Transmission of Monetary Policy to Consumption and Population Aging*

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April 21, 2016
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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 younger people is significantly more responsive to interest rate shocks than older people, and explains most of the aggregate response. The consumption responses are driven by homeowners who refinance or enter new loans after interest rate declines. Younger people are both more likely to adjust their loans and have higher short-term liquidity constraints. 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. Moreover, younger people are more likely to be short-term liquidity constrained. As a result, there is a correlation between those who adjust their loans when rates decline and short-term liquidity constraints, which can generate a large consumption response in the aggregate. Quantitatively, the loan adjustment channel accounts for a sizable share of the difference in consumption elasticities between young and old individuals. This implies that under an older demographic structure, aggregate consumption will response less to monetary policy shocks.

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

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*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, Guido Lorenzoni, Emi Nakamura, and numerous seminar participants 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.

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1 Introduction

Most industrialized countries are currently undergoing a sustained process of population aging, which is projected to continue through this century. In Japan, for instance, individuals aged over 60 now account for 30 percent of the population. The share of the population aged over 60 is three times what it was in 1970, and is expected to continue rising to over 40 percent by 2050.\footnote{The projections are from the United Nations.} 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.\footnote{See e.g. Auerbach and Kotlikoff (1985), Auerbach et al. (1989), Ríos-Rull (2001), and Abel (2003).}

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.\footnote{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.} 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.\footnote{Some recent examples include Gertler and Karadi (2015), Gorodnichenko and Weber (2015), and Nakamura and Steinsson (2015).}

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

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

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

Third, the response of consumption 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 intensive margin of homeowners refinancing, and the extensive margin of households entering into a new loan. I find that the consumption of homeowners who adjust their loans after expansionary shocks rises significantly more than that of homeowners who do not adjust their loan.

Fourth, a higher fraction of young people adjust their loans after expansionary monetary policy shocks, compared with older people. The higher fraction accounts for the larger consumption response of young people to monetary policy shocks. Moreover, I find that the household’s propensity to adjust their loan rises with loan 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 household model of mortgages and housing that generates the empirical findings. The features of model are: an uninsurable labor income risk, a life-cycle savings motive, and a fixed-rate mortgage structure. Individuals pay a fixed cost to adjust their long-term assets, which includes their housing and their fixed-rate mortgage. The interest rate on the mortgage is fixed unless the individual pays a cost to adjust their loan.

The key intuition behind the model is as follows. The fixed-rate mortgage structure generates heterogeneity in the pass-through of monetary policy to the interest payments of households, because individuals vary in their refinancing and new borrowing decisions. Individuals with larger loan sizes are more likely to adjust their loans when interest rates decline because interest savings

5My 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).
rise with loan size, while the cost of adjustment is fixed. Consistent with the data, the model implies that younger people have larger loans than older people, as they borrow against higher expected future income. Therefore, young people also have a higher propensity to adjust their loans relative to older people. Younger people are also more likely to be short-term liquidity constrained. As a result, there is a positive correlation between those who decide to adjust their loans and short-term liquidity constraints, which can generate large consumption responses in the aggregate.

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

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

I quantify the role of the refinancing channel by shutting down the refinancing decision and re-estimating the model under a variable rate mortgage structure, without any fixed costs. I find that the difference between the consumption response of young and old people declines by 40 percent under the model with a variable mortgage structure. So according to my model, the refinancing channel accounts for 40 percent of the difference in the consumption response of younger and older people. The remaining is accounted for by the standard income and substitution effects, wealth effects and other channels, which have been emphasized in existing literature on the redistributive effects of monetary policy.\textsuperscript{7} The model therefore implies that a shift in demographics can reduce the aggregate consumption responses to monetary policy shocks, because the loan adjustment channel becomes weaker.

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, describes the calibration process. Section 6 discusses the results of the two experiments in the model. Section

\textsuperscript{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.

\textsuperscript{7}Some examples of recent empirical studies include Adam and Zhu (forthcoming), Auclert (2015), Doepke, Schneider and Selezevna (2015), Meh and Terajima (2011), Sterk and Tenreyo (2015), Doepke and Schneider (2006b) and Doepke and Schneider (2006a).
7 concludes.

Related literature

This paper contributes towards four main strands of literature. First, this paper adds to the literature that studies the relationship between consumption, mortgage refinancing and homeownership. Studies, such as Cochrane and Piazessi (2002), Cochrane and Piazessi (n.d.), Hamilton (2008), Nakamura and Steinsson (2015) and others, show that monetary shocks can have significant effects on long-term yields through affecting market expectations about the future path of interest rates and/or affecting risk premia. I build on these studies by showing that these changes in long-term rates can affect real variables, in particular consumption, for households who differ in their mortgage decisions.

Recent studies have focused on the consumption response, taking as given a change in the individual’s mortgage rate. For instance, Keys et al. (2014) and Di Maggio, Kermani and Ramcharan (2014) exploit the change in the outstanding auto loan balance following anticipated rate resets on adjustable rate mortgages to measure the consumption response. Cloyne, Ferreira and Surico (2015) examine consumption responses in the U.S. and the U.K. of outright homeowners and mortgagees. This paper differs from these studies by examining the individual’s decision to change their rates, while the other papers focus on the consumption effect taking as given the rate change. I show that there is heterogeneity, not only in the consumption response, but also in the decision to adjust a loan or not. This highlights a novel feature of transmission mechanism: large responses can occur if those who choose to adjust their loans are also those who spend a larger portion of the savings. I show that this decision is related to the age of the household – younger individuals are simultaneously more likely to be short-term liquidity constrained, and more likely to adjust their loans when rates decline. The correlation between spending coefficients and refinancing decisions is a specific form of the correlation explored in Auclert (2015).

The second strand of literature studies the redistributive effects of monetary policy and taxation rebates. Recent empirical work on monetary policy 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, or transitory shocks to interest rates.

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8 Hurst and Stafford (2004) and Beraja, Hurst and Ospina (2015) also examine the refinancing decision. Hurst and Stafford (2004) focuses on the relationship between refinancing and income shocks, while Beraja, Hurst and Ospina (2015) examine the refinancing decision and home equity at a county level. The latter examines the response to quantitative easing across counties, while I focus on monetary policy shocks over a longer period time and the household-level heterogeneity to shed light on the role of heterogeneity and shifts in population mix for monetary transmission.

9 See Doepke, Schneider and Selezneva (2015) and Doepke and Schneider (2006a) 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.

In this paper, I examine an alternative 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. This paper also differs from studies on the redistributive effects of tax rebates, which are transitory and anticipated. Here, I focus on the heterogeneous effects of unanticipated and persistent shocks.\textsuperscript{11} I find that households adjust their consumption by much more and in more heterogeneous way to unanticipated and persistent monetary policy shocks than to anticipated and transitory tax rebates, which highlights the importance of the nature of the shock for determining the consumption responses.

Third, 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.\textsuperscript{12} My framework builds on these models with liquid and illiquid assets by incorporating a number of additional features, which are important for generating the heterogeneous age-specific consumption responses to interest rate shocks. These features include a uninsurable labor income risk, a life-cycle savings motive, and a fixed-rate mortgage structure. This provides a natural environment to quantitatively analyze monetary policy and demographic changes.

