Population Aging and the Aggregate Effects of Monetary Policy

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Abstract

This paper studies the effects of monetary policy on the expenditure of households of different ages using micro data from the U.S. Consumer Expenditure Survey. I find that contractionary monetary policy shocks reduce the expenditure of young households by significantly more than older households. Households react asymmetrically in part because young households tend to have lower savings and higher labor market risk. This implies that the age composition of the population affects the setting of optimal monetary policy in response to aggregate shocks. Counter-factual analysis suggests that the projected population aging in the U.S. will dampen the pass-through of monetary policy to the economy.

Keywords: Monetary policy; expenditure; age structure.

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1 Introduction

This paper investigates the impact of population aging on the pass-through of monetary policy to the aggregate economy. Significant aging is projected to occur in many countries around the world over the next few decades (Figure 1). In the United States, the share of individuals aged over 65 is expected to double to 30 percent by 2050 (Figure 2). These dramatic demographic shifts raise a number of questions. How different are the responses of young and old households to monetary policy shocks? How will shifts in demographic composition change the redistributive and aggregate effects of monetary policy? Will the channels of monetary policy transmission change? Answering these questions is important for the conduct of optimal monetary policy. While there has been substantial literature focusing on the effects of aging on government debt and fiscal policy, there has been limited study into the implications for monetary policy.

Monetary policy shocks result in substantial redistribution of wealth.[1] This is because an unexpected increase (decline) in the price level (interest rate) will erode the real value of assets. As a result, borrowers gain from an increase in real wealth and lenders experience a corresponding decline in real wealth. Aggregate effects can arise from this redistribution of wealth due to asymmetries in the reaction of borrowers and lenders to changes in wealth. Shifts in the age composition can alter the redistributive and aggregate effects of monetary policy for at least two reasons. First, older households engage in less consumption smoothing than young households. Due to their shorter future time horizon, older households absorb a larger fraction of their loss from a monetary policy shock immediately in terms of lower consumption. Second, changes in age composition can shift the aggregate labor market response. This is because older households are less exposed to labor market risk and adjust their labor supply less dramatically, in part because many of these households are already out of the labor force.[2]

This paper evaluates empirically and theoretically the extent to which the age composition of the population affects the pass-through of monetary policy. The first contribution of this paper is to empirically quantify the impact of monetary policy shocks on the expenditure of households of different age groups using the U.S. Consumer Expenditure Survey (CEX).

[1]The redistributive effects of inflation have been shown in a number of papers, including Doepke and Schneider (2005, 2006), Meh, Rios-Rull, and Terajima (2008), and others.

[2]The effect of population aging on labor market volatility has been established in Jaimovich and Sui (2009), Shimer (1999), Clark and Summers (1981), Ros-Rull (1996), Gomme et al. (2005), and others.

