on the aggregate consumption response is to examine the responses across regions in the U.S. In this section, I present evidence that the aggregate consumption in states with a younger demographic structure responds more to interest rate shocks, consistent with the household-level findings.

To investigate the regional variation in consumption responses, I estimate:

$$\triangle \ln C_{ht} = b_0 + \sum_{k=1}^{K} \beta_k \cdot \epsilon_{t-k} + \sum_{k=1}^{K} \alpha_k \cdot \epsilon_{t-k} \cdot P_{r(h),t-k} + \sum_{k=1}^{K} \gamma_k \cdot \epsilon_{t-k} \cdot S_{r(h),t-k} + \lambda_s(t) + \theta' Z_{ht} + \nu_{ht} \quad (10)$$

for household h in quarter t living in states r, and $K = 9$ quarters. $P_{r(h),t}$ denotes the share of old to young in region r (where the old and the young are defined as those aged over 65 and those between 25 and 35 year of age, respectively). $S_{r(h),t}$ is a vector of state-level variables that can affect the local area consumption response. These include the sectoral composition and local area housing supply elasticity.[47]

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

[46] These propensities are estimated based on Equation 9 using the Freddie Mac Loan Performance data over the sample period 2000-2007, and controls for the household's credit score, leverage (debt-to-income and debt-to-valuation ratios) and loan age. See Section 2 for more detail on the data construction. The Freddie Mac Loan Performance data does not have information on household age and zip-code of residence. Therefore, I further explore the effects of these demographic variables in Justiniano et al. (2012), using Equifax data. The results, based on the Equifax data, are consistent with the findings based on the Freddie Mac Loan Performance data.

[47] As shown in Mian and Sufi (2014) and Mian, Rao and Sufi (2013), the local area housing supply elasticity

The term

$$\beta_k + \alpha_k \cdot P_{r(h),t} + \gamma_k \cdot S_{r(h),t}$$

gives the change in the growth rate of consumption k periods after an initial shock at time t. The consumption elasticity after T periods for region r is:

$$\left.\frac{\partial \ln C_{h,t+T}}{\partial \epsilon_t}\right|_r = \sum_{k=1}^{T} \left.\frac{\partial \triangle \ln C_{h,t+k}}{\partial \epsilon_t}\right|_r = \sum_{k=1}^{T} \left[\beta_k + \alpha_k \cdot P_{r(h),t-k} + \gamma_k \cdot S_{r(h),t-k}\right] \tag{11}$$

The effect of the local area population structure on the local area consumption elasticity, relative to the national average response, is given by

$$\sum_{k=1}^{T} \alpha_k \cdot P_{r(h),t} - \sum_{k=1}^{T} \alpha_k \cdot P_{U.S.,t} \tag{12}$$

where $P_{U.S.,t}$ denotes the national young-old ratio.

I estimate Equation 10 using the Nielsen Homescan data. I obtain data on the population structure from the U.S. Census.[48] Data on the sectoral composition is from the BEA. This is comprised of the share of output accounted for by each sector, including manufacturing, services, and other sectors.[49] I obtain the local area housing supply elasticity from Saiz (2010).

Table 15 gives the estimated coefficients from Equation 10. The demographic effects, given by the α_k coefficients, are negative and statistically significant. The negative coefficient implies that an older demographic structure results in a more muted response.

Using the estimated coefficients, I compute the implied consumption response to an interest rate shock after $T = 4$ quarters for each state, given the state-specific demographic structure, relative to the national average. Figure 6 shows the average annual consumption elasticities for each state, relative to the national average. The states are ordered from the youngest to oldest state, ranked in terms of their share of old-young average over 1980-2007. States with relatively young demographic structures have a stronger consumption response relative to the national average, while older states have a relatively more muted response. For example, consider California and Florida, which have a old-young ratio of 0.19 and 0.32, respectively, compared with the national average of 0.23. The estimated

is highly correlated with refinancing decisions.

[48]I assume the population structure linearly changes across quarter within the year.

[49]The data is annual and I assume the sector shares are constant within the year.

consumption elasticities imply that the population structure alone results in a 15 percent higher consumption response in California relative to the national average response. In comparison, the demographic structure in Florida implies a 28 percent lower consumption response relative to the national average response.

5 Model

In this section, I build a partial equilibrium life-cycle model that is able to generate the five key empirical results in Section 4, and use it to draw inferences for the national economy.

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 incorporate into this 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.

These two features combined 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.

I develop the model in order to perform two exercises. First, 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

[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 Berger et al. (2015).

is relevant for assessing whether the same shock will be more or less effective under different macroeconomic conditions.

Second, I use the model to quantify the potential effects of demographic shifts on the aggregate consumption response to monetary policy shocks. I use the structural model to take into account the reoptimzation of household consumption and investment decisions under different demographic structures.

5.1 Setup

I now describe the set-up of the model. I consider a partial equilibrium overlapping-generations economy with heterogeneous agents that face idiosyncratic income risk and aggregate shocks (described in the following sections). 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.

Agents maximize expected utility, have time-separable preferences and discount the future at rate β. The per-period utility is

$$\frac{\left(c_{jat}^{\alpha} \cdot h_{jat}^{1-\alpha}\right)^{1-\sigma} - 1}{1-\sigma}$$

where c_{jat} is consumption of non-durable goods for agent j who is aged a at time t. The housing stock h_{jat} provides housing services. They can either rent or own a home.[51] Any housing and non-housing wealth left by the household at the end of the period t upon death is bequeathed and enters the utility function through the bequest function

$$B\left(W_{jat} - 1\right)^{1-\sigma} / (1-\sigma)$$

where B captures the bequest utility parameter and W_{jat} denotes the total wealth, defined more formally below in Equation 23.

Each period, agents make decisions on the amount of non-durable consumption and housing services to consume, how to obtain the housing services (to rent or buy a house),

[51] 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.

holdings of assets, and whether to refinance an existing mortgage. These decisions are described in more detail below.

5.2 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, (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. The agent can choose to either own a house or rent at price p_t^r. The housing stock owned by the agent depreciates at a rate of δ each period.

While the stock of rental housing can be freely adjusted each period, a lump-sum transaction cost of F applies when the household enters a new loan or refinances an existing mortgage. Households enter a new loan when they switch from being a renter to a homeowner, and when they move houses (i.e. adjust their housing stock by more than the per-period housing depreciation).[52] For households with an existing mortgage, they can choose each period whether to refinance their loan. If they refinance, the mortgage rate is reset and the household can also choose a new mortgage balance. When households decide to enter a new loan or refinance an existing loan, they are 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. Agents also face a borrowing constraint on the short-term asset

$$s_{jt} \geq -\underline{s}.$$

The mortgage is structured as follows. The loan is assumed to be amortized over the life of the agent.[53] Hence the duration of a new loan for an agent aged a is

$$d(a) = T - a.$$

[52] This is consistent with reality, where individuals typically sign a new loan when they move houses.

[53] 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.

When an individual aged a enters a loan at date 0, the fixed rate $R_{ja0} = r_t^{d(a)}$, the current market mortgage rate with a $d(a)$ duration. The agent's payment M_{ja0} is determined at date 0 and remains fixed each period for the remaining duration of the loan. Therefore, the loan balance b evolves as

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

where the initial amount borrowed and the mortgage payment satisfies[54]

$$b_{ja0} = M_{ja0} \left[\sum_{k=1}^{d(a)} \frac{1}{(1 + R_{ja0})^k} \right]. \tag{13}$$

The interest rate paid on the loan, R_{ja0}, remains fixed over the life of the loan unless the loan is refinanced. If the loan is refinanced, the new fixed rate is the current market mortgage rate in that period. Therefore, the interest rate that the agent can be expressed recursively as

$$R_{j,a+1,t+1} = r_{t+1}^{d(a+1)} \cdot 1(\text{refi})_{t+1} + R_{jat} \cdot [1 - 1(\text{refi})_{t+1}] \tag{14}$$

where the variable $1(\text{refi})_{t+1}$ equals one if the agent refinances in period $t + 1$ and zero otherwise. When the agent refinances, they can also choose a new loan balance b_{jat}.

5.3 Income

Each period, the agent of age a receives an exogenous income y_{jat}. When the household is working, the income process follows

$$\log(y_{jat}) = \chi_a + \eta_{jat} + \phi_a(y_t) \tag{15}$$

where χ_a is deterministic and captures the hump shape of life-cycle earnings.

[54]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 13, as

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

The persistent idiosyncratic income component follows the process

$$\eta_{jat} = \rho_\eta \eta_{j,a-1,t-1} + \psi_{jt}$$

where ψ_{jt} is an i.i.d shock drawn each period from $N(0, \sigma_\eta^2)$. 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).

The term $\phi_a(y_t)$ captures fluctuations to income that arise from aggregate shocks to the aggregate income in the economy (the process for y_t is described in detail below). The exposure of income to aggregate shocks is age-specific, reflected in ϕ_a.

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. The social security transfer is modeled as in Guvenen and Smith (2014).

5.4 Aggregate shocks to the economy

In addition to idiosyncratic income shocks, households also face aggregate shocks. I now describe the exogenous aggregate processes in the model. The purpose of this set-up is to specify processes that generate dynamics which resemble the time series and impulse response functions to monetary policy shocks observed in the data. This allows me to examine the household's policy decisions in an environment with realistic dynamics in prices and aggregate variables, while preserving the household heterogeneity in income and mortgages. The latter is important for capturing the factors that drive the age-specific consumption responses to interest rate shocks.

The aggregate variables in the economy are: real aggregate income, real house prices,

[55] As shown in a number of papers, including Krueger and Perri (2006), the idiosyncratic income component creates a precautionary savings motive, which helps to more closely match the rising profile of savings (decline in debt holdings) over the life that is observed in the data.

and the one-period interest rate. The dynamics of the aggregate variables, denoted by the vector S_t, are captured in the reduced form specification[56]

$$S_t = A_0 + A_1 S_{t-1} + u_t \tag{16}$$

where S_t is a vector of log income $\log(y_t)$, log house prices $\log(p_t)$, and the short-term interest rate r_t. u_t is the residual, which is normally-distributed with mean 0 and variance-covariance V. The estimation of Equation 16 are described in Section 6 below. Households make decisions knowing the distribution of these shocks.

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:

$$r_t^d = f^d(S_t) \tag{17}$$

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:

$$\log(p_t^r) = f^{pr}(S_t) \tag{18}$$

I describe the estimated functional forms of f^d and f^{pr} in Section 6.

5.5 Recursive formulation

I now summarize the recursive formulation of the household's maximization problem. In each period, households choose whether (i) to rent, (ii) to continue owning their same home and 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. Conditional on their adjustment decision, the households choose their level of non-durable consumption, savings in liquid one-period bonds, and their mortgage debt. The household problem is solved recursively. Section 1.3 of the online appendix describes the model computation in more detail.