Lastly, this paper contributes to the literature that looks at the impact of demographics changes on capital accumulation, labor markets and asset pricing. A number of studies examine the implications for the setting of optimal fiscal policy.\textsuperscript{13} A related set of papers have also shown the implications of population aging for aggregate labor market volatility,\textsuperscript{14} and the implications of long-term structural changes on the natural rate of interest.\textsuperscript{15} 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.\textsuperscript{16}
2 Data

Consumption data

I use data from the Consumer Expenditure Survey (CEX) interview sample. The CEX interview survey is a rotating panel of households that are selected to be representative of the U.S. 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.\textsuperscript{17} See Appendix A details on the construction of the categories, and discussion of robustness around measurement issues.

I complement the analysis with a second data set on household expenditure from Nielsen Homescan.\textsuperscript{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 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 (see Appendix E).\textsuperscript{19}

\textsuperscript{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.
\textsuperscript{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.
\textsuperscript{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.
Mortgage data

I obtain household-level data on mortgages from two sources: the CEX survey and the Freddie Mac Single Family Loan-Level data. I use the CEX detailed expenditure files on owned living quarters and other owned real estate, and mortgages, over the sample period is 1990-2007. The Freddie Mac Single Family Loan-Level data is a loan-level panel data of all 30-year mortgages securitized by Freddie Mac. In total, there are approximately 17 million loans in the sample period 2000-2007. See Appendix A for more detail.

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

3 Empirical methodology

In this section, I discuss the identification of the monetary policy shocks. 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. 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.

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20This data can be obtained from Freddie Mac (link here).
21The use of high-frequency data has been widely used in a number of other papers, including Kuttner (2001), Cochrane and Piazzesi (2002), Rigobon and Brian (2004), Nakamura and Steinsson (2015), Gertler and Karadi (2015), Gorodnichenko and Weber (2015), and others.
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.\footnote{I stop the sample in 2007 to abstract from issues surrounding the zero-lower bound.}

I also obtain identified shocks prior to 1994 from Gürkaynak, Sack and Swanson (2005).\footnote{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.
}

We can think about a monetary policy shock both in terms of a shock to rates in the current period and to the future path of the Federal Reserve’s actions (in other words, a shock to the slope of the yield curve). I consider both measures of the shock. First, I define a current period monetary policy shock as:

$$
\epsilon_t = \frac{D}{D-t} \left( f^{0}_{t+\Delta^+} - f^{0}_{t-\Delta^-} \right)
$$

where $t$ is the time when the FOMC issues an announcement, $f^{0}_{t+\Delta^+}$ is the Federal Funds futures rate shortly after $t$, $f^{0}_{t-\Delta^-}$ is the Federal Funds futures rate just before $t$, and $D$ is the number of days in the month. The $D/(D-t)$ term adjusts for the fact that the Federal Funds futures settle on the average effective overnight Federal Funds rate.

Following Gorodnichenko and Weber (2015), Nakamura and Steinsson (2015), and others, I consider a 60 minute time window around the announcement that starts $\Delta^- = 15$ minutes before the announcement.\footnote{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.} 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.\footnote{The futures contracts incorporate all publicly available information at the beginning of the window. Therefore the public information will not show up as spurious variation in the monetary shock.
}

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.\footnote{One concern that we might have with the identification scheme is that the Federal Reserve Bank may have private information about aggregate economic conditions that are correlated with household consumption, which are not reflected in the futures contracts. The measured monetary policy shock would then be a combination of the true shock and some error that is correlated with consumption. I consider the potential measurement error in three ways. First, in the Appendix, I consider regressing consumption on forwards of the monetary policy shocks. If the shocks are exogenous, then current consumption should not respond to future shocks. I show that the estimated coefficients are statistically insignificant. Second, I also consider other identification assumptions, including the Cholesky decomposition of the residuals, and the narrative approach in Romer and Romer, to show that the results are qualitatively robust across different assumptions. Finally, I note in the case where the error is additive (i.e. the}
Following Cochrane and Piazessi (2002) and others, I aggregate up the identified shocks to obtain a quarterly measure of the monetary policy shock. 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). 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).

As I will show below, these current period shocks can potentially have persistent effects on long-term rates and consumption. This can occur when the current period shocks change expectations about the Federal Reserve’s future path of rates set in addition to interest rates in the current period. To isolate out the shock to the path of rates, the literature has also considered monetary policy shocks to “forward guidance”. This refers to the Central Bank’s ability to affect both the current short term rate and the future expected path of short term rates. The role of forward guidance has become more important in the recent period, with interest rates at the zero lower bound. 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.

3.2 Estimating consumption elasticities

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

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26 Cochrane and Piazessi (2002) aggregate up daily shocks to obtain a monthly shock series.
27 I exclude the rate cut of September 17, 2001, which is the first trading day after the terrorist attacks of September 11, 2001, to abstract from potential noise in the rates caused by the event.
28 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.
29 Recent studies that examine the role of forward guidance in affecting aggregate outcomes include McKay, Nakamura and Steinsson (2015), Gilchrist, López-Salido and Zakrajsek (2015), Justiniano et al. (2012) and others.
30 I thank Alejandro Justiniano for sharing with me the shocks estimated in Justiniano et al. (2012).
estimate how consumption responds to interest rate shocks:

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

(2)

\(C_{ht}\) denotes real consumption for household \(h\) in quarter \(t\). I estimate the regression for the change in consumption, denoted by \(\triangle \ln C_{ht} = \ln C_{ht} - \ln C_{h,t-1}\). \(\lambda_{s(t)}\) denotes seasonality fixed effects. \(X_{ht}\) denotes household-level controls: changes in family size, the number of children, and marital status over the quarter, and household-specific interview fixed effects.\(^{31}\) I cluster the standard errors by time, to capture the fact that there may be correlations across households in their changes in consumption since the monetary policy shocks are aggregate.\(^{32}\)

I denote expansionary and contractionary monetary policy shocks by \(\epsilon_{t-k}^-\) and \(\epsilon_{t-k}^+\), 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.\(^{33}\) The \(\beta_k\) and \(\gamma_k\) 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:

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

(3)

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

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

(4)

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

To explore heterogeneity in consumption responses over the life-cycle, I further condition on

\(^{31}\)I control for these changes in household size in order to obtain a measure of the individual’s response, which maps most closely to standard macro models that do not model household formation separately.

\(^{32}\)I also considered clustering by age group, to capture the potential correlations in consumption across the life-cycle. Clustering by age group gave tighter standard errors than clustering by time period.

\(^{33}\)Not allowing for potential asymmetry would potentially downward bias the estimates towards zero in, for instance, cases where households respond to interest rate declines but not interest rate rises. I also considered other non-linearities and functional forms, such as by size of the shock. However, I did not find the non-linearities to be statistically significant. Part of the reason for this could be that the sample of shocks is relatively short and there magnitude of shocks is not dispersed enough to precisely identify non-linearities with size.
the age of the head of household. Formally, I estimate:

\[
\Delta \ln C_{ht} = b_0 + \sum_{k=1}^{K} \beta_k^a \cdot \psi_{t-k} \cdot \text{Age}_{h,t-k} + \sum_{k=1}^{K} \gamma_k^a \cdot \psi_{t-k}^+ \cdot \text{Age}_{h,t-k} + \alpha X_{ht} + \lambda_h(t) + \nu_{ht}. 
\]  

(5)

\(X_{ht}\) denotes household-level controls, which include changes over the quarter in employment status, marital status and family composition. I control for seasonality and household-specific interview fixed effects. \(\text{Age}_{ht}\) 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.\(^{34}\) Defining age groups in this way captures any differential consumption response to interest rate shocks that may be related to home-ownership decisions.\(^{35}\) I also consider narrower groups based on 10-year age ranges using the Nielsen Homescan data, which has a larger number of households.