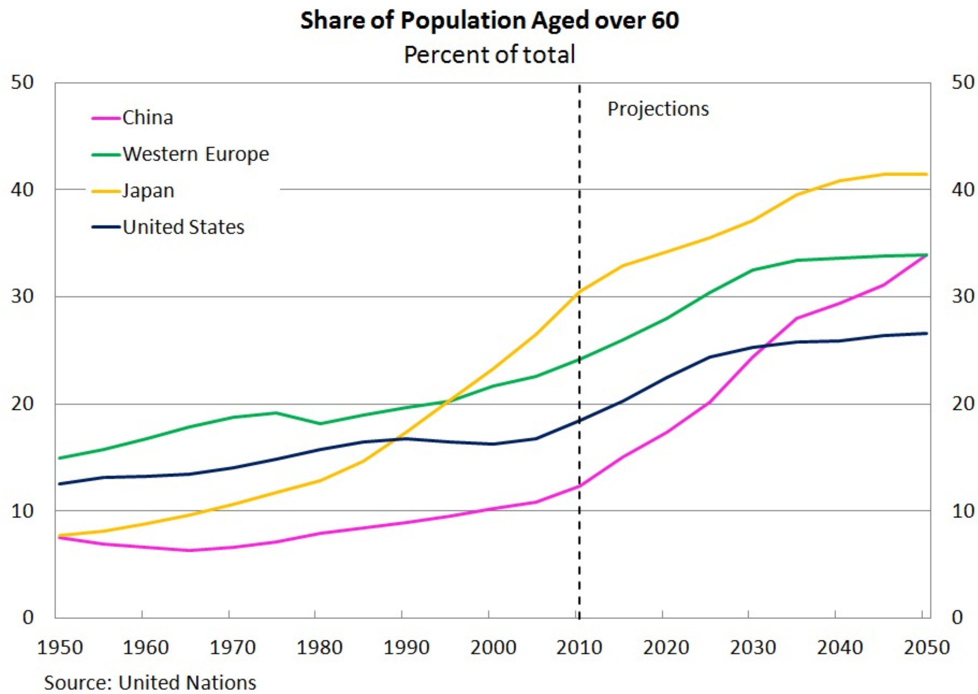

Figure 1: Projected share of households aged over 60

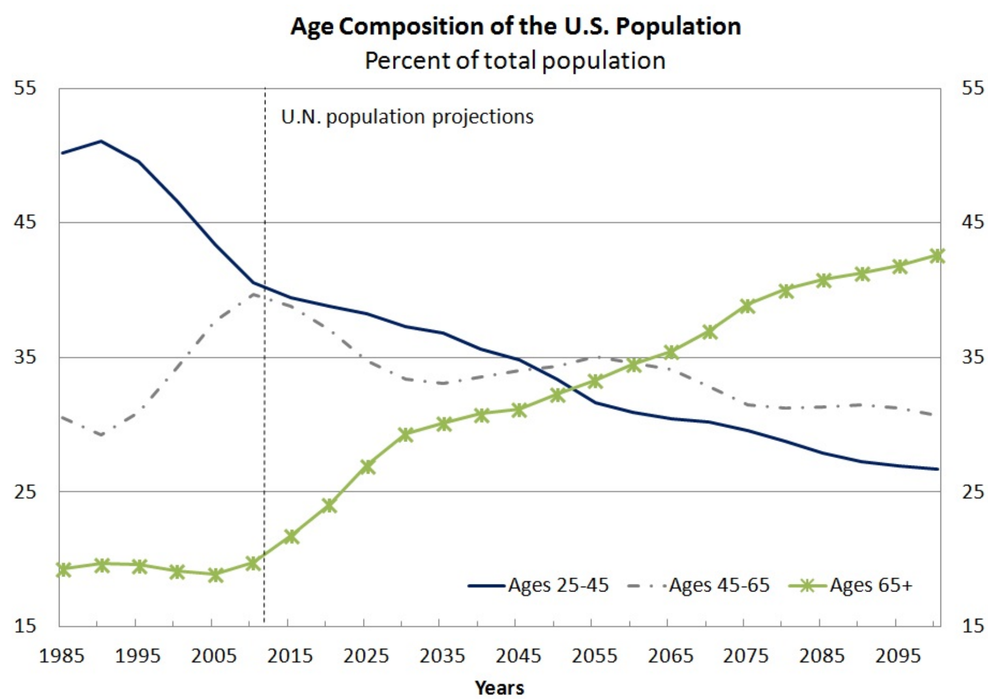

Figure 2: Projected age composition of the U.S. population

Source: United Nations

I find evidence of significant heterogeneity in the response of households to policy shocks. In particular, I find that a contractionary monetary policy shock results in young households (aged 25-35 years) reducing their expenditure significantly more than older households (aged over 50 years). The differences in the expenditure responses of the young and old are statistically significant and persistent, lasting around 15 quarters. Disaggregating the data further, I provide evidence that the heterogeneity in response is related to the fact that a larger share of young households have lower financial liquidity and higher unemployment risk relative to older households. This is consistent with existing studies, including Parker et al (2013) and Kaplan and Violante (2013), that have empirically shown that younger, financially constrained households had a higher marginal propensity to consume out of recent fiscal policy pay-outs.

I then investigate the potential effects of aging on the aggregate response by performing a quantitative exercise using the estimated heterogeneous household responses based on the U.S. population distribution in 1980 and the projected distribution in 2100. The counterfactual exercise shows that the aggregate response of household expenditure to contractionary policy shocks will be more muted under the projected demographic shifts.

The empirical findings motivate the second part of the paper, where I develop a theoretical over-lapping generations framework with age-specific labor productivity and portfolio choices to investigate the optimal monetary policy under different demographic structures. The model is estimated to match the heterogenous responses observed in the data, and used to study the dynamic effects and implications for setting of optimal monetary policy under different demographic regimes. Two applications of the model are considered to understand the relationship between monetary policy and demographics: First, I ask how the setting of optimal monetary policy may change given the projected demographic shifts in the U.S. Secondly, I examine the extent to which the limited response of the Japanese economy to monetary policy stimulus in the 1990s reflected the demographic structure of Japan.

This paper relates to a number of strands of literature. First, it relates to the life-cycle literature which documents that cross-sectional consumption dispersion increases as an individual ages, in part due to cumulated income shocks (see for example, Heathcote, Storesletten and Violante (2006), Carroll and Summers (1991), Blundell, Browning, and Meghir (1993), Attanasio and Weber (1994), Fernandez-Villaverde and Krueger (2006), and Aguiar and Hurst (2013)). This paper adds to this literature by showing that monetary policy shocks can contribute towards some of the dispersion in consumption as it disproportionately affects the young and old.

The paper also contributes towards the literature on the distributive effects of inflation. For example, Doepke and Schneider (2006) and Meh, Rios-Rull and Terajima (2008) provide empirical evidence that inflationary shocks redistribute wealth from the asset-rich households towards households with low asset holdings. These studies corroborate findings in a recent study by Coibion et al (2012) and Gornemann et al (2014) who show that monetary policy contributes towards cyclical household consumption and income equality.

This paper also relates to the extensive literature on the effectiveness of monetary policy.[3] Recent studies have examined potential changes in the effectiveness of monetary policy over time (see for example, Boivin and Giannoni (2003)). These studies empirically show that the response of real variables to monetary policy in the post-1980 period (compared to the 1960-1980 period) has reduced in magnitude, but has been more persistent. Other studies, including Vavra (2013) and Oliveri and Tenreyro (2007), have also argued that the effectiveness of monetary policy may be state-dependent. Specifically, Vavra (2013) shows that monetary policy is less effective in stimulating the economy during recessions, due to greater price dispersion during these periods. Our study highlights an alternative channel which may influence the effectiveness of monetary policy - that is, gradual demographic shifts in the age distribution of the population.

The paper is organized as follows. Section 2 describes the data used in the study. Section 3 outlines the empirical strategy for identifying the monetary policy shocks, and the effect on household expenditures by age. Section 4 discusses the empirical results. Sections 5 and 6 specifies the theoretical model and findings, respectively. Section 7 discusses robustness around our empirical findings and Section 8 concludes.

2 Data

This section describes the aggregate data that is used to identify the monetary policy shocks, and the micro data used to examine life-cycle expenditure.

[3]For a summary, see Christiano, Eichenbaum, and Evans (1999), and Romer and Romer (2004).

2.1 Aggregate data

Quarterly aggregate data between 1960 and 2007 is used to identify the exogenous monetary policy shocks using a vector autoregression (VAR, discussed further below). As in Christiano, Eichenbaum, and Evans (1996), I use log of real U.S. GDP, the log of the GDP deflator, and the average Federal Funds rate over the quarter, obtained from the St. Louis Federal Reserve Bank. I also use the log of the Reuters CRB Index, obtained from Global Financial Data. This is an index of sensitive commodity prices, based on 19 commodity futures contracts.[4]

The commodity price index is included to capture information that the Federal Reserve Bank might have about future inflation at the time when it sets monetary policy. As discussed in Christiano, Eichenbaum, and Evans (1996), and Sims and Zha (1995), the inclusion of the index resolves the 'price puzzle' associated with the identification of monetary policy shocks - that is, the anomonaly of inflation rising following an identified contractionary monetary policy shock. This is because the index captures potential information that the monetary authority may have on future price expectations at the time when they set policy, which is therefore relevant for identifying the policy shock.