[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.

The household's state variables are denoted by $z_{jat} = \{S_t, y_{jat}, \text{assets}_{j,a-1,t-1}\}$. The household faces uncertainty from two different sources: aggregate state variables, denoted by S_t, and their idiosyncratic labor income, denoted by y_{jat}. The term $\text{assets}_{j,a-1,t-1}$ is a vector of the asset-related variables, which include the start-of-period holdings of short-term asset ($s_{j,a-1,t-1}$), housing stock ($h^{\text{own}}_{j,a-1,t-1}$), mortgage balance ($b_{j,a-1,t-1}$) and the fixed rate associated with any existing mortgage ($R_{j,a-1,t-1}$).

Formally, in each period prior to retirement, the household solves:

$$V_{jat}(z_{jat}) = \max\left\{V_{jat}(z_{jat})^{\text{rent}}, V_{jat}(z_{jat})^{\text{own \& no-adjust}}, V_{jat}(z_{jat})^{\text{own \& adjust}}\right\} \tag{19}$$

Rent case

The value function of the agent decides to rent in period t is given by:

$$V_{jat}(z_{jat})^{\text{rent}} = \max_{c_{jat}, h^{\text{rent}}_{jat}, s_{jat}} \frac{\left(c^{\alpha}_{jat} \cdot h^{1-\alpha}_{jat}\right)^{1-\sigma} - 1}{1-\sigma} + E_{jat}\left[V_{j,a+1,t+1}(z_{j,a+1,t+1})\right] \tag{20}$$

s.t.

$$\begin{aligned}
h_{jat} &= h^{\text{rent}}_{jat} \\
c_{jat} + s_{jat} + p^r_t h^{\text{rent}}_{jat} &= y_{jat} + (1-\delta)p_t h^{\text{own}}_{j,a-1,t-1} + (1+r_t)s_{j,a-1,t-1} - b_{j,a-1,t-1}(1+R_{j,a-1,t-1}) \\
h^{\text{own}}_{jat} &= b_{jat} = 0 \\
s_{jat} &\geq -\underline{s} \\
\log(y_{jat}) &= \chi_a + \eta_{jat} + \phi_a(y_t/y) \\
S_t &= A_0 + A_1 S_{t-1} + u_t
\end{aligned}$$

and Equations 17-18 for the mortgage yields and rental rate.

Own & no-adjust case

If the agent decides to own a house and does not adjust any existing mortgage and housing stock in period t, the value function is given by:

$$V_{jat}(z_{jat})^{\text{own \& no-adjust}} = \max_{c_{jat}, s_{jat}} \frac{\left(c^{\alpha}_{jat} \cdot h^{1-\alpha}_{jat}\right)^{1-\sigma} - 1}{1-\sigma} + E_{jat}\left[V_{j,a+1,t+1}(z_{j,a+1,t+1})\right] \tag{21}$$

s.t.

$$
\begin{aligned}
h_{jat} &= (1-\delta)h^{\text{own}}_{j,a,t-1} \\
c_{jat} + s_{jat} &= y_{jat} + (1+r_t)s_{j,a-1,t-1} - M_{jat} \\
s_{jat} &\geq -\underline{s} \\
\log\left(y_{jat}\right) &= \chi_a + \eta_{jat} + \phi_a(y_t/y) \\
S_t &= A_0 + A_1 S_{t-1} + u_t
\end{aligned}
$$

and Equations 17-18 for the mortgage yields and rental rate. The variable M_{jat} denotes the constant mortgage payment based on Equation 13. The mortgage balance evolves according

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

and the mortgage rate remains fixed

$$R_{j,a,t} = R_{j,a-1,t-1}.$$

Own & adjust case

If the agent decides to own a house and pays a fixed cost to adjust any existing mortgage and housing stock in period t, the value function is:

$$V_{jat}(z_{jat})^{\text{own \& adjust}} = \max_{c_{jat}, s_{jat}, h^{\text{own}}_{jat}, b_{jat}} \frac{\left(c^{\alpha}_{jat} \cdot h^{1-\alpha}_{jat}\right)^{1-\sigma} - 1}{1-\sigma} + E_{jat}\left[V_{j,a+1,t+1}(z_{j,a+1,t+1})\right] \quad (22)$$

s.t.

$$
\begin{aligned}
h_{jat} &= h^{\text{own}}_{j,a} \\
b_{jat} &\leq (1-\phi)p_t h^{\text{own}}_{jat} \\
c_{jat} + s_{jat} + p_t h^{\text{own}}_{jat} - b_{jat} - F &= y_{jat} + (1-\delta)p_t h^{\text{own}}_{j,a-1,t-1} + (1+r_t)s_{j,a-1,t-1} - b_{j,a-1,t-1}(1+R_{j,a-1,t-1}) \\
s_{jat} &\geq -\underline{s} \\
\log\left(y_{jat}\right) &= \chi_a + \eta_{jat} + \phi_a(y_t/y) \\
S_t &= A_0 + A_1 S_{t-1} + u_t
\end{aligned}
$$

and Equations 17-18 for the mortgage yields and rental rate. F is the fixed cost of refinancing or entering a new loan. The mortgage rate updates to the current market rate

$$R_{jat} = r_t^{d(a)}.$$

Retirement and death

The problem for a retired household is identical, except that social security benefits replace labor earnings. Upon death, the agent bequeathes total net wealth:

$$W_{jat} = (1-\delta)p_t h^{\text{own}}_{j,a-1,t-1} + (1+r_t)s_{j,a-1,t-1} \tag{23}$$

6 Model Calibration

6.1 Demographics, initial asset positions and preferences

The model period is annual. I interpret the first period of life as 25 years of age. Households work for $T_y = 40$ years (between 25 and 64), and are retired for up to 20 years (between 65 and 85). Each year, agents face age-dependent survival probabilities, given by the U.S. actuarial life-expectancy tables and assume a maximum age of $T = 85$.[57] I initialize the model by giving the 25-year old agents holdings of housing and liquid assets and income to match the distribution of ages 20 to 29 households in the 2004 SCF.

As is standard in the risk-sharing literature, I set $\sigma = 2$ to generate an inter-temporal elasticity of substitution of 1/2. I follow Cocco, Gomes and Maenhout (2005) in setting the bequest parameter $B = 2$.

6.2 Jointly Calibrated parameters

There are 3 calibrated parameters in the model. The discount rate β and the utility parameter α are jointly estimated to target the average home-ownership rate of 66 percent in the SCF, and the median wealth-to-income ratio of 1.52 from the SCF data.[58] These targets yield $\beta = 0.962$ and $\alpha = 0.88$.

[57] 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.

[58] This follows Kaplan and Violante (2014) and Hurst et al. (2015).

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 refinancing fraction of 24 percent over 1999-2007.[59] Targeting this refinancing fraction 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.

6.3 Income

I exogenously set the parameters on the three components of pre-retirement income from Equation 15 as follows. First, I follow Floden and Lindén (2001) in 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.

The second component of earnings is the deterministic life-cycle earnings profile. I set the deterministic age-specific vector χ_a equal to the average log earnings for each age from 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.[60]

The third component of earnings is the exposure to aggregate fluctuations in the economy. I set the parameter ϕ_a based on the correlation between real aggregate income per capita and age-specific earnings in the CPS (see Appendix A.3 for more detail). Table 8 gives the estimated coefficients, which show a higher exposure of the earnings for young workers (25-34 years) and older workers (55-64 years) relative to the middle aged workers.[61]

During retirement, households receive social security benefits, which I calculate using the method of Guvenen and Smith (2014). This involves forecasting life-time income given

[59] The loan-level panel data is obtained from the Freddie Mac Single Family Loan-Level database. The data set covers 17 million 30-year, fixed-rate mortgages originated between January 1, 1999, and March 31, 2014. Using this data, I compute the average fraction refinanced loans in a year to the total stock mortgages. These are the new loans in each year which are recorded in the data as refinanced loans (inclusive of both cash-out and non-cash out refinancing).

[60] See Table 4 of Guvenen et al. (2015) for more detail. An alternative approach, used in the life-cycle literature, is to specify a quadratic functional form for the life-cycle earnings profile. This can then be estimated using PSID data. The two approaches lead to similar qualitative results in this model.

[61] 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.

income in the final period of working and then applying the actual benefits ratios from Social Security charts to this imputed lifetime income.

6.4 Aggregate variables

The parameters on the aggregate variables (income, house prices and short-term interest rate) in Equation 16 are exogenously set based on estimated coefficients from a reduced-form quarterly VAR of these variables over the period 1984-2007. The data on income and interest rates are obtained from the Federal Reserve Board. 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 then simulate the quarterly series to obtain an annual probability transition matrix for the aggregate states that is used in solving the household's decision problem.[62]

6.5 Mortgage rates

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

$$r_t^d = a_0 + a_1 r_t + a_2 \log y_t \tag{24}$$

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 24 for the 30-year, 15-year and 1-year real mortgage rates. I obtain the real mortgage rates by deflating the nominal mortgage rate using the break-even inflation rate implied from Treasury inflation protected bonds.[63] I then interpolate the mortgage rates with durations between 30, 15 and

[62] I estimate the process at a quarterly, rather than monthly, frequency because the house price data has a longer history at a quarterly frequency. For robustness, I also computed estimates based on the monthly series. The simulated annual process based on the monthly data is similar to the annual process based quarterly series.

[63] 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

1 year.[64] The estimated coefficients are shown in Table 12.

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 24. In Section 1.4 of the online appendix, I provide evidence that the specification in Equation 24 is a good approximation of the actual mortgage rate dynamics.

6.6 Housing constraints and prices

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.[65]

The house price-to-rent ratio is assumed to depend on the aggregate state of the economy:

$$\log(p_t^r) = \alpha_0 + \alpha_1 r_t + \alpha_2 \log y_t + \alpha_3 \log p_t \tag{25}$$

I estimate Equation 25 using the national house price and rent indices obtained from the Dallas Federal Reserve. See Column (III) of Table 12 for the regression coefficients.

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, and therefore define the relationship based on the data. In Section 1.4 of the online appendix, I plot the predicted values of house prices and rental ratios against the data to show that the specifications are a good approximation of actual dynamics in the data.

data from the period when TIPS liquidity was limited.

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

[65] I also considered other short-term constraints that allow for some borrowing. This did not change the qualitatively implications of the model.

7 Model Fit and Computational Experiments

7.1 Model Fit

The estimated model fits non-targeted life-cycle moments well. Figure 7 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 life-cycle profile of non-durable consumption, as well as the increase in the home-ownership rate by age. The model also replicates the rising profile of total wealth (housing net of mortgages plus short-term asset holdings). The model also captures the decline in household debt holdings over the life-cycle. The unconditional average moments in the model include: a home-ownership rate of 66 percent, a total wealth to income ratio of 1.52, and a debt-to-asset ratio of 15.8.