### 3.3 Estimating the effects on mortgage rates and loan adjustments

One reason why the consumption response of young and old people differ is that they can vary in their decision to adjust their loans after interest rate shocks. Under fixed rate mortgage contracts, the nominal interest rate on the fixed-rate mortgage only resets if the household 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.\(^{36}\)

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:\(^{37}\)

\[
\Delta R_t = b_0 + \sum_{k=1}^{K} \beta_k \cdot \epsilon_{t-k}^+ + \sum_{k=1}^{K} \gamma_k \cdot \epsilon_{t-k}^- + \epsilon_\tau t. 
\]  

(6)

\(^{34}\)The broad age ranges also ensure that there is a sufficient number of households to reliably estimate age-specific responses using the CEX data set.

\(^{35}\)This follows the approach of Hurst et al. (2015) who examine the effect of GSE policies on the young, middle age and old households.

\(^{36}\)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.

\(^{37}\)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).
$\Delta R_t$ denotes the change in the average mortgage rate in quarter $t$; $\epsilon_t$ denotes the monetary policy shock at date $t$, and $\eta_t$ 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.\textsuperscript{38}

I then examine the propensity of the household to enter a new home loan or refinance their existing loan into the lower mortgage rate, after an expansionary monetary policy shock. Formally, I estimate a linear probability model of loan adjustment.\textsuperscript{39}

$$P_{ht} = b_0 + \sum_{k=1}^{K} \beta^a_k \cdot \epsilon^+_{t-k} + \sum_{k=1}^{K} \gamma^a_k \cdot \epsilon^-_{t-k} \cdot \text{Age}_{h,t-k} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \quad (7)$$

$P_{ht}$ is an indicator equal to one if household $h$ adjusts their loan in quarter $t$. The monetary policy shocks are denoted by $\epsilon^+_{t-k}$ and $\epsilon^-_{t-k}$. $X_{ht}$ 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 $\beta^a_k$, which effect of a 1 percentage point expansionary shock on the loan adjustment propensity for people in age group $a$. Equation 7 is estimated using the CEX detailed expenditure data.

In addition to the age-specific propensities, I also explore the relationship between loan size and loan adjustment propensities. 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

$$P_{ht} = b_0 + \sum_{k=1}^{K} \beta^a_k \cdot \epsilon^+_{t-k} + \sum_{k=1}^{K} \gamma^a_k \cdot \epsilon^-_{t-k} + \alpha X_{ht} + \lambda_{s(t)} + \nu_{ht}. \quad (8)$$

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

4 Empirical Results

My four main empirical results are: (1) expansionary monetary policy shocks have large and persistent effects on consumption; (2) the aggregate consumption response is driven by the response of young people, which is significantly larger than that of older people; (3) the consumption response of homeowners who adjust their loans after monetary policy shocks is significantly larger than that of renters and homeowners that do not adjust their loans; and (4) young people have a higher

\textsuperscript{38} The path shock is based on the GSS decomposition.

\textsuperscript{39} Alternative specifications include probit and logit regressions. The results are similar under the different approaches.
propensity to adjust their loans following interest rate shocks, which contributes towards their higher consumption elasticity. The heterogeneity highlights the role of loan adjustment decisions and liquidity constraints for generating the large consumption responses. My empirical findings then motivate the set-up of the theoretical model, which is used to understand the monetary transmission mechanism.

4.1 The Consumption Response

In this section, I first show that expansionary monetary policy shocks have large and persistent effects on consumption over the sample period 1990-2007. The left panel of Figure 1 shows a statistically significant and persistent effects of expansionary monetary policy shocks on consumption. Figure 1 plots the estimated impulse response functions of total consumption to a one-standard deviation monetary policy shock. The 85th percent confidence interval is represented by the dashed lines. The average annual consumption elasticity over the first year is 1.4 percent. The effect on consumption is statistically significant and persists for over two years. The magnitudes of the consumption response based on the CEX data are within the ranges to elasticity estimates in the literature, which are based on aggregate output data (see for instance Barakchian and Crower (2013), Romer and Romer (2004), and Cloyne and Surico (2015)).

The right panel of Figure 1 shows the consumption response to a contractionary monetary policy shock. In contrast to the response to expansionary shocks, the effect of the contractionary shock on consumption is statistically insignificant. The wide standard errors reflect, in part, the smaller number of contractionary shocks that occurred during the sample period. Given the clear evidence of the expansionary effects on consumption, I focus the discussion on the heterogeneous consumption responses to expansionary interest rate shocks.

Figure 1 reflects the consumption response to lags of the monetary policy shock. In the appendix, I provide estimates on consumption response regressed on forwards of the monetary policy shock. This provides a useful test of the exogeneity of the measured shock. To the extent that the Federal Funds futures contracts capture past information about the aggregate, including consumption, then consumption should not response to future measured shocks. Indeed, Appendix Table 12 confirms that consumption does not have a statistically significant response to future expansionary or contractionary monetary policy shocks.

**Total consumption elasticities by age**

40 The online appendix compares the response of the CEX to the estimates from the NIPA data.
41 There were 20 contractionary shocks during the sample period, which is less than half of the number of expansionary shocks.
42 I discuss the interpretation of the contractionary shocks using the quantitative model in Section 7.
My second empirical result is that the response of total consumption of young people is significantly larger than that of older individuals, and accounts for most of the aggregate response. This finding is seen in Table 1, which summarizes average annual responses of total consumption (both durable expenditure and non-durable goods and services) to an expansionary monetary policy shock by age. Young people adjust their consumption by around 1-2 percentage points more than middle aged and older people. The consumption elasticity of the young is about twice as large as the average elasticity. The difference between the response of the young to the response of the middle and the old is statistically significant and lasts for about 1-2 years (Figure 2). In contrast, the consumption responses of the middle and the old are statistically indistinguishable from each other. The decline in the consumption elasticities by age is also observed if households are partitioned into finer age groupings using the larger panel of households in the Nielsen Homescan data (Table 1). Consumption elasticities decline by age, starting from an annual elasticity of 1.04 percent for young people to 0.01 percent for older people.

The finding that consumption elasticities decline with age is broad-based across consumption categories. Table 1 shows the consumption elasticities for total items, non-durable goods and services, and food expenditures. Figure 12 depicts the differences in consumption response by age over time. The non-durable consumption elasticities vary less by age than the total consumption elasticities. This implies greater heterogeneity on durable spending following monetary policy shocks.

The finding that consumption elasticities decline with age is also robust to different measures of monetary policy shocks. The previous results were based on a measure of the current period shock over the quarter. In Appendix Figure 12, I show the consumption responses to long-term measures of a monetary policy shock, such as the long-term “path” shock, based on the GSS decomposition. I find that the heterogeneity in consumption responses is more pronounced for long-term shocks than the quarterly shocks. This may reflect the greater persistency of the long-term path shock on interest rates. Similar results can be seen with other measures of long-term shocks, such as the change in the two-year Treasury rate.