2.2 Micro data

For detailed data on household expenditure between 1980 and 2007, I use the U.S. Consumer Expenditure survey (CEX), obtained from the Inter-university Consortium for Political and Social Research (ICPSR) at the University of Michigan. The survey is conducted on a quarterly basis by the U.S. Department of Labor, Bureau of Labor Statistics (BLS) for the main purpose of constructing the consumer price index weights. It is the only U.S. dataset that has detailed micro information on both household expenditures and income for a long time frame and at a high enough frequency that allows us to examine the effects of monetary policy shocks. Other sources of disaggregated household expenditure are either conducted too infrequently (such as the Panel Study of Income Dynamics, which is conducted every two-three years), or has a shorter history (such as the Nielsen Homescan dataset, which has reliable data from 2004 onwards).

[4]The CRB index is currently based on the weighted prices of futures contracts of energy (crude oil, heating oil, natural gas), grains and oilseed (corn, soybeans, wheat), industrials (copper, cotton), livestock (live cattle, live hogs), precious metals (gold, platinum, silver), and soft goods (cocoa, coffee, orange juice, sugar).

The unit of survey is the household level, and each household is interviewed by the BLS once per quarter, for at most five consecutive quarters. Data is collected on expenditures at a detailed level for non-durable and durable goods, and services. Similar to Krueger and Perri (2005), I define non-durable expenditure to include food, alcohol and tobacco, gasoline and other fuel, and clothing. Services expenditure covers household utilities, household operations, service charges, recreational services, public transportation, personal care services, health care, and education, and excludes housing. Durable goods expenditure includes spending on vehicles, housing furnishings, and recreational equipment. Each category of expenditure is deflated using the BLS consumer price indices.

While expenditure is reported at the household level, demographics are reported for individuals. These include age, income, education attainment, family size, and year of birth of the head of household. The survey also includes sample weights, which are based on the household demographics and reflects how representative the household is in the population. These weights are used in the empirical regressions.

Following Aguiar and Hurst (2013), Coibion et al. (2012), and others, I restrict the sample to ensure that the data is comparable over time. Specifically, I restrict the sample to include only households where the head of household is aged between 25 and 75 years (inclusive). To reliably estimate cohort effects, I include only households who are born between 1914 and 1973 inclusive, to ensure that each cohort has at least 10 years of data. The sample includes only households who report expenditures in all four quarters of the survey, and with non-zero food expenditure. Only urban households are included in the sample, since the BLS did not interview rural households prior to 1983. I also restrict households with complete income reports, and with at least three monthly observations per quarter. This leaves 235,933 households in total over the period 1980-2007.

There are some well-known measurement issues with the CEX data.[5] Over time, total spending measured by the CEX has fallen relative to the National Income and Product Accounts (NIPA) measure. Moreover, the discrepancy has differed by consumption category. This discrepancy will not affect the results of analysis qualitatively in a number of cases. First, if the discrepancy in reporting is uniform across households, then the comparison of old and young households will not be affected, even though the levels of expenditure are mismeasured. Alternatively, in the case where the mismeasurement is not uniform across

[5]For a discussion of these issues, see for example, Heathcote, Perri, and Violante (2010), Attanasio (2003), Aguiar and Bils (2011), and Attanasio, Hurst, and Pstaferri (2012).

households, the results will still hold if the relative mismeasurement is constant over time. This is because the constant measurement error will drop out when the change in expenditure is computed. Section 7 on robustness further explores the measurement issues following the approach of Aguiar and Hurst (2013). Specifically, the CEX data is scaled up for each category to match the NIPA counterpart. I then redo all the estimation on the rescaled data to examine the robustness of our results.

3 Empirical Approach

The first contribution of this paper is to quantify the heterogeneity in consumption and income responses across households of different ages following a monetary policy shock. To do so, monetary policy shocks are first identified using aggregate data. These shocks are then combined with detailed quarterly microeconomic household consumption and income data from the U.S. Consumer Expenditure Survey (CEX) over 1980 to 2007. In the baseline analysis, the post-2007 data is not included to avoid the period when disruptions to financial markets were most severe, and when policy was implemented in a number of other ways besides lowering the Federal Funds rate.

3.1 Identification of monetary policy shocks

I consider three approaches to identifying the monetary policy shocks: vector autoregressions (VAR) with aggregate data, the Romer and Romer (2004) procedure using qualitative information, and using high-frequency data (Kuttner, 2001). The baseline results presented in the following section are based on monetary policy shocks identified using a VAR with standard recursive assumptions (as described in Christiano, Eichenbaum, and Evans, 1999). Section 7 considers the robustness of the results using the other two methods of identification.

The standard VAR procedure fits the following regression

$$Z_t = B_0 + \sum_{k=1}^{4} B_k Z_{t-k} + u_t \tag{1}$$

where the error term u_t is assumed to be serially uncorrelated and to have a variance-covariance matrix V, that can be decomposed into a lower triangular matrix and a matrix of the underlying exogenous shocks ϵ_t which has covariance matrix equal to the identity matrix. The aggregate variables in the vector Z include, in the following order: the log of real GDP, the log of the GDP deflator, the log of an index of sensitive commodity prices, and the Federal Funds rate. The VAR is estimated using quarterly data over the period 1960:Q1-2007:Q4, using four lags of the variables in the system. The monetary policy shocks correspond to the fourth element of the vector ϵ.

Following CEE (1999), I include the following aggregate variables in the vector Z in the following order: the log of real GDP, the log of the GDP deflator, the log of an index of sensitive commodity prices, and the Federal Funds rate. The monetary policy shocks therefore correspond to the fourth element of the vector ϵ, and are the unexpected changes to the Federal Funds rate. The VAR is estimated using quarterly data over the period 1960:Q1-2007:Q4, using four lags of the variables in the system.