Given that the model is able to replicate life-cycle key moments, I now use it to perform two exercises. First, it is used to quantify how much of the differences between the consumption responses of the young and old are due to the refinancing and home-ownership channel. Second, the model is used to quantify the effects of the demographics structure on the aggregate consumption response to monetary policy shocks.

7.2 Monetary Policy Experiment

In this section, I examine the model predicted responses of consumption and refinancing decisions to interest rate shocks. Recall the aggregate state variables were $S_t = [\log y_t, \log p_t, r_t]$, which followed the process

$$S_t = A_0 + A_1 \cdot S_{t-1} + u_t \tag{26}$$

where u_t were the residuals with mean 0 and variance V.

A monetary policy shock ϵ_t affects the residuals u_t in the following way:

$$u_t = \Gamma(\epsilon_t) + \psi_t \tag{27}$$

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 that Equation 28 has the form

$$u_t = \Gamma_0 + \Gamma^+ \epsilon_t^+ + \Gamma^- \epsilon_t^- + \psi_t \tag{28}$$

where $\epsilon_t^+ = \max(\epsilon_t, 0)$ denotes the contractionary monetary policy shocks, and $\epsilon_t^- = \min(\epsilon_t, 0)$ denotes the expansionary monetary policy shocks.

I set the Γ parameters based on empirically estimated coefficients. Formally, I obtain an estimate for Γ by regressing the residuals u_t on the Federal Funds futures shocks (identified in Section 2). 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 28. 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.[66] 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.[67] The parameter coefficients are presented in Table 11.

Figure 8 shows the pass-through to the short-term interest rate, aggregate income, and prices after a 1ppt expansionary monetary policy shock based on Equations 26 and 28. 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. Figure 9 shows the flow-on effects from an initial contractionary monetary policy shock. The absolute magnitudes of the change in the short-term rate, aggregate income, and prices are smaller than the responses after an expansionary shock. This reflects the asymmetry in the contemporaneous responses to the sign of the shock in Equation 28.

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,

[66]See Section 3 for more discussion on the construction and identification of these shocks in the data.
[67]For instance, I do not impose the Cholesky decomposition of the shocks.

refinancing and home-ownership responses to a realistic monetary policy shock. 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

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

Similarly, the impulse response function to a one-standard deviation contractionary shock is computed as

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

7.2.1 Consumption Responses

Figure 10 shows the impulse response of aggregate consumption to an expansionary shock (left panel) and a contractionary shock (right panel). The solid lines are the model predicted consumption responses, while the light and dashed lines reflect empirical point estimates and 90 percent confidence intervals of the consumption responses from Section 4.[68] There is a pronounced and persistent effect of monetary policy shocks on aggregate consumption. Consumption rises by a peak of around 1 percent in response to an expansionary monetary policy shock, while consumption declines by 0.5 percent following a contractionary shock. The model predicted responses lie within the confidence intervals of the empirically estimated response functions.[69]

There is significant heterogeneity underlying the aggregate consumption response to interest rate shocks. First, Figure 11 shows that young people adjust their consumption by more than old individuals after both expansionary and contractionary shocks. For instance, young people adjust their consumption by 8 percentage points more than old people following an expansionary shock. The response generally declines with age. This is consistent with the empirical consumption elasticities, presented in Section 4, which were not directly targeted in the model. Second, Figure 11 highlights asymmetry in the consumption response to the sign of the shock. The difference in the response between young-old is particularly

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

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

pronounced for expansionary shocks. In contrast, the age heterogeneity is less dispersed following contractionary shocks.

7.2.2 Heterogeneity in Refinancing and Homeownership Decisions

Why does the consumption of young people respond so much more than old individuals following declines in interest rates? An important channel which exhibits substantial heterogeneity is the refinancing and homeownership decisions of households. To see why the refinancing and homeownership decision affects consumption, consider an interest rate decline. For households that do not refinance their existing loan, their mortgage rate remains fixed and there is no change in their interest payments. In contrast, households that do refinance their loan have their rate reset to the lower current mortgage rate. This reduces their interest payment, which boosts consumption. Similarly, a decline in interest rate can also reduce the user cost of housing services, relative to the rental rate, for a household that switched from being a renter to a homeowner. The heterogeneity in refinancing and homeownership decisions, and the flow-on effects to consumption are discussed further below.

A higher share of young people refinance their existing mortgages to take advantage of the lower rate after an expansionary monetary policy shock, as depicted in Figure 12. In contrast, very few older borrowers choose to refinance their existing mortgages. A similar picture is observed for new home ownership, which captures the extensive margin of mortgage adjustment. These model predicted responses for homeownership are consistent with the empirical findings in Kirkman, Justiniano and Wong (2015).

The refinancing and homeownership decisions translate to differences in the transmission of interest rate shocks to consumption across households. This is seen in Figure 13 which shows the average annual consumption elasticity to a one standard deviation expansionary monetary policy shock by age and refinancing decision. The consumption of those who refinance rises by significantly larger than that of those who do not refinance for all age groups. This reflects the impact of lower mortgage payments arising from the reduction in interest rate for those who refinance their existing mortgage. Since young people have a greater propensity to adjust their loans, this translates to a higher average consumption response to monetary policy shocks.

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 19 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.[70] This intuition is reflected in Figure 14. The left panel shows the fraction of borrowers that refinance by loan size distribution (from low to high). The figure shows that the fraction of borrowers who refinance rises with loan sizes. There is a jump in the fraction of borrowers that refinance between the 40th and 60th loan size percentile, consistent with the presence of the fixed cost of refinancing. The propensity to refinance then steadily increases with loan size to close 90 percent.[71] The right panel shows that young people have much larger debt holdings relative to old individuals, reflecting the life-cycle borrowing profile.[72] As a result, young people have a higher propensity than old individuals to adjust their existing mortgages in response to expansionary monetary policy shocks.

The refinancing channel does not exist in standard models with variable short-term mortgage rates. In these models, the interest rate shock passes through to all households that hold mortgages, and there is no variation across households in the magnitudes of the mortgage rate changes.[73]

A similar intuition can be seen in the extensive margin decision to become a homeowner. Figure 15 shows that going from a renter to a homeowner after an expansionary monetary policy shock results in greater consumption, for all age groups, relative to remaining a renter. This reflects the decline in the user cost of housing relative to the rental rate due to the lower interest rate, which boosts the consumption of housing services and non-durable goods.[74]

[70] The intuition is that effectively the cost is spread out over a larger loan size and duration, therefore the percentage interest saving is higher.

[71] The rise in the fraction of borrowers that refinance by loan size also exists if the sample of borrowers is split by high and low holdings of short-term assets, and by high and low income.

[72] In the 2007 Survey of Consumer Finances, the median mortgage balance outstanding for young, middle aged and old borrowers were $150,000, $100,000, and $70,000 respectively.

[73] 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. By entering a new home loan, the household can potentially lower the owner-occupied expenses, due to lower interest payments, relative to the per-period rental expense. Evidence of the increase in consumption following the switch from renter into homeownership is given in **?**.

[74] It is possible to derive an analytical expression for the user cost of housing for the case where transaction costs are smooth and convex, and there is no fixed-rate mortgage structure (see for example, Dìaz and Luengo-Prado (2011)).

7.2.3 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 shutdown 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 within this standard model arise from the usual income, substitution, Fisher, and other life-cycle effects.

Figure 16 shows the consumption responses for different age groups, relative to old individuals, following an expansionary interest rate shock.[75] 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 16 shows that the relative consumption response for the youngest two groups (< 35, and $35 - 44$ years) is 0.8 percent and 0.4 percent higher than the oldest age group, respectively. The difference in consumption response for the two youngest groups relative to the response of old individuals declines by 40 percent when refinancing is excluded. This implies that the refinancing channel explains around 40 percent of the different in consumption responses between young and old, in response to interest rate shocks.

The remaining 60 percent is accounted for the standard income and substitution effects, and the Fisher channel, which have been emphasized in existing literature on the redistributive effects of monetary policy.[76] This paper adds to this literature by highlighting the importance of an alternative mechanism for explaining life-cycle elasticites: the mortgage adjustment channel.

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

[76] 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*).

7.3 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. Given this age-specific heterogeneity, I now ask how the aggregate consumption response will change as the population ages.

I conduct a second experiment using the model, where I quantify the aggregate consumption responses to a monetary policy under two different economies. The two economies are identical in terms of utility preferences and mortgage market structure, but differ in their demographics. I consider the demographic structures of Florida and California, since these two states provide a wide bound on the range of old-young ratios across the U.S. states. Florida has an older demographic structure relative to the national average, while California has a younger demographic structure. The young-to-old ratio is 1.32 in Florida and 0.67 in California, compared to a national average of 0.82. Florida is also a particularly relevant case, since its current young-old ratio is equivalent to the projected national young-old ratio in 2060.[77]

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. To take into account the possible effects on interest rates and employment, I estimate state-specific aggregate processes.[78]

Specifically, the Florida state-process is given by

$$S_{f,t} = B_0 + B_1 \cdot \mathrm{Pop}_f^{O/Y} \cdot S_{f,t-1} + u_{jt}$$

[77] The projected young-old ratio is obtained from the United Nations population forecasts.

[78] The idea is that general equilibrium effects of differences in demographics will be reflected in the state-level data use to estimate the state-specific processes, since the data reveals equilibrium outcomes within the states.

and the California state-process is given by

$$S_{c,t} = B_0 + B_1 \cdot \mathrm{Pop}_c^{O/Y} \cdot S_{c,t-1} + u_{jt}$$

where $\mathrm{Pop}_f^{O/Y}$ and $\mathrm{Pop}_c^{O/Y}$ denote the average ratio of the old-young population in Florida and California, respectively, over 1980-2007 (where old and young are defined as those aged over 65 and those aged between 25 and 35, respectively). Appendix F describes the estimation procedure and coefficients in more detail. The estimated coefficients of the aggregate variables are shown in Table 13.

I solve the household's decision recursively for Florida and for California, under the state-specific aggregate processes. I then compute the aggregate consumption response to a one-standard deviation expansionary interest rate shock.

Based on this exercise, I find that the aggregate consumption response to interest rate shocks is lower in Florida and higher in California than the national average. Specifically, I find that in Florida, where the old-young ratio is 63 percent higher than the national ratio, the aggregate consumption response is 33 percent less than for the national response (Table 14, Column 2). This implies that, on average, for every 1 percent rise in the old-young ratio, the aggregate consumption response to an interest rate shock declines by 0.5 percent (this is given by 0.33/0.63). Similarly, in California, where the old-young ratio is 13 percent lower than the national ratio, the aggregate consumption response is 9 percent more than for the national response (Table 14, Column 3). This implies that, on average, for every 1 percent rise in the old-young ratio, the aggregate consumption response to an interest rate shock declines by 0.7 percent (this is given by 0.09/0.13).