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

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.

In Section 1.1 of the online Appendix, I show robustness of the results to different age group definitions. The age-specific results also distinct from cohort effects – the latter refers to the birth cohort. The finding that the young respond more than the old holds even after controlling for cohort fixed effects interacted with the monetary policy shocks. The estimated elasticities are depicted in the Appendix Table 14.
Contribution to aggregate consumption response

Given the heterogeneity of consumption responses by age and the large projected demographic shifts in the population structure, a natural question to ask is how much each age group contributes to the aggregate consumption response. I compute the percentage point and percent contributions of each age group to the aggregate elasticity in Table 2 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).

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 66 percent of the aggregate response of total consumption, and 80 percent of non-durable consumption. Their large contribution to the aggregate consumption response reflects the fact that they have a consumption elasticity that is twice as high as the average person. In comparison, the consumption response of the middle aged to a monetary policy shock account for 30 percent of the aggregate total consumption elasticity. Older individuals do not contribute very much towards the aggregate consumption response.

The differences in elasticities imply that shifts in demographics can potentially have significant effects on the aggregate consumption response. A simple exercise that changes the population weights to the 2050 U.N. projected population distribution (and therefore column II), holding fixed the consumption elasticities, would imply a decline of 18 percent in the aggregate response to a same-sized monetary policy shock. This exercise, however, ignores the fact that the household’s consumption elasticities may also change, as they re-optimize their consumption and savings profiles under a older population structure and longer life-expectancy. Therefore, in the model Section, I develop a theoretical framework that endogenizes the consumption and savings decisions, to estimate the impact of demographics on the aggregate transmission to consumption.

4.2 Loan adjustment decisions

In this section, I provide evidence that loan adjustment decisions (related to housing purchases and refinancing of existing mortgages) are important for explaining the variations in consumption responses by age. The monetary transmission depends on: (i) the pass-through to mortgage rates, which in turn depends on whether the household refines or enters a new mortgage at the current rate, and (ii) the fraction of mortgage or rental savings that the household chooses to consume. Recent studies have focused on the consumption response, taking as given a change in the individual’s mortgage rate.\textsuperscript{46} I build on these studies by examining the individual’s decision to change their rates. I highlight a novel feature of transmission mechanism: large responses can

\textsuperscript{46}For instance, Di Maggio et al (2016) and Keys et al (2016) exploit the change in the outstanding auto loan balance following anticipated rate resets on adjustable rate mortgages to measure the consumption response.
occur if those who choose to adjust their loans are also those who spend a larger portion of the savings. I show that this decision is related to the age of the household – younger individuals are simultaneously more likely to be short-term liquidity constrained, and more likely to adjust their loans when rates decline. The correlation between spending coefficients and refinancing decisions is a specific form of the correlation explored in Auclert (2016).

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

Housing and mortgage characteristics by age

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

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

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. 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.

Response of mortgage rates

I find that monetary policy shocks significantly affect mortgage rates. Table 3 decomposes
the effect of the monetary policy shock into two components: surprises in the current quarterly
rate (columns I and II), and surprises in the path of the futures rate (columns III and IV). Columns I and III of Table 3 shows that about 25-40 percent of a monetary policy shock passes through to the long-term mortgage rates. Columns II and IV of Table 3 allow for different effects depending on the sign of the shock. We can observe two interesting asymmetries. First, the pass-through is particularly pronounced for expansionary monetary policy shocks, while the effect of contractionary shocks is statistically indistinguishable from zero. Second, for expansionary shocks, the pass-through of the long-term path shock to the 30-year mortgage rate is larger than the pass-through of a current-quarter shock (56 percent relative to 50 percent). These results are consistent with Gertler and Karadi (2015) and Hamilton (2008), who also document significant effects of monetary policy shocks on long-term rates.

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

Consumption elasticities and loan adjustment decisions

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

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, recorded in the CEX detailed mortgage and housing data, which arises due to new borrowing or refinancing of existing loans.

47 The decomposition is based on the GSS target and path shocks, described in Section 3.
48 As discussed earlier, the statistically insignificant results could reflect the fact that there were much fewer contractionary shocks, relative to expansionary shocks, during the sample period, which makes it harder to precisely estimate these coefficients.
49 These studies have highlighted the possibility of short-term shocks affect long-term yields through changing expectations about the Fed’s future path of rates, and through risk premia. See Gertler and Karadi (2015) for a more detailed discussion.
50 To the extent that the policy shocks are exogenous to these trends, then the coefficients are unbiased even without these controls.
51 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).
For each of these sub-samples of households, I estimate the consumption elasticities to interest rate shocks (based on Equation 5).

My third empirical result is that homeowners increase their consumption following an expansionary monetary policy shock, while the consumption response of renters is statistically insignificant (Table 5). Individuals who adjust their loans increase their consumption by about 3 percentage points more than the response of those that do not adjust their loans. The average dollar difference is about $120 per quarter over the first year.

My forth 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 a much higher fraction of young people adjust their loans within a year of an expansionary monetary policy shock (annual fraction of 28%, relative to 12% and 4% for middle aged and old people, respectively). This highlights a novel feature of the mechanism – that is, those who adjust their loans tend to be younger in age. These younger individuals on average have higher consumption elasticities and have a much higher level of short-term credit utilization which suggests they are more likely to be credit constrained.

One explanation for the higher loan adjustment propensities of young people is that they have larger loan sizes. In the Appendix, I show using the Freddie Mac data, 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 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 empirical results complement the findings in Keys et al. (2014) Di Maggio, Kermani and Ramcharan (2014), and Cloyne, Ferreira and Surico (2015), who show that the mortgage channel is important for the monetary transmission to consumption. While Keys et al. (2014) and Di Maggio, Kermani and Ramcharan (2014) examine the response to an given anticipated rate change, I highlight the importance of the loan adjustment decision for the transmission of monetary policy. I show that younger individuals are simultaneously more likely to be short-term liquidity constrained and more likely to adjust their loans when rates decline, which can generate large consumption responses in the aggregate. My results also suggest that the mortgage channel depends critically on the decision and ability of homeowners, particularly the young, to adjust their loans. Large effects on consumption are possible during the period 1990-2007, when individuals were able to refinance their loans in the wake of rising house prices. Conversely, it also implies that the monetary transmission can become more muted if households are unable to enter adjust their loans, such as during

\[52\] These propensities are estimated based on Equation 7 using the CEX data over the sample period 1993-2007.
the Great Recession.

Regional variations in responses and local area demographics

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

5 Model

In this section, I build a household model of housing and mortgage decisions that is able to generate the key empirical results in Section 4, and use it to draw inferences for the national economy. Households in the model face exogenous idiosyncratic and aggregate shocks. The shock processes generate dynamics that resemble business cycle fluctuations in the data. This allows me to examine the household’s policy decisions in an environment with realistic dynamics in prices and aggregate variables, while preserving the household heterogeneity in income and mortgages.\(^{53}\)

The model contains two key features. First, individuals pay a fixed cost to adjust their long-term assets.\(^{54}\) Fixed costs are paid when entering a new loan or refinancing an existing mortgage. Second, I model a fixed-rate mortgage structure. The mortgage rate is fixed unless the individual refines their loan. The balance of the loan is amortized over the life of the individual.