This recursive identification approach is based on a number of key assumptions. First, it assumes that the information set of the monetary authority can be summarized by the contemporaneous output, GDP deflator, and commodity price index. Second, the ordering of the variables in Z and the lower triangular structure of the Γ implies that shocks to monetary policy only contemporaneously affect the Federal Funds rate and none of the other aggregate variables. Thirdly, it assumes that there is no heteroskedasticity and serial correlation in the error terms, and no regime shifts over the sample period.

Figure 3 depicts the estimated time series of the Federal Funds rate policy shock. For ease of interpretation, the figure reports the centered, three quarter moving average of the shocks

$$\sigma(\epsilon_{s,t+1} + \epsilon_{s,t} + \epsilon_{s,t-1})/3$$

The shaded regions reflect the recession periods as defined by the National Bureau of Economic Research (NBER). The estimated standard deviation, σ, of the shocks is 0.72 percent, at an annual rate, and the mean (of the absolute value of the shock) is 0.47 percentage points. Consistent with previous studies, the shocks are particularly large and volatile in the early 1980s, during the Volcker disinflationary period. In describing the results in the following section, I characterize monetary policy as "contractionary" when the policy shock is positive, and "expansionary" when the shock is negative.

In the following section, I present results based on the VAR identified shocks. For robustness, I redo the analysis using two alternative identification schemes and present the results in Section 7. I consider the Romer and Romer (2004) procedure and using high-frequency

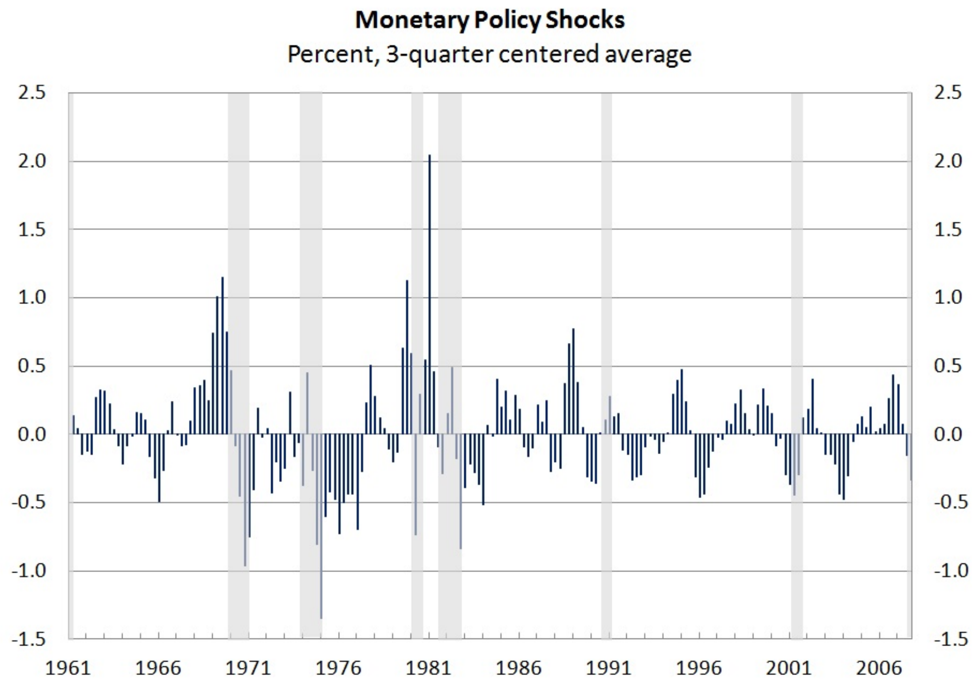

Figure 3: Quarterly Monetary Policy Shocks
Shaded recession periods

identification of monetary policy shocks.[6] The Romer and Romer (2004) procedure defines monetary policy shocks as the component of policy changes from each meeting which is orthogonal to the Federal Reserve's information set (embodied by the Greenbook forecasts for the GDP deflator, unemployment rate, and real output growth). Specifically, the shocks are identified from the residual term of the following regression:

$$\begin{aligned}\triangle f_t =& \alpha + \beta f b_t + \sum_{i=-1}^{2} \gamma_i \triangle y_{t-i} + \sum_{i=-1}^{2} \lambda_i (\triangle y_{t-i} - \triangle y_{t-i-1}) \\ &+ \sum_{i=-1}^{2} \phi_i \pi_{t-i} + \sum_{i=-1}^{2} \lambda_i (\pi_{t-i} - \pi_{t-i-1}) + \rho u_t + \epsilon_t\end{aligned}$$

where $\triangle f_t$ is the change in the Fed Funds rate at meeting t; fb_t is the intended Fed Funds Rate just before the meeting; and π, $\triangle y_t$ and u_t are forecasted inflation, output growth, and unemployment rate, respectively. Thus, ϵ_t identifies the monetary policy shocks at a quarterly frequency.

[6] I thank Lorenz Kueng for sharing his data from his paper with Coibion et al. (2012).

A second alternative identification approach is using high-frequency data, following the methodology described in Kuttner (2001), and more recently used in Gertler and Karadi (2013) and Nakamura and Steinsson (2013). Specifically, monetary policy surprises are measured by the change in the 30-day futures rate over a time interval surrounding the FOMC announcement dates. I consider two measures of futures (Eurodollar and Federal Funds), and two different time intervals (30-minute and 1-day windows on the day of announcement). The policy shock is measured by the change in the future rates:

$$\epsilon_t = \triangle f_t \cdot \left(\frac{n_t}{n_t - d_t} \right)$$

where $\triangle f_t$ denotes the change in 30-day futures rate in month t over a time window surrounding the FOMC announcement. $\left(\frac{n_t}{n_t - d_t} \right)$ scales for remaining days in the month affected by the change, where n_t denotes number of days in month t and d_t denotes the day of month of the announcement. The results are presented in the Section 7 on robustness.