The U.N. projects that the old-young ratio in the U.S. will increase by 50 percent by 2035. The Florida and California results suggest that the projected 50 percent increase in the share of old to young can potentially dampen the aggregate consumption response to interest rate shocks by 26-35 percent.[79] These results imply that population aging can significantly dampen the transmission of monetary policy to aggregate consumption.

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. However, it is worth noting that this approach abstracts from other potential effects

[79] This is computed for Florida as 0.33/0.63 times 50 percent, and for California as 0.13/0.1 times 50 percent. This calculation gives the average effect of the 50% increase in share of old-young, assuming linearity in the age effects.

of demographics on variables such as the level of the interest rate, which can then have effects on the aggregate savings rates and capital accumulation.[80] My set-up also abstracts from other considerations related to labor force participation trends, and possible changes to social security and fiscal policy, which could have implications for the transmission of monetary policy. 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 of monetary policy.

8 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 refi-

[80]These factors have been discussed in papers including Auerbach and Kotlikoff (1985), Auerbach et al. (1989) and Ríos-Rull (2001).

nancing and new lending channel for explaining the difference in 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. Second, I examine the implications of population aging by considering two economies: Florida and California. These results imply that population aging can significantly dampen the transmission of monetary policy to aggregate consumption.

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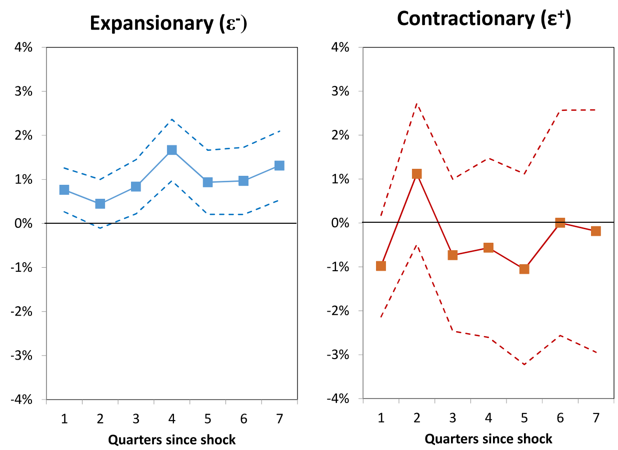
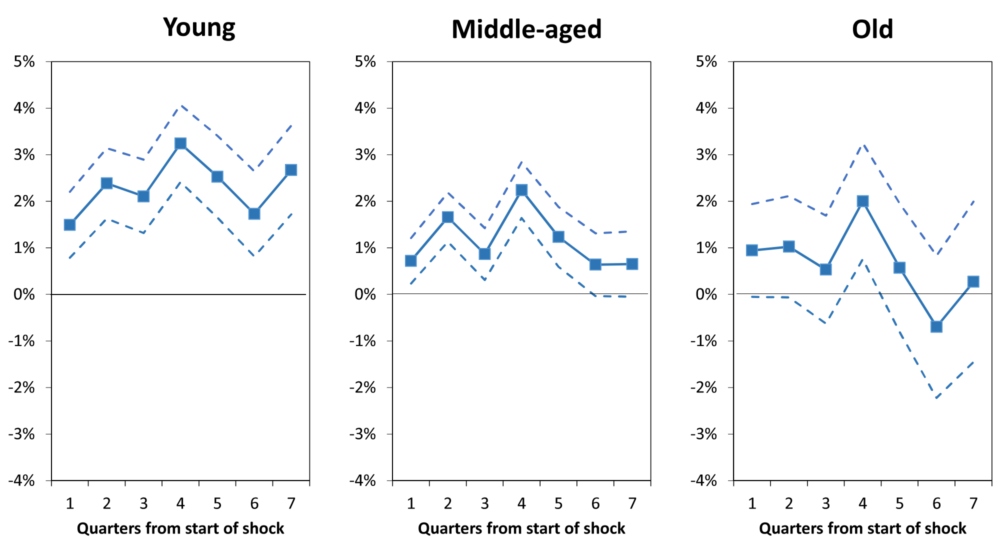
9 Figures: Empirics

Figure 1: Consumption Response to a Monetary Policy Shock



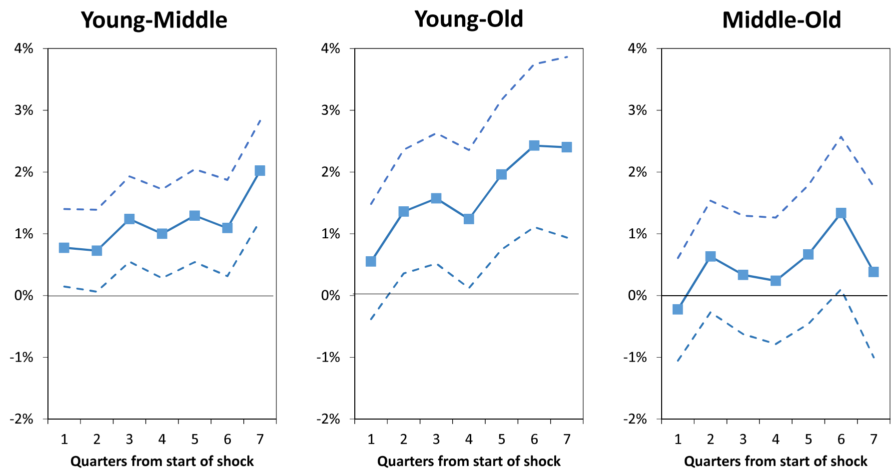
Notes: This figure depicts the impulse response function to a 1 standard deviation monetary policy shock. The solid lines plots the coefficients from Equations 4 and 5. The dashed lines depict the 90 percent confidence intervals.

Figure 2: Consumption Response to an Expansionary Monetary Policy Shock



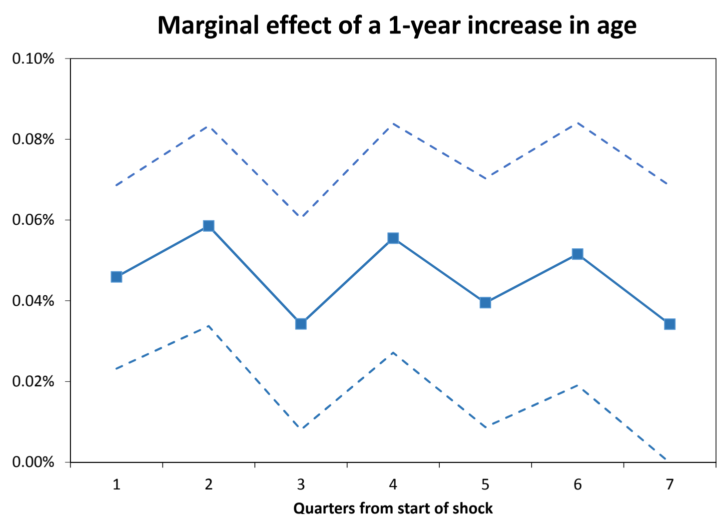
Notes: This figure depicts the impulse response function to a 1 standard deviation expansionary monetary policy shock for the young, middle aged and old separately. The solid lines plots the coefficients from Equation 4. The dashed lines depict the 90 percent confidence intervals.

Figure 3: Difference in Consumption Response Between Age Groups



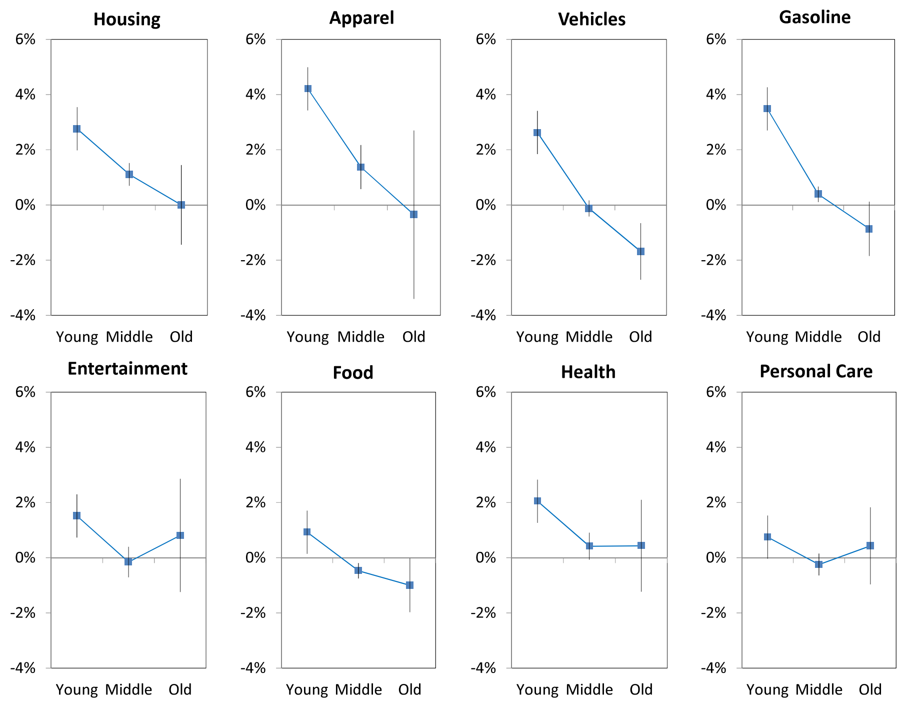
Notes: This figure depicts the differential impulse response function to a 1 standard deviation expansionary monetary policy shock for the young relative to the middle (left panel), young relative to the old (middle panel), and middle relative to the old (right panel). The dashed lines depict the 90 percent confidence intervals.

Figure 4: Impulse response functions of consumption



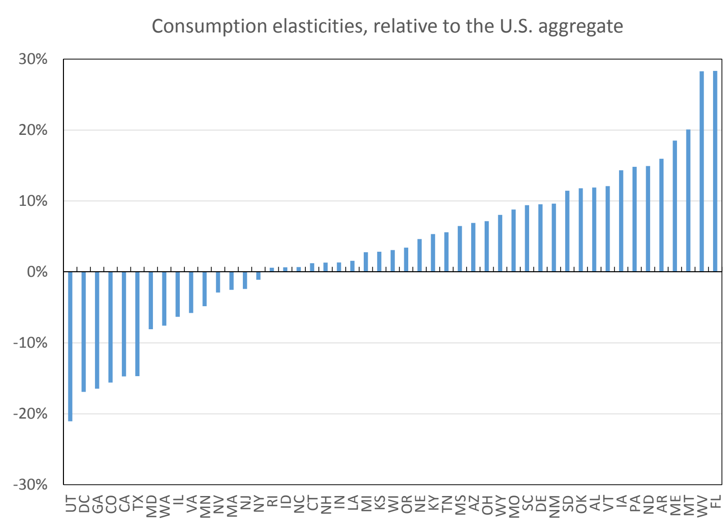
Notes: This figure depicts the marginal effect of age on the impulse response function of consumption to a one standard deviation expansionary monetary policy shock. The dashed lines plot the 90% confidence interval.