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

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

\(^{53}\)The latter is important for generating age-specific consumption responses to interest rate shocks.

\(^{54}\)This builds on the recent work that models liquid and illiquid assets separately, such as Alvarez, Guiso and Lippi (2012), Alvarez and Lippi (2009), Abel, Eberly and Panageas (2009), Kaplan and Violante (2014), and others.
data has sparsely information on short-term financial asset holdings and does not have high frequency labor income data. Distinguishing between the factors affecting consumption is relevant for assessing whether the same shock will be more or less effective under different macroeconomic conditions. In the Appendix, I also use the model to quantify the potential effects of demographic shifts on the aggregate consumption response to monetary policy shocks.

5.1 Setup

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

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

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

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

where the initial amount borrowed $b_{ja0}$ and the mortgage payment $M_{ja0}$ satisfies

$$b_{ja0} = M_{ja0} \left[ \sum_{k=1}^{d(a)} \frac{1}{(1 + R_{ja0})^k} \right]. \tag{9}$$

While the stock of rental housing can be freely adjusted each period, I assume a lump-sum transaction cost of $F$ applies when the household enters a new loan or refinances an existing

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55Papers, 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.

56Note, 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 9, as

$$M_{jat} = b_{jat} \left[ \sum_{k=1}^{d(a)} \frac{1}{(1 + R_{jat})^k} \right]^{-1}$$
mortgage. Upon refinancing, the mortgage rate is reset and the household can also choose a new mortgage balance, subject to a minimum equity requirement

\[ b_{jat} \leq (1 - \phi) p_t h_{jat} \]

where \( \phi \) is the minimum down payment or equity that must be held in the house. If the loan is refinanced, the new fixed rate is the current market mortgage rate in that period. The mortgage rate can be expressed recursively as

\[ R_{j,a+1,t+1} = r_{t+1}^{d(a+1)} \cdot 1(\text{refi})_{t+1} + R_{jat} \cdot [1 - 1(\text{refi})_{t+1}] \]  \hspace{1cm} (10)

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

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

\[ \log(y_{jat}) = \chi_a + \eta_{jat} + \phi_a(y_t) \]  \hspace{1cm} (11)

where \( \chi_a \) is deterministic; \( \eta_{jat} \) is idiosyncratic, with \( \eta_{jat} = \rho \eta_{j,a-1,t-1} + \psi_{jt} \) where \( \psi_{jt} \) is an i.i.d shock drawn each period from \( N(0, \sigma^2_\eta) \).\(^{57}\) and \( \phi_a(y_t) \) captures age-specific fluctuations to income that arise from aggregate shocks to the aggregate income in the economy (the \( y_t \) process is described below). When the household is retired, income is given by a social security transfer, which is a function of income in the last working-age period, as modeled in Guvenen and Smith (2014).

**Aggregate shocks to the economy** In addition to idiosyncratic income shocks, households also face exogenous aggregate shocks. The vector \( S_t \) of aggregate variables include log of real aggregate income \( \log y_t \), log of real house prices \( \log p_t \), and the one-period interest rate \( r_t \). I assume the dynamics of \( S_t \) are given by\(^{59}\)

\[ S_t = A_0 + A_1 S_{t-1} + u_t \]  \hspace{1cm} (12)

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

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

$$r_t^d = f^d(S_t)$$

(13)

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:

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

(14)

5.2 Recursive formulation

For notational clarify, I drop the agent and age indices when describing the household’s problem. Each period, households choose whether (i) to rent, (ii) to continue owning their same home and not adjust any existing mortgage, or (iii) to adjust their mortgage and housing stock. The adjusters include those homeowners who went from being renters to a homeowner and those who were homeowners in both periods. Households also choose their consumption, savings in liquid one-period bonds, and mortgage debt.\(^{60}\) I assume agents derive per-period utility from consumption and housing services, $u(c, h) = \left(\frac{c^{\alpha}h^{1-\alpha}}{1-\sigma}\right)^{1-\sigma}$. Housing can be rented or owned.\(^{61}\)

Denote the household’s state variables by $z = \{a, S, y, \text{assets}\}$, where $a$ denotes age, $S$ and $y$ are the aggregate state and idiosyncratic labor income realizations, respectively, and assets is a vector of start-of-period holdings of short-term assets ($s$), housing owned ($h^{\text{own}}$), mortgage balance ($b$) and the fixed rate on any existing mortgage ($R$). The value function can be written as

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

(15)

$$V(z)^{\text{rent}} = \max_{c, h^{\text{rent}}, s'} u(c, h^{\text{rent}}) + E[V(z')]$$

(16)

s.t. $c + s' + p^r h^{\text{rent}} = y + (1 - \delta)p h^{\text{own}} + (1 + r)s - b(1 + R)$

$h'^{\text{own}} = b' = 0, \quad s' \geq -s$

\(^{60}\)The household problem is solved recursively. Section 1.3 of the online appendix describes the model computation in more detail.

\(^{61}\)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.
and Equations 12-14 for income and aggregate state processes, mortgage yields and rental rate.

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

and Equations 12-14 for income and aggregate state processes, mortgage yields and rental rate. The mortgage payment \( M \) follows Equation 9.

\[
V(z)^\text{own \& adjust} = \max_{c,s',h^\text{own},b'} u(c, h^\text{own}) + E[V(z')] \\
\text{s.t. } c + s' + ph^\text{own} - b' - F = y + (1 - \delta)ph^\text{own} + (1 + r)s - b(1 + R) \\
b \leq (1 - \phi)ph^\text{own}, \quad s' \geq -\delta, \quad R' = r^d
\]

and Equations 12-14 for income and aggregate state processes, mortgage yields and rental rate. \( F \) is the fixed cost of adjusting the loan.

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

### 5.3 Model Calibration

**Demographics and preferences** The model period is annual. Households work for 40 years and are retired for up to 20 years. Agents face age-dependent survival probabilities, given by the U.S. actuarial life-expectancy tables and assume a maximum age of \( T = 85 \).

I interpret the first period of life as 25 years of age and initialize the model by these agents assets and income to match the distribution of ages 20 to 29 households in the 2004 SCF. I set \( \sigma = 2 \) to generate an inter-temporal elasticity of substitution of 1/2. I follow Cocco, Gomes and Maenhout (2005) in setting the bequest parameter \( B = 2 \).

The discount rate \( \beta \) and the utility parameter \( \alpha \) are estimated to target the average homeownership rate of 66 percent in the SCF, and the median wealth-to-income ratio of 1.52 from the SCF data. These targets yield \( \beta = 0.962 \) and \( \alpha = 0.88 \). The fixed cost of transaction \( F \) is calibrated to target the average annual fraction of loans that are refinanced. I use the Freddie Mac Life Expectancy Tables and the Social Security Administration’s life expectancy tables for male and female survival probabilities.

\[62\] 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.

\[63\] This follows Kaplan and Violante (2014) and Hurst et al. (2015).
Mac pool of mortgages to obtain a refinancing fraction of 24 percent over 1999-2007.\footnote{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.)} This yields a transaction cost of approximately $F = 5K$, which is approximately 2.8 percent of the median house price in the model. I interpret the fixed costs as inclusive of both monetary and non-monetary costs involved in refinancing a mortgage or entering a new loan.