3.2 Empirical Analysis: Household Heterogeneity

After identifying the monetary policy shocks, panel regression analysis is used to quantify the response of household consumption and income to these shocks, and to examine variation in response by age. To isolate the life-cycle component of the response, I adjust for family composition and cohort effects, which are identified from cross-sectional differences in family composition and the multiple cohort cross-sections in the CEX sample. Formally, I estimate the following regression:

$$\triangle \ln x^a_{ht} = \alpha^a + \sum_k \beta^a_k \cdot \hat{\epsilon}^{mp}_{t-k} + \gamma^a \cdot Z^a_{ht} + \lambda^a_{ht} + \nu^a_{ht} \tag{2}$$

where i indexes households and t indexes time (quarterly); x is deflated total household expenditure (excluding housing); $\hat{\epsilon}^{mp}$ denotes the identified monetary policy shocks (up to 20 lagged quarters); Z is a vector of household h demographics in quarter t; and λ is a vector of vector of household and cohort fixed effects. Equation 2 is estimated for each age group a (there are five groups, each with an age range of 10 years, starting from 25 years of age). The key coefficients are β^a_k, which measure the response of the expenditure of the households in age group a to a monetary policy shock that occurred k quarters ago.

4 Empirical Patterns and Demographics

4.1 Response of households to monetary policy shocks

There exists significant heterogeneity across households of different ages with respect to their response to monetary policy shocks. Figure 4 plots the estimated household expenditure impulse response functions by age groups following an unanticipated one percentage point increase in short-term interest rates.[7] The dashed lines give the 95-percent confidence intervals from the estimated standard errors of the coefficients from Equation 2. I find that young households (aged 25-35 and 34-44 years, panels 1 and 2) reduce their expenditure, while older households (aged 55-64 and 65-75 years, panels 3 and 4) do not make significant adjustments to their consumption. The differences between the responses of the young (aged 25-35) and the old (aged 67-75) are statistically significant and persistent, lasting around 15 quarters.

To gain insight into the channels that may be driving the heterogenous responses of young and old households, I further disaggregate the data by household demographics, including financial liquidity and education attainment, and consider the responses of these household groups to identified shocks to monetary policy.

I measure financial liquidity based on the household debt-servicing ratio, which is defined as the share of household expenditure that is spent on debt repayments over the year within the CEX sample. Households with low (high) financial liquidity are defined as households who are in the top (bottom) quintile of the debt-servicing ratio distribution. Households with low financial liquidity are disproportionately younger in age, with the debt-servicing ratio declining with age from around 45 years of age. This is consistent with evidence from the Survey of Consumer Finances (Appendix A, Figure 8), and studies including Parker et al (2006) and Hurst and Stafford (2004), who use PSID data to show that households who refinance their debt tend to be younger in age.

Re-estimating Equation 2 for low and high financial liquidity household groups separately, I find that households with low levels of financial liquidity reduce their expenditure more dramatically than households of high financial liquidity (Figure 5). The dashed lines give the 95-percent confidence intervals from the estimated standard errors of the coefficients from

[7] To aid in graphical presentation, the Figures present the centered 3-period averages of the estimates from Equation 2 for each age group.

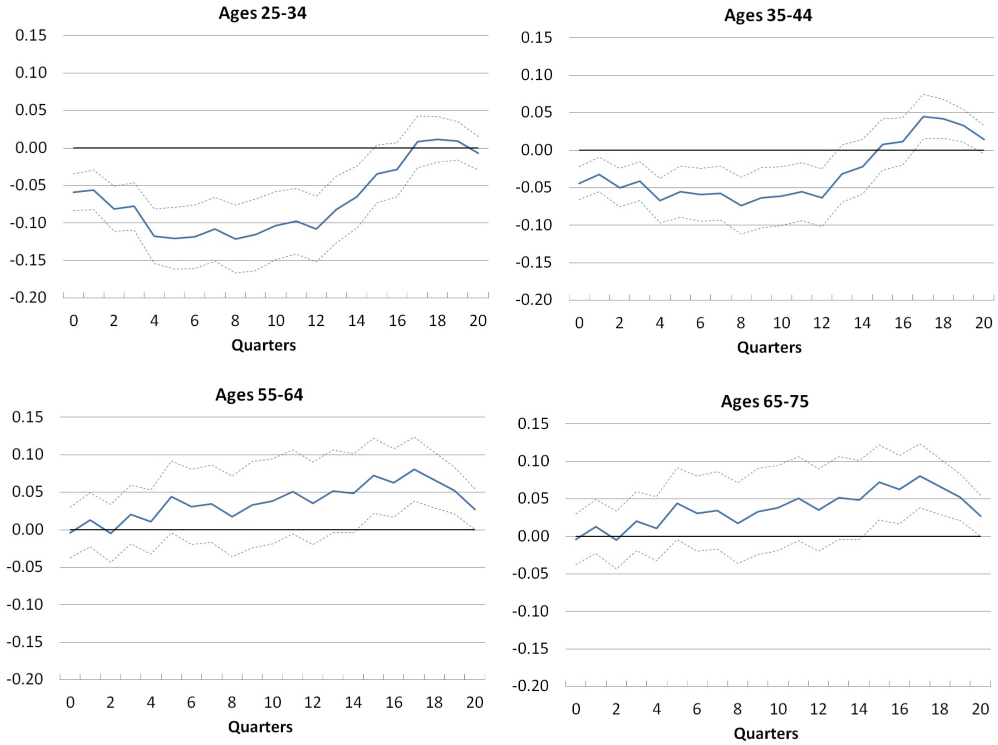

Figure 4: Fraction change in expenditure
after a 1ppt shock to monetary policy

Equation 2. These findings are consistent with studies of the recent fiscal stimulus, which show that young households with lower levels of liquid assets tend to have a higher marginal propensity to consume out of temporary income shocks (Parker et al. (2012) and Kaplan and Violante (2012)). Households with low levels of financial liquidity may be more susceptible to liquidity shocks, particularly if the household needs to refinance existing housing or credit card debt, or need to take out a new loan. These results imply that part of the differences in response across households by age may reflect life-cycle differences in financial constraints.