Figure 5: Difference in Consumption Response Between Age Groups



Notes: This figure depicts the annual elasticity to a 1 standard deviation expansionary monetary policy shock for the young (25-35), middle (36-65) and old (65+) within each product category.

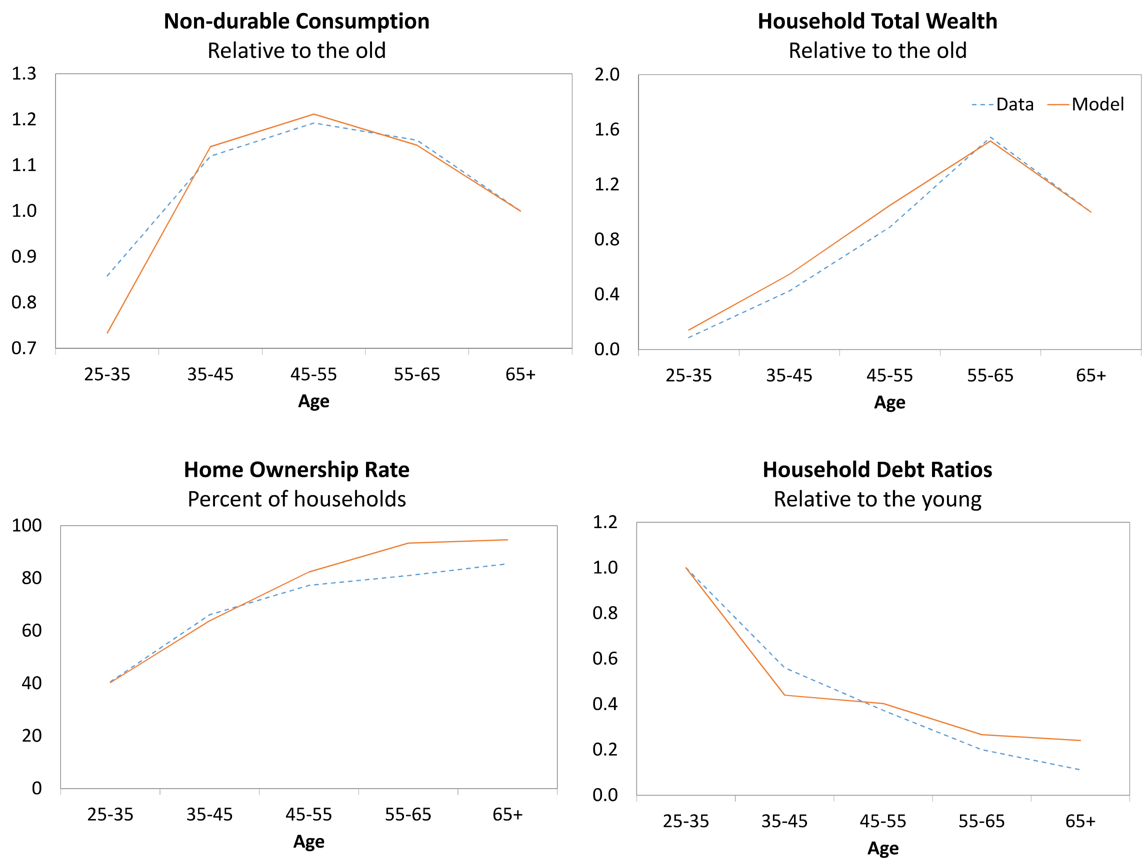
Figure 6: Annual Consumption Elasticities Across U.S. States



Notes: This figure depicts the annual consumption elasticities to a 1 standard deviation monetary policy shock in each of the states relative to the national average. Each bar is computed based on Equation 12, which conditions on demographics and controls for other non-demographic state factors. See text for more detail.

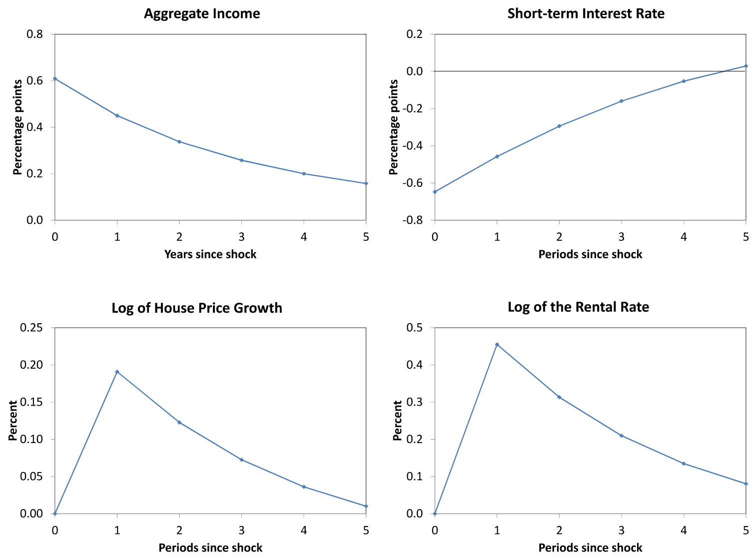
10 Figures: Model

Figure 7: Life-cycle Consumption and Asset Profiles: Model vs Data



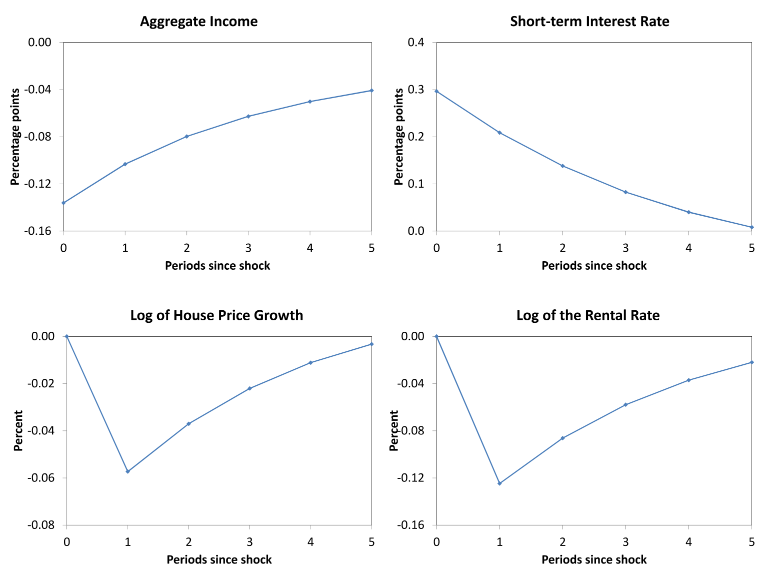
Notes: This figure depicts four key life-cycle moments by age group: non-durable consumption, total household wealth, homeownership rate, and household leverage (debt to asset ratio). Each panel plots both the model implied average moments (solid line) and the empirical moments (dashed line), which are from the CEX data (for non-durable consumption) and the 2004 Survey of Consumer Finances for wealth, homeownership and leverage.

Figure 8: Response to an Expansionary Monetary Policy Shock



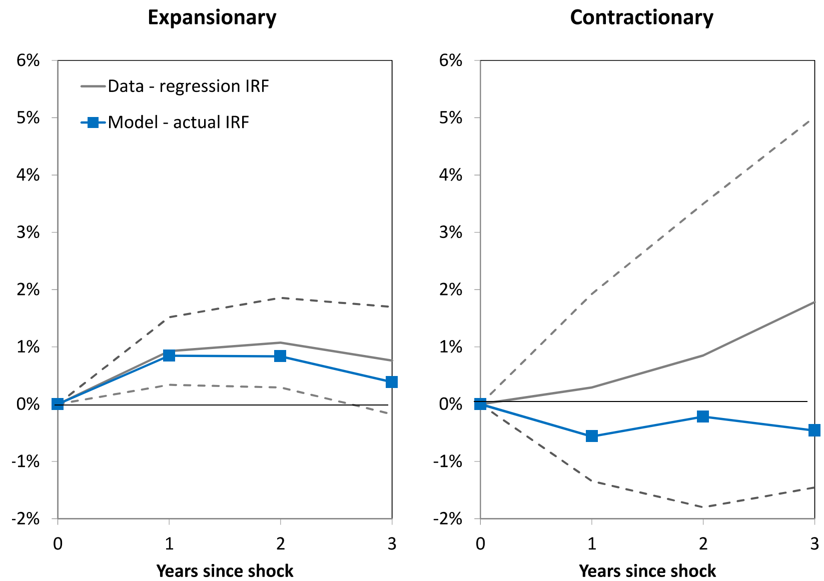
Notes: This figure depicts the annual impulse response functions for aggregate income, the short-term interest rate, log of house price growth, and log of house price to rent ratio following a 1ppt expansionary monetary policy shock. See text for more detail.

Figure 9: Response to a Contractionary Monetary Policy Shock



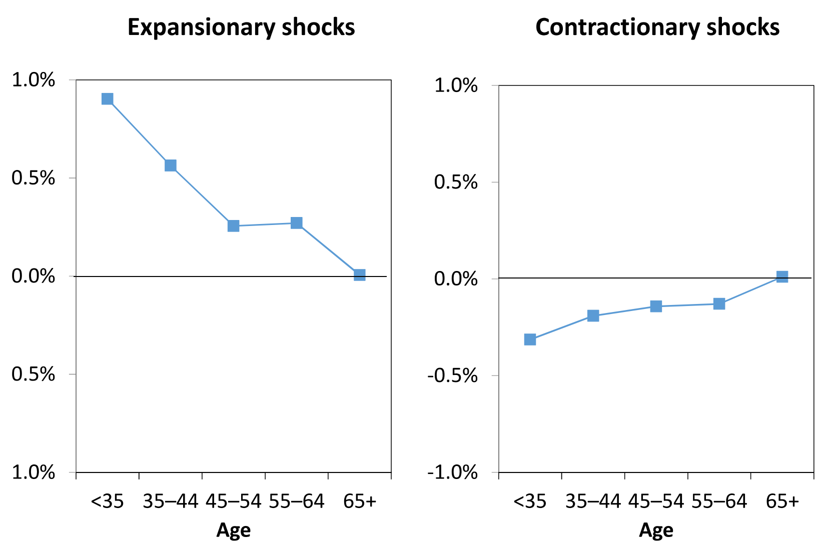
Notes: This figure depicts the annual impulse response functions for aggregate income, the short-term interest rate, log of house price growth, and log of house price to rent ratio following a 1ppt contractionary monetary policy shock. See text for more detail.