**Income** I follow Floden and Lindén (2001) in exogenously setting the idiosyncratic income process terms $\rho_\eta = 0.91$ and $\sigma_\eta = 0.21$ to match the annual persistence and standard deviation of residual earnings in the PSID. The process is discretized with two states using the Tauchen method. I set the deterministic age-specific vector $\chi_a$ equal to the average log earnings for each age from Guvenen et al. (2015).\footnote{See Table 4 of Guvenen et al. (2015), which are estimated from a regression of earnings of individuals on a full set of age and cohort dummies using a long panel of administrative data.} I set the parameter $\phi_a$ based on the correlation between real aggregate income per capita and age-specific earnings in the CPS (see the Appendix for more detail). Table 7 gives the estimated coefficients, which show a higher exposure of the earnings for young workers relative to the middle aged workers.\footnote{The findings are consistent with Jaimovich and Siu (2009), Rios-Rull (1996) and others, who show that younger and older workers have relatively higher cyclical volatility in hours worked than the middle aged workers.}

**Aggregate variables** The parameters on the aggregate variables (income, house prices and short-term interest rate) in Equation 12 are exogenously set based on estimated coefficients from a reduced-form quarterly VAR of these variables over the period 1984-2007.\footnote{The data on income and interest rates are obtained from the Federal Reserve Board.} Table 8 gives the coefficient estimates and the variance-covariance matrix of the residuals $u_t$. These residuals are multi-normal with mean 0 and variance-covariance $V$. The aggregate processes are discretized with 18 states using the Tauchen method.

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

$$r^d_t = a_0 + a_1 r_t + a_2 \log y_t$$  \hspace{1cm} (19)$$

where $r^d_t$ 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 19 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.\footnote{These data are available on the Feds website at http://www.federalreserve.gov/pubs/feds/2008/200805/200805abs.html. TIPS were first issued in 1997, but the market was initially illiquid (as discussed in Nakamura and Steinsson (2015)). Therefore I use data from 2003 onwards to avoid relying on data from the period when TIPS liquidity was limited.} I then interpolate the mortgage rates with durations between 30, 15 and 1 year.\footnote{I assume the yield curve beyond 30 years is flat, consistent with the flattening of the yield curve in the data.} The estimated coefficients are shown in Table 9.\footnote{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 19. In Section 1.4 of the online appendix, I provide evidence that the specification in Equation 19 is a good approximation of the actual mortgage rate dynamics.}

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

$$\log(p^*_t) = \alpha_0 + \alpha_1 r_t + \alpha_2 \log y_t + \alpha_3 \log p_t$$

I estimate Equation 20 using the national house price and rent indices obtained from the Dallas Federal Reserve. See Column (III) of Table 9 for the regression coefficients.\footnote{An alternative approach would be to specify the rental rate based on a no-arbitrage condition within the housing market. I find the dynamics of the house price to rent ratio match the data better under the current approach. In Section 1.4 of the online appendix, I plot the predicted values of house prices and rental ratios in the data.}

6 Model Fit and Computational Experiments

**Model Fit** The estimated model fits non-targeted life-cycle moments well. Figure 3 shows the life-cycle profiles in the model compared to the data from the 2004 U.S. Survey of Consumer Finances (SCF) asset profiles and consumption profiles. The model captures the hump-shaped profile of non-durable consumption, the increase in the home-ownership rate by age, the rising profile of total wealth, and 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.

**Monetary Policy Experiment** I use the model to quantify how much of the differences between the consumption responses of the young and old to expansionary monetary policy shocks is due to the refinancing and home-ownership channel. Recall the aggregate state variables were $S_t =$
\[ \log y_t, \log p_t, r_t \], which followed the process \( S_t = A_0 + A_1 \cdot S_{t-1} + u_t \). A monetary policy shock \( \epsilon_t \) affects the residuals \( u_t \) in the following way: \( u_t = \Gamma(\epsilon_t) + \psi_t \) where \( \psi_t \) denotes all other non-monetary policy shocks (i.e. house price and aggregate income shocks). Consistent with the data estimation described in Section 3, I allow the sign of the monetary policy shock to have a different contemporaneous effect on the aggregate variables, by assuming

\[
u_t = \Gamma_0 + \Gamma^+ \epsilon^+_t + \Gamma^- \epsilon^-_t + \psi_t
\]  

(21)

where \( \epsilon^+_t = \max(\epsilon_t, 0) \) and \( \epsilon^-_t = \min(\epsilon_t, 0) \) denotes the expansionary and contractionary monetary policy shocks, respectively. I set the \( \Gamma \) parameters based on empirically estimated coefficients. Formally, I regress the residuals \( u_t \) on the Federal Funds futures shocks (identified in Section 2).\(^{72}\) The parameter coefficients are presented in Table 10. Figure 4 shows the pass-through to the short-term interest rate, aggregate income, and prices after a 1ppt expansionary monetary policy shock. The short-term interest rate declines upon impact, aggregate income falls, while house price growth and the price-to-rent ratio rise over the first year.

Since the parameters on the aggregate variables were set based on empirically estimated processes, the dynamics resemble the time series and impulse response functions to monetary policy shocks observed in the data. This allows me to then examine the consumption, refinancing and home-ownership responses to a realistic monetary policy shock.

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

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

Table 11 depicts the response of aggregate consumption to an expansionary shock and a contractionary shock in the model, and the estimated response from the data.\(^{73}\) There is a pronounced and persistent effect of monetary policy shocks on aggregate consumption. Consumption rises by a peak of around 1.8 percent in response to an expansionary monetary policy shock, while consumption

---

\(^{72}\)Empirically, the Federal Funds futures shocks give a measure of the true monetary policy shock plus some measurement noise \( \epsilon_t^{\text{true}} + \text{noise} \). 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 21. This assumption is plausible since the Federal Funds futures shocks were identified within a narrow window around the FOMC announcements, and so the only shock identified within that period are likely to be monetary policy shocks. See Section 3 for more discussion on the construction and identification of these shocks in the data. Note that as in Gertler and Karadi (2015), this structure does not impose any timing restrictions on the effects of monetary policy and non-monetary policy shocks on the aggregate variables.

\(^{73}\)The empirical impulses responses are from Section 4, cumulated to an annual frequency.
declines by 0.6 percent following a contractionary shock. The model predicted responses lie within the confidence intervals of the empirically estimated response functions.\(^{74}\)

There is significant heterogeneity underlying the aggregate consumption response to interest rate shocks. The model is also able to generate heterogeneous responses by age that are in line with the data. Figure 5 shows that young people adjust their consumption by more than old individuals over the year. The responses are within one standard deviation of the estimated responses in the data.

**Heterogeneity in Refinancing and Homeownership Decisions** The model is also able to generate the empirical finding that younger people are more likely to adjust their loans (either refinancing or entering new loans) than older people following an expansionary monetary policy shock. The average fraction of young people that adjust their loans over the year in the model is in line with the estimated responses in the data (Figure 6).

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 15 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.\(^{75}\) This intuition is reflected in Figure 7. 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.\(^{76}\) The right panel shows that young people have much larger debt holdings relative to old individuals, reflecting the life-cycle borrowing profile.\(^{77}\) 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,

\(^{74}\)These aggregate impulse response functions for consumption are not targeted in the model, and therefore provides a validation of the model specification.

\(^{75}\)The intuition is that effectively the cost is spread out over a larger loan size and duration, therefore the percentage interest saving is higher.