A second explanation for why younger households have a larger response to contractionary monetary policy shocks may be the higher unemployment risk that they face (as highlighted in studies such as Jaimovich and Sui (2009)). It is possible that the decline in output associated with a contractionary monetary policy shock may disproportionately affect the employment of the young. To explore the importance of this second explanation, I examine the response of unemployment for each age group following a contractionary shock using disaggregated data from the BLS. I find that young households aged under 35 experience more pronounced increases in unemployment following a monetary policy shock (Figure 6).

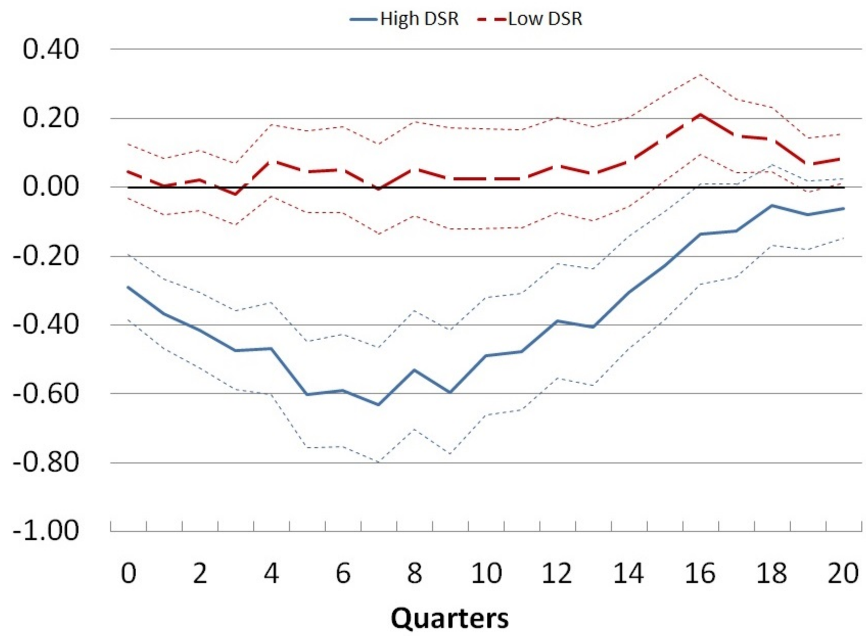

Figure 5: Fraction change in expenditure
after a 1ppt shock to monetary policy

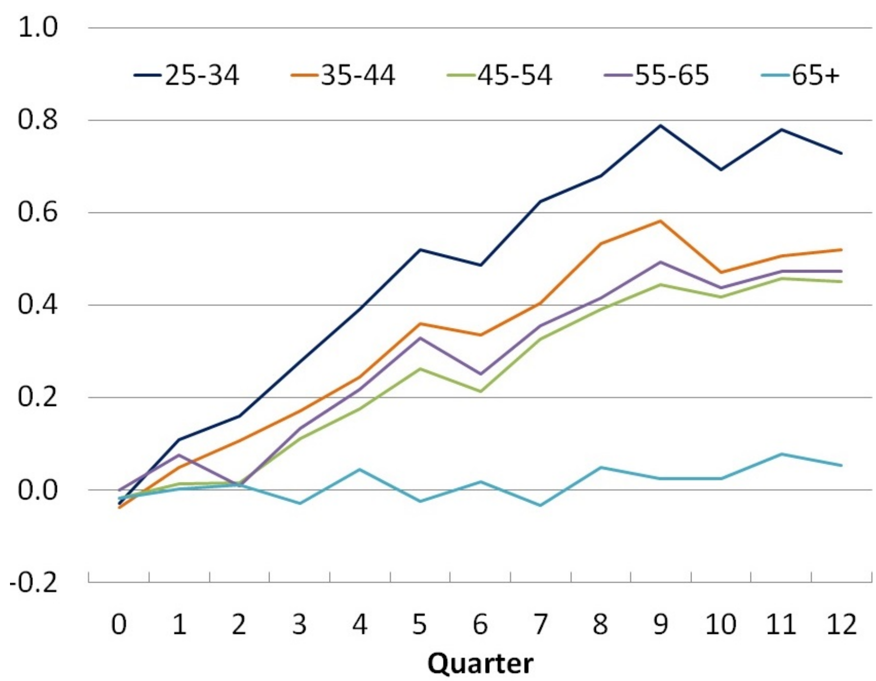

Figure 6: Percentage point change in unemployment
after a 1ppt shock to monetary policy

This is consistent with studies of variation in labor for different age groups over the business cycle.[8]

4.2 Counterfactual exercise of population aging

These results imply that population aging may dampen the aggregate response of household expenditure and income to a monetary policy shock, as it lowers the share of households facing tight financial constraints and high labor market risks. Given the empirical results, a natural conjecture is that the responsiveness of aggregate variables to monetary policy shocks depends on the age composition of the population. This motivates the second part of the paper, which investigates the effect of aging on the aggregate effects of monetary policy. First I perform a simple quantitative exercise based on the estimated impulse responses (which were shown in Figure 2).[9] Specifically, I construct the aggregate response of household consumption (denoted by β_{t+k}) at each quarter $t+k$ following a monetary policy shock at time t based on

$$\beta_{t+k} = \beta^{25}_{t+k} c^{25}_{t+k} + \beta^{35}_{t+k} c^{35}_{t+k} + \cdots + \beta^{65}_{t+k} c^{65}_{t+k}$$

where β^{25}_{t+k} is the change in consumption of 25-34 year olds, β^{35}_{t+k} is the change in consumption of 34-39 year olds, and so on, progressing in 10-year age groups. The expenditure share of age group a is denoted by c^{a}_{t+k}. I compute the aggregate response using expenditure shares in 1980, and using projected expenditure shares in 2100 based on the U.N projected population composition.

Figure 7 depicts the aggregate response of household expenditure under the 1980 and 2100 age compositions. I find that the projected demographic shift associated with population aging dampens the response of expenditure to a 1 percentage point contractionary monetary policy shock. Specifically, I find that aggregate expenditure declines by a trough of 4 percent under the 2100 age composition, which is almost half the response estimated using the 1980 age composition. These findings corroborate preliminary cross-state panel regression results, which show that states with more pronounced aging over the period 1980-2007 also have more muted output and labor responses to monetary policy shocks.