Figure 10: Response of Aggregate Consumption a Monetary Policy Shock



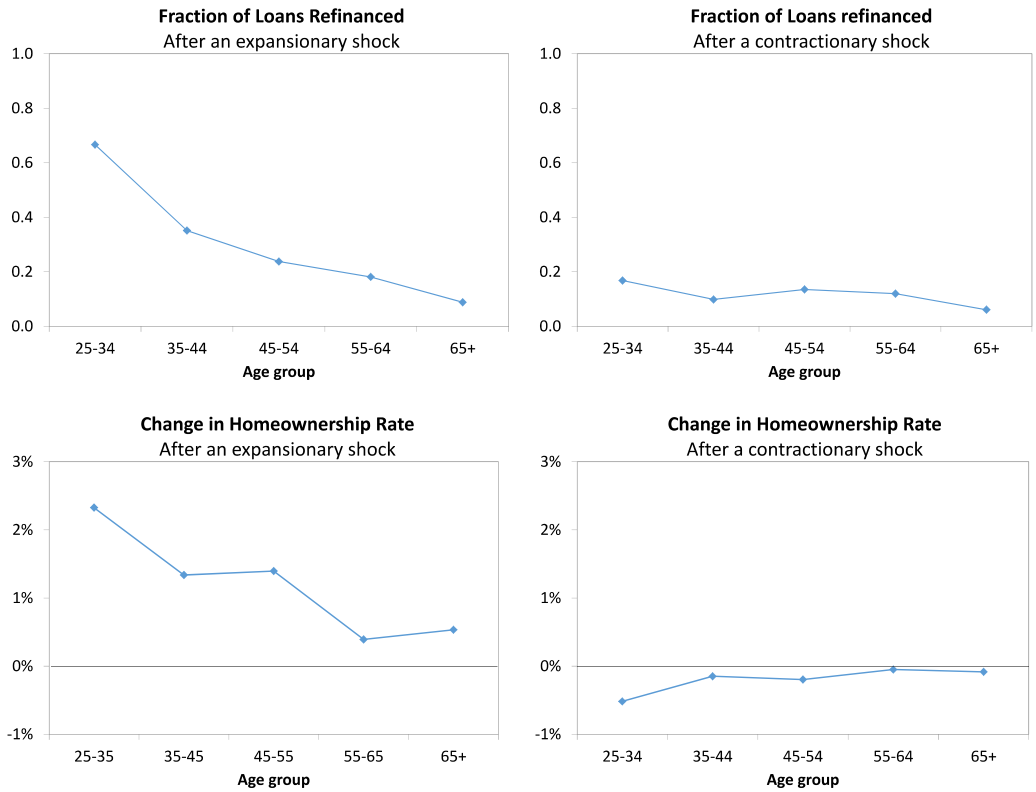
Notes: This figure depicts the impulse response function of aggregate consumption to a 1 standard deviation shock to monetary policy. The grey solid line depicts the empirically estimated response. The dashed lines are the 90 percent confidence interval. The blue lines with square points are the model implied impulse response functions.

Figure 11: Age-specific Consumption response to a Monetary Policy Shock



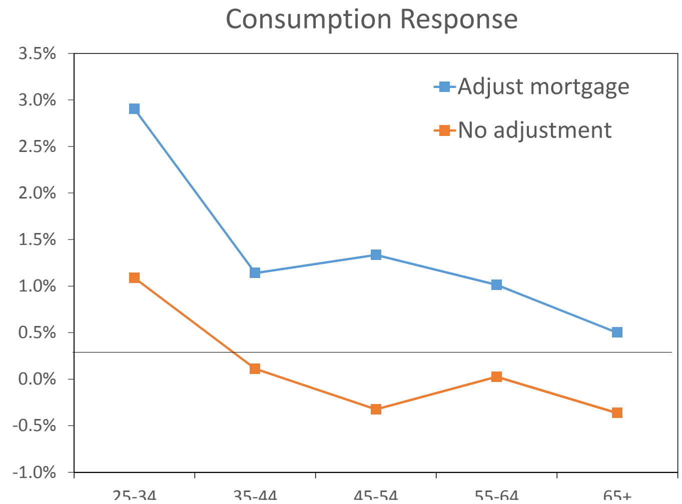
Notes: This figure depicts the model implied impulse response function of aggregate consumption by age group to a 1 standard deviation shock to monetary policy.

Figure 12: Age-specific Consumption Response to a Monetary Policy Shock



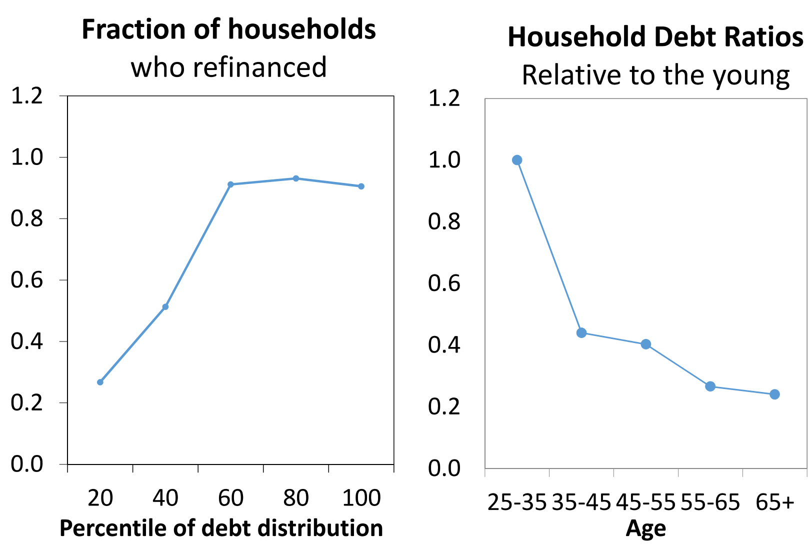
Notes: This figure depicts the fraction of loans refinanced and change in the homeownership rate by age group following a 1 standard deviation shock to monetary policy. The left panels show the responses after an expansionary shock. The right panels show the responses after a contractionary shock.

Figure 13: Age-specific Consumption Responses by Refinancing Decision



Notes: This figure depicts the annual consumption elasticity by age and mortgage adjustment decisions, following an expansionary monetary policy shock.

Figure 14: Age-specific Consumption Response to a Monetary Policy Shock



Notes: The left panel shows the fraction of loans refinanced by loan size following a one standard deviation expansionary monetary policy shock. The right panel plots the average debt holdings relative to the young, by age.

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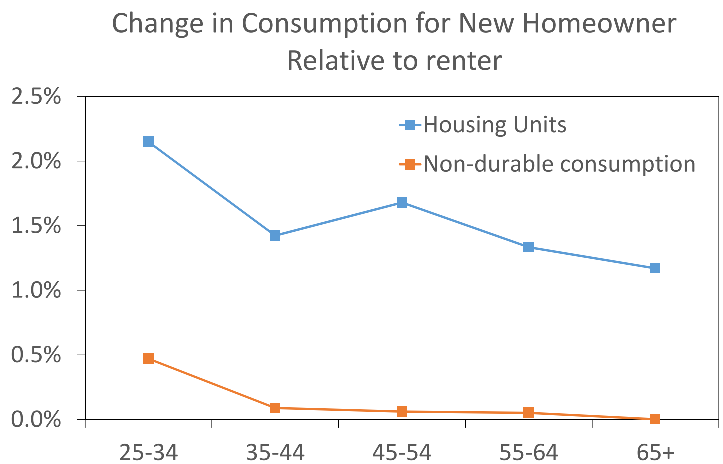
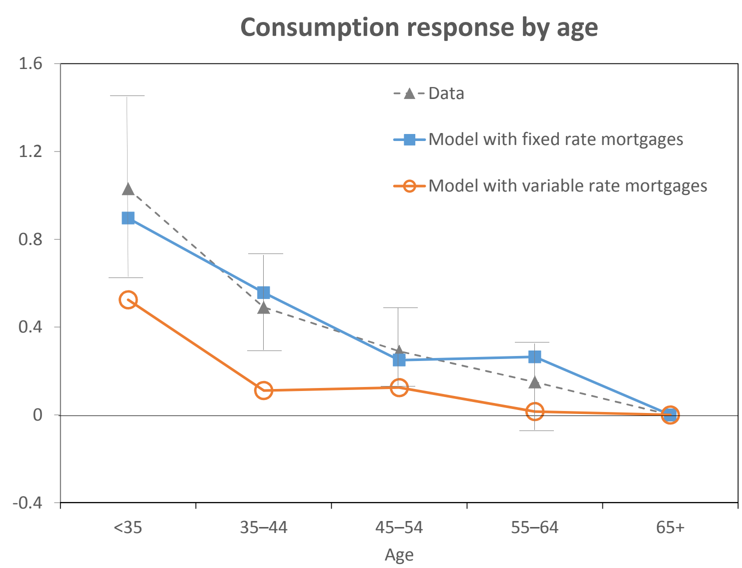
Figure 15: Age-specific Consumption Responses for New Homeowners



Notes: This figure depicts the change in consumption of non-durable goods and units of housing services for individuals who become new homeowners, by age. See text for more detail.

Figure 16: Decomposing the Effects of Monetary Policy on Consumption



Notes: This figure depicts consumption response to a 1 standard deviation expansionary monetary policy shock for each age group relative to the old. The grey lines depict the empirically estimated elasticities using the Nielsen Homescan data. The bars represent the 90 percent confidence interval. The blue line depicts the age specific elasticities implied by the full model with fixed-rate mortgages and fixed costs. The orange line depicts the age specific elasticities implied by the model with variable rate mortgages.

11 Tables: Empirics

Table 1: Response of Mortgage Rates to Monetary Policy Shocks

Indicator	1-year rate	15-year rate	30-year rate
	(I)	(II)	(III)
Current month shock	0.439***	0.197*	0.184*
	(0.0809)	(0.116)	(0.106)
Path shock	0.215***	0.322***	0.332***
	(0.0767)	(0.103)	(0.0963)
Total effect	0.654***	0.519***	0.516***
	(0.111)	(0.155)	(0.143)

Notes: This table shows change in the mortgage rates to a 1 percentage point monetary policy shock. The regressions are estimated over the sample period 1990-2007 for the 1-year adjustable mortgage rate and the 30-year fixed mortgage rate, and the period 1991-2007 for the 15-year fixed mortgage rate (which is only available from 1991 onward). I consider two types of monetary policy shocks: the shock in the current month and the shock to the path of the Federal funds rate (the GSS path shock). The total effect is the sum of the current and path shock effects. Each row is based on a separate regression of the mortgage rate on the shock. Standard errors are in parentheses. ***, **, and * denote the 1, 5 and 10 % significance levels, respectively. See text for more detail.