\(^{76}\)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.

\(^{77}\)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.
and there is no variation across households in the magnitudes of the mortgage rate changes.\textsuperscript{78}

The loan adjustment decisions translate to differences in the transmission of interest rate shocks to consumption across households. This is seen in Table 8 which shows the average annual consumption elasticity to a one standard deviation expansionary monetary policy shock by loan adjustment decisions. The consumption of those who refinance rises by significantly larger than that of those who do not adjust their loans. 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.

A similar intuition can be seen in the extensive margin decision to become a homeowner. Figure 9 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.\textsuperscript{79}

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

\textit{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.

\textsuperscript{78} 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 Agarwal et al. (2015).

\textsuperscript{79} 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, Diaz and Luengo-Prado (2011)).
ture, while keeping the calibrated parameters on the utility functions the same. There are no fixed transaction costs for adjusting either housing or mortgages, and the mortgage rates change for all households following the interest rate shock. Variations in the consumption responses by age arise from the income and substitution, labor income, wealth and life-cycle effects.

Figure 10 shows the consumption responses for different age groups, relative to old individuals, following an expansionary interest rate shock. 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 10 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 difference in consumption responses between young and old, in response to interest rate shocks.

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

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

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

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80I focus on explaining the expansionary shock response, since that is where the consumption heterogeneity by age is most pronounced.

81Some examples of recent empirical studies include Adam and Zhu (forthcoming), Auclert (2015), Doepke, Schneider and Selzneva (2015), Meh and Terajima (2011), Sterk and Tenreyo (2015), Doepke and Schneider (2006b) and Doepke and Schneider (2006a).
imply a decline of 18 percent in the aggregate response to a same-sized monetary policy shock. This exercise, however, ignores the fact that the household’s consumption elasticities may also change, as they re-optimize their consumption and savings profiles under an older population structure and longer life-expectancy.

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.

Therefore, in the Appendix, I develop use my structural model to endogenize the consumption and savings decisions. 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. To take into account the possible effects on interest rates and employment, I estimate state-specific aggregate processes. 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. 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. 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 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. 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.

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

83 These factors have been discussed in papers including Auerbach and Kotlikoff (1985), Auerbach et al. (1989) and Rios-Rull (2001).
policy to consumption. It is also useful for understanding the effects of demographics on regional variations in the effects of monetary policy.

7 Conclusion

In this paper, I address the question of how changes in demographic structure affect the transmission of monetary policy shocks to consumption. First, this paper provides new empirical evidence, using two sources of micro household-level data, that young people are more responsive than old individuals to interest rate shocks. The consumption elasticities of young people are significantly larger than that of the average person, and drive most of the aggregate response. The consumption responses are driven by homeowners with mortgage transactions. I estimate that young people have a higher propensity to adjust their loans following interest rate declines, which can account for their higher consumption elasticities.

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

I use the model to perform two exercises. First, I quantify the importance of the refinancing 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.

References


Cochrane, John, and Monica Piazessi. “Decomposing the Yield Curve.”


8 Figures and Tables

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 3 and 4. The dashed lines depict the 85 percent confidence intervals.

Table 1: Consumption Elasticities by Age

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Middle</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25-34</td>
<td>35-64</td>
<td>65+</td>
</tr>
<tr>
<td><strong>CEX data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.90</td>
<td>0.89</td>
<td>0.70</td>
</tr>
<tr>
<td>[1.25 , 4.56]</td>
<td>[-0.39 , 2.16]</td>
<td>[-1.13 , 2.53]</td>
<td></td>
</tr>
<tr>
<td>Non-durables</td>
<td>1.77</td>
<td>0.31</td>
<td>0.59</td>
</tr>
<tr>
<td>[0.75 , 2.8]</td>
<td>[-0.32 , 0.93]</td>
<td>[-0.86 , 2.03]</td>
<td></td>
</tr>
<tr>
<td><strong>Nielsen data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-durables (food)</td>
<td>1.04</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>[0.76 , 1.32]</td>
<td>[0.35 , 0.65]</td>
<td>[0.17 , 0.43]</td>
<td>[0.02 , 0.3]</td>
</tr>
</tbody>
</table>

Notes: This table shows the annual elasticities of consumption to a 1 standard deviation expansionary monetary policy shock, based on Equation 5. 80 percent confidence intervals are depicted in parentheses. The elasticities are estimated using the CEX data and the Nielsen Homescan data.
Figure 2: Difference in Consumption Response by Age Group

(a) Total consumption

(b) Non-durables

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

Table 2: Contribution by Age-group to Aggregate Consumption Elasticity

<table>
<thead>
<tr>
<th></th>
<th>Annual response</th>
<th>Share of response consumption</th>
<th>Contribution to total elasticity in ppt</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Consumption</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>2.90</td>
<td>33%</td>
<td>0.97%</td>
<td>63%</td>
</tr>
<tr>
<td>Middle</td>
<td>0.89</td>
<td>56%</td>
<td>0.50%</td>
<td>32%</td>
</tr>
<tr>
<td>Old</td>
<td>0.70</td>
<td>10%</td>
<td>0.07%</td>
<td>5%</td>
</tr>
<tr>
<td>Average</td>
<td>1.54</td>
<td>100%</td>
<td>1.54%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Non-durables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>1.77</td>
<td>31%</td>
<td>0.56%</td>
<td>70%</td>
</tr>
<tr>
<td>Middle</td>
<td>0.31</td>
<td>57%</td>
<td>0.17%</td>
<td>22%</td>
</tr>
<tr>
<td>Old</td>
<td>0.59</td>
<td>12%</td>
<td>0.07%</td>
<td>9%</td>
</tr>
<tr>
<td>Average</td>
<td>0.80</td>
<td>100%</td>
<td>0.80%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Notes: This table shows the annual elasticities of consumption by age group in column (I). The elasticities are obtained by estimating Equation 5 separately for each consumption category using the CEX data. Column (II) shows each age group’s the share of overall consumption within the consumption category. Column (III) and (IV) give the contribution of each age group to the total elasticity in percentage points and percent of total, respectively. Column (III) is computed based on the product of (I) and (II). (IV) is computed based on (III) divided by the total elasticity within each consumption category. See text for more detail.
Table 3: Response of Mortgage Rates to Monetary Policy Shocks

<table>
<thead>
<tr>
<th>Policy shock</th>
<th>(I)</th>
<th>(II)</th>
<th>(III)</th>
<th>(IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current shock (no sign restriction)</td>
<td>0.392</td>
<td>[0.181, 0.602]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expansionary current shock</td>
<td>0.507</td>
<td>[0.375, 0.639]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractionary current shock</td>
<td>-0.445</td>
<td>[-1.041, 0.151]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-term shock (no sign restriction)</td>
<td>0.243</td>
<td>[0.031, 0.454]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expansionary long-term shock</td>
<td>0.563</td>
<td>[0.115, 1.012]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractionary long-term shock</td>
<td>-0.239</td>
<td>[-0.82, 0.343]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Table 4: Homeownership and Mortgage Statistics