[8]These studies include Jaimovich and Sui (2009), Gomme et al. (2005), Clark and Summers (1981), Moser (1986), Ros-Rull (1996), Eva Nagypal (2005) and others.

[9]The quantitative accounting exercise in this paper is in the spirit of the exercise used in Jaimovich and Sui (2009) and Shimer (1999).

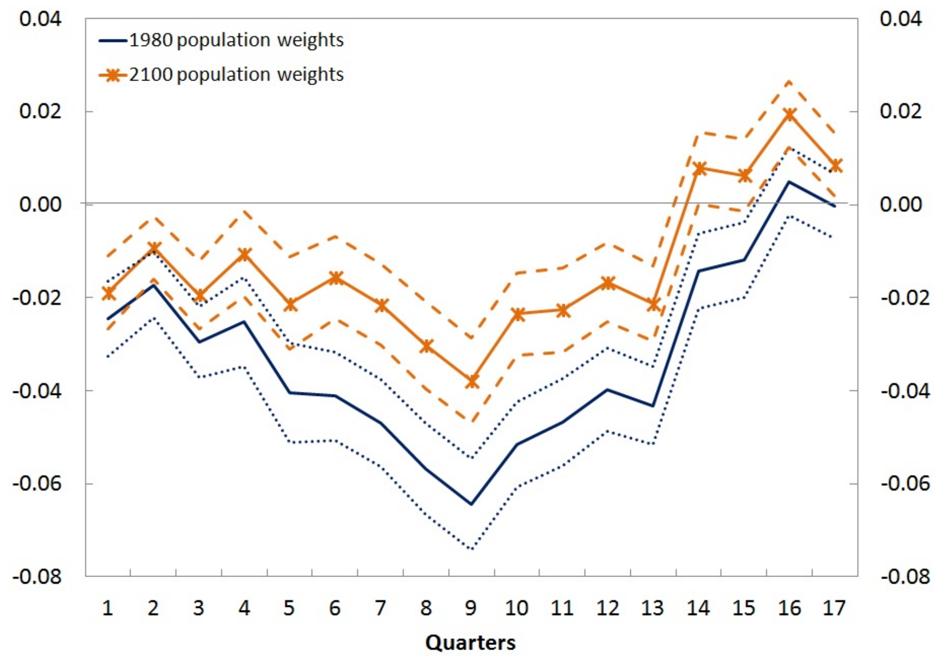

Figure 7: Fraction change in expenditure
after a 1ppt contractionary shock.

The results from the stylized accounting exercise are suggestive of potential changes in the aggregate effects of monetary policy shocks owing to demographic considerations, and indicative of the need to pursue careful quantitative analysis. These results motivate the following section, in which I develop a theoretical over-lapping generations model to allow for general equilibrium effects that may attenuate the stylized accounting exercise.

5 A Theoretical Framework

This section is preliminary and incomplete.

This section develops a closed economy New Keynesian model which embeds overlapping generations. The model emphasizes two dimensions of heterogeneity across people, which were shown to be empirically relevant in the previous section: age and labor risk. These dimensions are related, with all agents sharing a common life-cycle profile of labor market risk, which then affects their savings and consumption decisions. Individuals are identical along all other dimensions.

The model is estimated and used to study the dynamic effects and implications for the setting of optimal monetary policy under different demographic regimes (Section 6). Two applications of the model is then provided to understand the relationship between monetary policy and demographics: First, I ask how the setting of optimal monetary policy may change given the projected demographic shifts in the U.S. Secondly, the model is used to examine the extent to which the limited response of the Japanese economy to monetary policy stimulus in the 1990s reflected the demographic structure of Japan.

5.1 Final Goods Producer

There is a single final homogeneous market good in the economy, which is produced by a continuum of competitive and identical firms using the following technology:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}$$

where $\epsilon < 1$. The representative firm chooses specialized inputs $Y(i)$ from intermediate firm i to maximize profits:

$$\max_{Y_t, Y_t(i)} P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$$

subject to the production technology. The price of the final good is denoted by P_t and the price of the intermediate input is denoted by $P_t(i)$. The firm's first order condition for the ith input is

$$Y_t = \left(\frac{P_t(i)}{P_t} \right)^{\epsilon} Y_t(i)$$

which implies a price of

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di \right)^{1/(1-\epsilon)}$$

5.2 Intermediate Firms

The intermediate firms are monopolistically competitive and produce output $Y_t(i)$ according to the production function:

$$Y_t(i) = Z_t \left[\mu(L_{u,t})^\sigma + (1-\mu)\left[\lambda K_t(i)^\rho + (1-\lambda)(L_{s,t})^\rho\right]^{\sigma/\rho}\right]^{1/\sigma} - Z_t\phi$$

where Z_t denotes a technology factor, which follows a stationary AR(1) process in logs with i.i.d. innovations denoted by ϵ_t^Z and persistence ρ_z. The variable ϕ denotes the fixed cost of production to ensure that steady state profits are zero.

The production function exhibits capital-experience complementarities, in the spirit of Jaimovich and Sui (2012). The firm uses two types of labor: inexperienced labor denoted by $L_{u,t}$ and experienced labor hours denoted by $L_{s,t}$. The elasticity of substitution between the inexperienced labor and capital $K_t(i)$ is denoted by $(1-\rho)^{-1}$, while $(1-\sigma)^{-1}$ affects the elasticity of substitution between unskilled labor hours and the $L_s - K$ composites. There exists capital-experience complementarity if $\sigma > \rho$. The parameters λ and μ affect the income shares. The two types of labor are included in the production function to capture the life-cycle variation in the labor income which was seen to be empirically important in the previous section. The capital-experience complementarity implies that inexperienced labor is more volatile relative to experienced labor. Assuming that consumers gain experience with age, then this implies more volatile labor for younger households relative to older households who are still in the labor force.