Table 2: Annual Elasticities of Consumption

CEX data	**Young**		**Middle**		**Old**
	25-34		35-64		65+
Total	2.39		0.76		0.40
	(0.48)		(0.34)		(0.72)
Durables	3.23		1.57		0.44
	(0.73)		(0.52)		(1.11)
Non-durables	1.94		0.07		-0.24
	(0.39)		(0.28)		(0.59)
Nielsen data			**Ages**		
	25-34	35-44	45-54	55-64	65+
Non-durables (food)	1.04	0.50	0.30	0.16	0.01
	(0.22)	(0.12)	(0.10)	(0.11)	(0.11)

Notes: This table shows the annual elasticities of consumption to a 1 standard deviation expansionary monetary policy shock, based on Equation 6. Standard errors are in parentheses. The elasticities are estimated using the CEX data (top panel) and the Nielsen Homescan data (bottom panel).

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

	Annual Elasticity (I)	Share of total C (II)	Contribution to total elasticity: in ppt (III)	Contribution to total elasticity: % of total (IV)
Total Consumption				
Young	2.39%	33%	0.80%	65%
Middle	0.76%	56%	0.43%	35%
Old	0.00%	10%	0.00%	0%
Total	**1.22%**	**100%**	**1.22%**	**100%**
Non-durables				
Young	1.94%	31%	0.61%	100%
Middle	0.00%	57%	0.00%	0%
Old	0.00%	12%	0.00%	0%
Total	**0.61%**	**100%**	**0.61%**	**100%**
Durables				
Young	3.23%	34%	1.11%	56%
Middle	1.57%	56%	0.88%	44%
Old	0.00%	10%	0.00%	0%
Total	**1.99%**	**100%**	**1.99%**	**100%**

Notes: This table shows the annual elasticities of consumption by age group in column (I). The elasticities are obtained by estimating Equation 6 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. See text for more detail.

Table 4: Homeownership and Mortgage Statistics

	Young	**Middle**	**Old**
	25-34	35-64	65+
Homeownership rate	48%	73%	78%
Fraction with mortgages	43%	54%	22%
Median loan size	108,322	93,178	61,118
Median loan duration (years)	27.00	21.50	16.25
Fraction of loans at fixed rates	78%	80%	82%

Notes: This table shows homeownership and mortgage statistics for each age group. The statistics are based on the CEX detailed expenditure data over the sample period 1993-2007.

Table 5: Consumption Elasticities

	Young	**Middle**	**Old**
	25-34	35-64	65+
Own housing and adjust loan	6.54***	5.30***	3.57
	(2.45)	(2.09)	(9.20)
Own housing and do not adjust loan	2.43***	0.87*	1.11
	(0.75)	(0.46)	(1.55)
Renters	0.62	0.12	-1.78
	(0.72)	(0.63)	(1.66)

Notes: This table shows consumption elasticities to a 1 standard deviation interest rate shock, for each age group, split by homeownership and loan adjustment. The elasticities are estimated using the CEX detailed expenditure (MOR) data and interview data over the sample period 1993-2007. See text for more detail.

Table 6: Loan Adjustment Behavior by Household Age

	Young	**Middle**	**Old**
	25-34	35-64	65+
Propensity to adjust loan	0.386***	0.12**	0.07
	(0.02)	(0.01)	(0.06)
Fraction of households within age group:			
- Own housing and adjust loan	0.19	0.09	0.05
- Own housing and do not adjust loan	0.30	0.64	0.72
- Renters	0.52	0.27	0.22

Notes: This table shows the average annual propensity to adjust a loan (given the household owns a home) by age. The standard errors are in parentheses and the 1, 5 and 10 significance levels are denoted by ***, **, and *, respectively. These estimates use the CEX data over the sample period 1993-2007.

Table 7: Loan Adjustment Behavior by Loan Size

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

Notes: This table shows the average annual propensity to adjust a loan (given the household owns a home) by quintile of loan size. Q1 and Q10 denote the smallest and largest 10% of loans in the loan size distribution, respectively. The standard errors are in parentheses and the 1, 5, and 10 percent significance levels are denoted by $***$, $**$, and $*$ respectively. The propensities are estimated using the Freddie Mac Loan Performance micro data, which spans 2000-2007. See text for more details.

12 Tables: Model

Table 8: Income Exposure to Aggregate Activity by Age

Age group	25-34	35-44	45-54	55-64
ϕ_a	4.633	1.655	3.626	0.358

Notes: This table shows the estimated coefficient ϕ_a for each age group a from Equation 15. This is obtained from an regression of the log earnings of each group on the log of the 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
	(0.0398)	(0.1011)	(7.3927)
$\log p_{t-1}$	0.002	0.9827	0.9629
	(0.005)	(0.0118)	(0.864)
r_{t-1}	-0.0001	-0.0013	0.9173
	(0.0002)	(0.0005)	(0.035)
constant	-0.0097	-4.5682	0.0930
	(0.1634)	(0.4146)	(30.323)

Notes: This table shows the estimated coefficients for Equation 16. 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. Standard errors are in parentheses. See text for more detail.

Table 10: Aggregate Processes: Variance-Covariance Matrix

	u_t^y	u_t^p	u_t^r
u_t^y	0.0029		
u_t^p	0.0371	0.5261	
u_t^r	0.0014	-0.0008	0.0072

Notes: This table shows the variance-covariance matrix of the residuals from the estimation of Equation 16. See text for more detail.

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
	(0.003)	(0.008)	(0.393)
Γ^+	0.001	-0.012	0.296
	(0.008)	(0.021)	(1.072)

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 28, estimated using high-frequency Federal Funds futures shocks. Standard errors are given in parentheses. See text for more detail.

Table 12: Real Mortgage Rates, House Prices and Rental Rates

Variables	30-year rate	15-year rate	1-year rate	$\log\left(p_t^R\right)$
	(I)	(II)	(III)	(IV)
$\log(y_t)$	-3.475	-2.272	3.093	0.843
	(0.168)	(0.156)	(0.059)	(0.119)
r_t	0.334	0.392	0.415	-0.002
	(0.058)	(0.053)	(0.029)	(0.001)
$\log(p_t)$				-0.022
				(0.014)
constant	-0.030	-0.029	0.027	3.187
	(15.82)	(14.618)	(5.619)	(0.488)

Notes: This table shows the estimated processes for real mortgage rates and rental rates from Equations 24-25. The sample period is 1988-2007. The data are from the Federal Reserve Board, St Louis Federal Reserve Bank and Freddie Mac. Standard errors are in parentheses.

Table 13: State-level Aggregate Processes: Coefficients

Variables	y_{jt}	p_{jt}	r_t
$y_{j,t-1}$	0.981	0.024	0.632
	(0.009)	(0.023)	(0.588)
$p_{j,t-1}$	-0.010	0.973	-0.173
	(0.006)	(0.013)	(0.343)
r_{t-1}	-0.001	-0.002	0.916
	(0.0003)	(0.001)	(0.02)
$y_{j,t-1} \times \text{Pop}_{jt}^{O/Y}$	0.011	-0.033	-1.141
	(0.011)	(0.027)	(0.702)
$p_{j,t-1} \times \text{Pop}_{jt}^{O/Y}$	0.015	0.007	0.644
	(0.007)	(0.016)	(0.412)
$r_{j,t-1} \times \text{Pop}_{jt}^{O/Y}$	-0.0003	0.0001	0.015
	(0.0004)	(0.001)	(0.023)
$\text{Pop}_{jt}^{O/Y}$	-0.002	0.019	0.125
	(0.003)	(0.007)	(0.191)
constant	0.017	-0.043	0.347
	(0.002)	(0.005)	(0.143)

Notes: This table shows the estimated processes for state j in period t income y_{jt}, house prices p_{jt}, and short-term interest rate r_t. The variable $\text{Pop}_{jt}^{O/Y}$ denotes the ratio of the old (aged over 65) to young (aged under 35) population. Standard errors are in parentheses. All regressions control for state-specific non-demographic variables (including sector composition and house price elasticities). See text for more detail.

Table 14: Estimated state-level aggregate processes

	U.S.	Florida	California
Population share			
25-34	25%	20%	26%
35-44	23%	22%	25%
45-54	18%	18%	19%
55-65	14%	15%	13%
65+	19%	26%	17%
Share of Old-Young	0.82	1.32	0.67
Aggregate C elasticity	0.54%	0.37%	0.58%
Relative to U.S.		-33%	9%

Notes: This table shows the population structure in the U.S., Florida and California, sourced from the Census. The first panel shows the share of total population for each age range, and the average ratio of the old to young over 1980-2007. The bottom panel shows the estimated response of aggregate state-specific consumption to a 1 standard deviation expansionary monetary policy shock.

A Data

A.1 CEX Data

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

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

Following Aguiar and Hurst (2013), Coibion, Gorodnichenko and Hong (2015), and others, I restrict the sample to ensure that the data is comparable over time. Specifically, I restrict the sample to include only households where the head of household is aged between 25 and 75 years (inclusive). To reliably estimate cohort effects, I include only households who are born between 1914 and 1973 inclusive, to ensure that each cohort has at least 10 years of data. The sample includes only households who report expenditures in all four quarters of the survey, and with non-zero food expenditure. Only urban households are included in the sample, since the BLS did not interview rural households prior to 1983. I also restrict households with complete income reports, and with at least three monthly observations per quarter. This leaves 235,933 households in total over the period 1980-2007.

There are some well documented measurement errors within the CEX data.[81] Over time, total spending measured by the CEX has fallen relative to the National Income and Product

[81] For a discussion of these issues, see for example, Aguiar and Hurst (2013) and Aguiar and Bils (2011).

Accounts (NIPA) measure. Moreover, the discrepancy has differed by consumption category. I approach this measurement issue in three ways. First, I note that this discrepancy will not affect the interpretations of the age-specific estimated results in this paper if the discrepancy in reporting is uniform across the age groups. That is, the comparison of old and young households will not be affected, even though the levels of expenditure are mismeasured. Second, for robustness, I recompute age-specific elasticities for consumption categories where has been little deterioration in the ratio of the CEX spending to NIPA spending over the past two decades.[82] Third, I repeat the analysis using a separate data set, the Nielsen Homescan data (described below), which is not subject to the same types of measurement issues as the CEX. The results in this paper are qualitatively robust within both the narrower CEX consumption categories and the Nielsen Homescan data.