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Middle</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homeownership rate</td>
<td>46%</td>
<td>72%</td>
<td>79%</td>
</tr>
<tr>
<td>Fraction with mortgages</td>
<td>42%</td>
<td>55%</td>
<td>23%</td>
</tr>
<tr>
<td>Median loan size</td>
<td>109,789</td>
<td>98,032</td>
<td>65,301</td>
</tr>
<tr>
<td>Median loan duration (years)</td>
<td>27.25</td>
<td>22.25</td>
<td>17.25</td>
</tr>
<tr>
<td>Median credit utilization rate</td>
<td>36%</td>
<td>25%</td>
<td>13%</td>
</tr>
<tr>
<td>Average fraction of loans at fixed rates</td>
<td>78%</td>
<td>80%</td>
<td>83%</td>
</tr>
</tbody>
</table>

Notes: This table shows homeownership and mortgage statistics for each age group. The statistics are based on the CEX data for the mortgage statistics and Equifax data for the credit utilization rates.
Table 5: Annual Elasticities of Consumption

<table>
<thead>
<tr>
<th></th>
<th>Adjust loan</th>
<th>Do not adjust loan</th>
<th>Renters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>4.95</td>
<td>1.01</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>[0.94, 8.95]</td>
<td>[-0.06, 2.08]</td>
<td>[-1.75, 2.24]</td>
</tr>
<tr>
<td><strong>Non-durables</strong></td>
<td>1.14</td>
<td>0.53</td>
<td>-0.93</td>
</tr>
<tr>
<td></td>
<td>[-1.5, 3.78]</td>
<td>[-0.33, 1.39]</td>
<td>[-2.34, 0.47]</td>
</tr>
</tbody>
</table>

Notes: This table shows the annual elasticities of consumption to a 1 standard deviation expansionary monetary policy shock, based on Equation 5. Standard errors are in parentheses. The elasticities are estimated using the CEX data (top panel) and the Nielsen Homescan data (bottom panel).

Table 6: Loan Adjustment Behavior by Household Age

<table>
<thead>
<tr>
<th></th>
<th>Young 25-34</th>
<th>Middle 35-64</th>
<th>Old 65+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propensity to adjust loan following shock</td>
<td>0.07</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>[0.09, 0.05]</td>
<td>[0.04, 0.02]</td>
<td>[0.02, 0]</td>
</tr>
<tr>
<td>Average annual fraction of households:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Own housing and adjust loan</td>
<td>0.28</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td>- Own housing and do not adjust loan</td>
<td>0.18</td>
<td>0.60</td>
<td>0.75</td>
</tr>
<tr>
<td>- Renters</td>
<td>0.54</td>
<td>0.28</td>
<td>0.21</td>
</tr>
</tbody>
</table>

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: Income Exposure to Aggregate Activity by Age

<table>
<thead>
<tr>
<th>Age group</th>
<th>25-34</th>
<th>35-44</th>
<th>45-54</th>
<th>55-64</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi_a )</td>
<td>4.633</td>
<td>1.655</td>
<td>3.626</td>
<td>0.358</td>
</tr>
</tbody>
</table>

Notes: This table shows the estimated coefficient \( \phi_a \) for each age group \( a \) from Equation 11. 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 8: Aggregate Processes: Coefficients

<table>
<thead>
<tr>
<th>Variables</th>
<th>$\log y_t$</th>
<th>$\log p_t$</th>
<th>$r_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log y_{t-1}$</td>
<td>0.9200</td>
<td>0.2857</td>
<td>-0.6344</td>
</tr>
<tr>
<td>$\log p_{t-1}$</td>
<td>0.002</td>
<td>0.9827</td>
<td>0.9629</td>
</tr>
<tr>
<td>$r_{t-1}$</td>
<td>-0.0001</td>
<td>-0.0013</td>
<td>0.9173</td>
</tr>
<tr>
<td>constant</td>
<td>-0.0097</td>
<td>-4.5682</td>
<td>0.0930</td>
</tr>
</tbody>
</table>

*Notes:* This table shows the estimated coefficients for Equation 12. The variables $\log y_t$, $\log p_t$, and $r_t$ denote the log income per capita, log house prices and the 3-month interest rate, respectively. See text for more detail.

### Table 9: Real Mortgage Rates, House Prices and Rental Rates

<table>
<thead>
<tr>
<th>Variables</th>
<th>30-year rate</th>
<th>15-year rate</th>
<th>1-year rate</th>
<th>$\log (p_t^{R})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(I)</td>
<td>(II)</td>
<td>(III)</td>
<td>(IV)</td>
</tr>
<tr>
<td>$\log(y_t)$</td>
<td>-3.475</td>
<td>-2.272</td>
<td>3.093</td>
<td>0.843</td>
</tr>
<tr>
<td>$r_t$</td>
<td>0.334</td>
<td>0.392</td>
<td>0.415</td>
<td>-0.002</td>
</tr>
<tr>
<td>$\log(p_t)$</td>
<td></td>
<td></td>
<td></td>
<td>-0.022</td>
</tr>
<tr>
<td>constant</td>
<td>-0.030</td>
<td>-0.029</td>
<td>0.027</td>
<td>3.187</td>
</tr>
</tbody>
</table>

*Notes:* This table shows the estimated processes for real mortgage rates and rental rates from Equations 19-20. The sample period is 1988-2007. The data are from the Federal Reserve Board, St Louis Federal Reserve Bank and Freddie Mac. See text for more detail.
Figure 3: Life-cycle Consumption and Asset Profiles: Model vs Data

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

Table 10: Monetary policy shocks and aggregate variables

<table>
<thead>
<tr>
<th></th>
<th>$u_t^{\log \gamma_t}$</th>
<th>$u_t^{\log p_t}$</th>
<th>$u_t^{r_t}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma^-$</td>
<td>0.006</td>
<td>0.004</td>
<td>0.648</td>
</tr>
<tr>
<td>$\Gamma^+$</td>
<td>0.001</td>
<td>-0.012</td>
<td>0.296</td>
</tr>
</tbody>
</table>

Notes: This table shows the contemporaneous effect of monetary policy shocks on the aggregate variables. The variables $u_t^{\log \gamma_t}$, $u_t^{\log p_t}$, 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 $\Gamma$ coefficients are from Equation 21, estimated using high-frequency Federal Funds futures shocks. See text for more detail.
Figure 4: 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.

Table 11: Response of Aggregate Consumption a Monetary Policy Shock

<table>
<thead>
<tr>
<th>Year</th>
<th>Source</th>
<th>Expansionary</th>
<th>Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Model</td>
<td>0.84</td>
<td>-0.56</td>
</tr>
<tr>
<td></td>
<td>Data</td>
<td>0.93</td>
<td>-2.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[-0.35,2.21]</td>
<td>[-4.31,0.03]</td>
</tr>
<tr>
<td>2</td>
<td>Model</td>
<td>1.83</td>
<td>-0.22</td>
</tr>
<tr>
<td></td>
<td>Data</td>
<td>2.65</td>
<td>-5.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[0.08,5.22]</td>
<td>[-12.2,1.86]</td>
</tr>
</tbody>
</table>

Notes: This table depicts the aggregate consumption response to a 1 standard deviation shock to monetary policy from the model and estimated from the data. The 80 percent confidence intervals are given in parentheses.
Figure 5: Age-specific Consumption Response to a Monetary Policy Shock

![Consumption response graph](image)

*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 6: Age-specific Loan Adjustments to a Monetary Policy Shock

![Loan adjustments graph](image)

*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.
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.

Figure 8: 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 9: 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 10: 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.