A.2 Nielsen data

Participating households record the data using hand-held scanners at home. The households record the store where the product was purchased, the date and quantity purchased at the Universal Product Code (UPC) level. Prices come from one of two sources. If the store where the product was purchased is one that reports prices to Nielsen as part of their store-level survey, then Nielsen obtains the price from the store data. Nielsen also reports the price paid which can include panelist-reported prices or Nielsen-ascribed prices if the panelist does not, or is not required to, enter a price.[83]

A.3 Mortgage data

I use the CEX detailed expenditure files on owned living quarters and other owned real estate and mortgages, over the sample period is 1993-2007. Some of the variables are unavailable prior to 1993, and therefore I focus on the period starting from 1993. I obtain the data from the BLS for the period 1996-2007, and the Inter-university Consortium for Political and Social Research (ICPSR) at the University of Michigan for the period 1993-1995. I focus on

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

[83] One concern with self-reported data is that the data may be recorded with error. However, Einav, Leibtag and Nevo (2010) compare the self-reported data in Homescan with data from cash registers and conclude that the reporting error is of similar magnitude to that found in commonly used economic data sets.

loans related to owner-occupied, by restricting the sample to loans for purchase of properties that the home of residence. This is based on the observations with a property code equal to 100, which denotes "The home in which you (your CU) currently live(s)").

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

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

The second data source that I use to examine loan-adjustment propensities is the Freddie Mac Single Family Loan-Level data.[84] This is loan-level panel data of all 30-year mortgages securitized by Freddie Mac. I merge the loan origination data file (with loan characteristic information, such as the original leverage ratios and credit scores) with the monthly panel performance data files. I keep only non-delinquent loans and loans with positive balances. I deflate the current loan balances using the BLS price index to obtain a measure of real loan balances, as at 1983. In total, there are approximately 17 million housing loans in the sample period of 2000-2007.

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

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

loan adjustment for all types of loan adjustments.

A.4 CPS Data

I use the quarterly CPS data over 1982-2007 to compute the correlations between age-specific earnings and aggregate earnings. I construct synthetic cohorts of earnings based on age groups, educational attainment, and gender. I define the age groups based on 10-year age buckets. Educational attainment is defined based on three groups: college educated, high-school diploma or less than 2 years of post-high school education, and no high school diploma. These definitions ensure that there are at least 657 individuals within each group per quarter, and an average of 2,648 individuals per group-quarter. I then regress the log earnings of each group on the log of the de-trended aggregate per-capita income interacted with the 10-year age range of the group, controlling for age-education-gender fixed effects and a linear time trend. The coefficients are shown in Table 8.

B Constructing age-specific price indices

Using the Nielsen data, I deflate total spending by age-specific price indices to focus on differences in life-cycle quantity response. The price indices are computed monthly. The approach is comparable to the BLS chained consumer price index approach.[85] Specifically, I compute the price index for individuals of age a in period t as:

$$P_t^a = P_{t-1}^a \times \frac{\sum_{i \in I} P_{it}^a \cdot q_{i,y(t)}^a}{\sum_{i \in I} P_{i,t-1}^a \cdot q_{i,y(t)}^a} \tag{29}$$

The price of a specific good i (within the set of UPCs I) in month t paid on average by individuals of age a is denoted by P_{it}^a. It is computed as a quantity weighted average over all households h of age a (the set is denoted by $H(a)$):

$$P_{it}^a = \sum_{h \in H(a)} \sum_{w \in t} P_{hiw}^a \times \frac{q_{hiw}^a}{\sum_k q_{kiw}^a}$$

where q_{hiw}^a denotes the quantity purchased in week w within the month t.

[85]Beraja, Hurst and Ospina (2015) also follow a similar approach for constructing region-specific price indices using the Nielsen data.

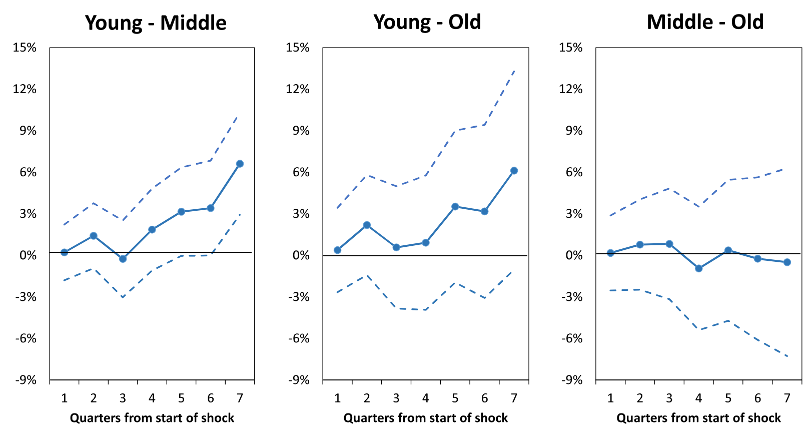
The variable $q^a_{i,y(t)}$ in Equation 29 denotes the average monthly quantity of good i purchased in year $y(t)$ by households of age a. It is computed as:

$$q^a_{i,y(t)} = \sum_{t \in y(t)} \sum_{h \in H(a)} \frac{q^a_{hit}}{H \times T}$$

This represents the weight on the price on each good i in age-specific price index in Equation 29. The weight is fixed over all months within the year and is updated annually. An alternative approach would be to have the weights fixed over the entire sample. I find the results are qualitatively robust to the two approaches.

C Contractionary monetary policy shocks

Figure 17: Difference in Consumption Response between Age Groups



Notes: This figure depicts the differential impulse response function to a 1 standard deviation contractionary monetary policy 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 90 percent confidence intervals.

D State-level Consumption Elasticities

I estimate Equation 10 using the Nielsen Homescan data since has a broad geographic coverage of household food consumption in U.S. The estimated coefficients are given in Table 15. See Section 4 for more detail and discussion.

Table 15: State-level Consumption Elasticities to Interest Rate Shocks

Variable	Coefficient	Standard deviation
ϵ_{t-1}	-0.2***	(0.07)
ϵ_{t-2}	-0.08	(0.064)
ϵ_{t-3}	0.097**	(0.044)
ϵ_{t-4}	-0.032	(0.039)
ϵ_{t-5}	-0.233***	(0.035)
ϵ_{t-6}	-0.059*	(0.036)
ϵ_{t-7}	-0.071**	(0.031)
ϵ_{t-8}	0.058**	(0.03)
ϵ_{t-9}	-0.159***	(0.031)
$\epsilon_{t-1} \cdot P_{r(h),t-1}$	0.721**	(0.291)
$\epsilon_{t-2} \cdot P_{r(h),t-2}$	1.561***	(0.27)
$\epsilon_{t-3} \cdot P_{r(h),t-3}$	-0.284	(0.189)
$\epsilon_{t-4} \cdot P_{r(h),t-4}$	0.016	(0.172)
$\epsilon_{t-5} \cdot P_{r(h),t-5}$	1.184***	(0.153)
$\epsilon_{t-6} \cdot P_{r(h),t-6}$	0.402***	(0.157)
$\epsilon_{t-7} \cdot P_{r(h),t-7}$	1.468***	(0.134)
$\epsilon_{t-8} \cdot P_{r(h),t-8}$	0.057	(0.125)
$\epsilon_{t-9} \cdot P_{r(h),t-9}$	-0.091	(0.125)

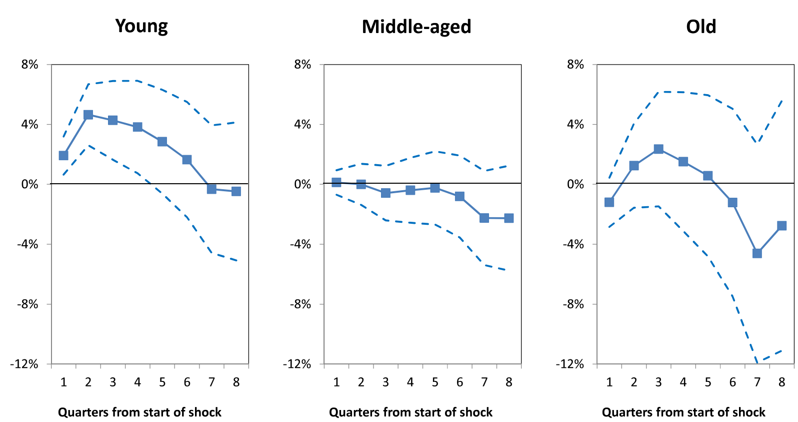
Notes: This table gives the coefficients estimated from Equation 10, which regresses the change in the log of consumption for the household in period t on lagged values of the monetary policy shocks ϵ and interactions of the lagged values of the monetary policy shocks with the share of old to young in region r. Standard errors are given in parentheses. ***, **, and * denotes significance at the 1, 5 and 10 percent level, respectively.

E Forward Guidance

In this section, I consider the responses of consumption to "forward guidance" provided by the Central Bank on the future expected path of short term rates. I assess the importance of forward guidance based on the approach of Gürkaynak, Sack and Swanson (2005) (GSS), which decomposes 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 estimation procedure is based on a principal components analysis to extract two factors from a panel of changes in the 1-year ahead Euro dollar and OIS rates. See Gürkaynak, Sack and Swanson (2005) for more detail.[86] The second component, which GSS refer to as the "path" factor, captures the effects of pure shocks to forward guidance.

I examine the consumption responses to path shocks based on the empirical specification of Equation 6. Figure 18 shows the estimated impulse response functions to a one standard deviation path shock. The consumption of the young adjust more than the old to path shocks, consistent with the responses to shocks to current target rate. The consumption responses to the forward guidance shocks are more pronounced than to the target shock. This suggest that the heterogeneity in consumption responses is related to movements in long term borrowing costs, consistent with the refinancing and mortgage borrowing channel.

Figure 18: Impulse response functions of consumption



Notes: This figure depicts the impulse response functions of real consumption to a one standard deviation expansionary monetary policy path shock. The consumption data is from the U.S. CEX Survey.

[86] I thank Alejandro Justiano for sharing with me the path and target shocks estimated in Justiniano et al. (2012).

F State-level processes for the model

I estimate the process for the aggregate variables using state-level data:

$$S_{jt} = B_0 + B_1 \cdot \text{Pop}^{O/Y}_{j,t-1} \cdot S_{j,t-1} + \lambda' X_{j,t-1} + u_{jt} \tag{30}$$

for state j in period t. The variables are the state-level income $\log y_{jt}$, state-level house prices $\log p_{jt}$, and national-level short-term interest rate r_t. I use the national-level 3-month Treasury rate to reflect the fact that the states in the U.S. are under the same monetary union.[87] The residual u_{jt} is a function of the shocks to economic activity, and positive and negative shocks to the short-term interest rate. The state-specific variables, denoted by $X_{j,t-1}$, include the local area housing supply elasticity, and the sectoral composition (share of manufacturing, services, and other sectors). I include these state-specific variables to control for other factors, besides demographics, that could influence the local area income and interest rate processes.

The estimated coefficients of the aggregate variables are shown in Table 13.

[87]This therefore abstracts from differences in transmission of monetary policy to local area interest rates due to possible region-specific mortgage characteristics, such as the concentration of lenders in the market.