Profit maximization on the part of the firm entails equating factor prices with marginal revenue products. The first order conditions (dropping i subscript) are:

$$\begin{aligned} r_t &= Y_t^{1-\sigma}(1-\mu)\Omega_t\lambda K_t^{\rho-1} \\ w_{ut} &= Y_t^{1-\sigma}(1-\mu)\Omega_t(1-\lambda)L_{st}^{\rho-1} \\ w_{st} &= Y_t^{1-\sigma}\mu L_{ut}^{\sigma-1} \end{aligned}$$

where $\Omega_t \equiv [\lambda K_t^\rho + (1-\lambda)L_{st}^\rho]^{(\sigma-\rho)/\rho}$.

The intermediate goods producer sets its price $P_{i,t}$ subject to its demand curve and the Calvo sticky price friction:

$$P_{i,t} = \begin{cases} P_{i,t-1} & \text{with probability } \theta \\ P_t^* & \text{with probability } 1-\theta \end{cases}$$

This implies that the aggregate price is given by

$$P_t = \left(\theta P_{t-1}^{1-\epsilon} + (1-\theta)(P_t^*)^{1-\epsilon}\right)^{\frac{1}{1-\epsilon}}$$

5.3 Demographics and Preferences

There is a continuum of consumers, indexed by h, who live for $T+1$ periods (from 0 to T). Age is indexed by $j = 0, 1, ..., T$. Consumers retire at age J and retirement lasts for $T-J$ periods.[10] Every period t, a cohort of measure N_t is born, which follows a geometric random walk:[11]

$$\ln N_t = \ln N_{t-1} + \epsilon_{N,t}$$

where the birth rate $\epsilon_{N,t}$ is an i.i.d random variable. Thus, a high realization of $\epsilon_{N,t}$ represents a baby boom. Thus, the total population in the economy at time t is given by

$$\sum_{s=1}^{T} N_{s,t}$$

where $N_{s,t}$ denotes measure of consumers aged s at time t.

The consumer derives utility from consumption goods and leisure. The utility function of consumer h, born at time a, is:

$$\max_{\{c_{a,t}, b_{a,t}, B_{a,T}, I_{a,t}\}} \; E_a \sum_{t=a}^{a+T} \beta^t u(c_{a,t}^h, 1 - l_{a,t}^h) + \beta^T v(B_{a,T})$$

where $c_{a,t}^h$ denotes consumption in period t, $l_{a,t}^h$ denotes labor supply, and $B_{a,t}$ denotes the bequest left to the next generation. The variables $I_{a,t}$ and $b_{a,t}$ denote the investment in capital and nominal bonds, respectively.

[10]For simplicity, the base model abstracts from mortality risk since the focus is to consider optimal monetary policy under two different demographic regimes, rather than to model the transition path. In an extension of the model, I endogenize the retirement decision of a household and include mortality and longevity risk. The later affects maximum age of the consumer.

[11]This formulation of demographics is also used in Abel (2003).

The consumer receives the bequest in the first period of life, works for J periods, and is retired during the last $T-J$ periods. Households can invest in two ways: First, via purchases of nominal bonds $b^h_{a,t}$, which pays a nominal rate of return of R_t. Secondly, they can also invest in capital denoted by $K_{a,t}$ and earn a nominal rental rate of $R_{K,t}$. The stock of capital $K_{a,t}$ evolves according to

$$K^h_{a,t} = (1-\delta)K^h_{a,t-1} + I_{a,t}$$

where $I_{a,t}$ denotes the purchase of investment goods.

Households can earn labor income, which given by the nominal wage rate $w_{a,t}$ times the hours worked $l_{a,t}$. This is related to age in the following way:

$$w_{a,t}l_{a,t} \equiv w_{u,t}\gamma_a l_{a,t} + w_{s,t}(1-\gamma_a)l_{a,t}$$

where $w_{u,t}$ denotes the inexperienced labor wage and $w_{s,t}$ denotes the experienced labor wage. This is a reduced form way of capturing the idea that individuals gain work experience at a rate of γ_a as they age and therefore increase their hourly income as they age. Individuals gain experience linearly over time as they age for the case where

$$\gamma_a \equiv \frac{T-a}{T}$$

This approach captures the fact that labor income of younger households, who have less work experience, fluctuate more following aggregate shocks when there exists complementarity between experience and capital in the production function.[12]

Thus, utility is maximized subject to the following budget constraints:

$$P_t c^h_{a,t} + P_t I_{a,t} + b^h_{a,t} = w_{a,t}l_{a,t} + B_{a,t-1} \qquad \text{if } t = a$$

$$P_t c^h_{a,t} + P_t I_{a,t} + b^h_{a,t} = R_t b^h_{a,t-1} + R_{K,t}K^h_{a,t-1} + w_{a,t}l_{a,t} \qquad \text{if } a < t \leq J$$

$$P_t c^h_{a,t} + P_t I_{a,t} + b^h_{a,t} = R_t b^h_{a,t-1} + R_{K,t}K^h_{a,t-1} \qquad \text{if } J < t < T$$

$$P_t c^h_{a,t} + B_{a,t} = R_t b^h_{a,t-1} + R_{K,t}K^h_{a,t-1} \qquad \text{if } t = T$$

and the following constraints:

$$b^h_{a,t} \geq \bar{b}$$

[12]This is related to the the approach taken in Jaimovich and Sui (2009), who equate age with experience.

$$c^h_{a,t} \geq 0$$

These preferences imply that households accumulate savings over the life-cycle for retirement and are exposed to lower labor income risk as they age. Both of these factors imply that households are less likely to be liquidity-constrained following monetary policy shocks as they age, which dampens their consumption response to these shocks.

5.4 Monetary Policy and Market clearing

A central bank is assumed to set the nominal interest rate based on the feedback rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{(\pi_t \cdot \pi_{t-1} \cdot \pi_{t-2} \cdot \pi_{t-3})^{\frac{1}{4}}}{\pi}\right)^{\rho_\pi} \left(\frac{Y_t}{e^{y^*_t}}\right)^{\rho_y}\right]^{1-\rho_R}$$

where π_t is the gross rate of inflation at time t, π is the Central Bank's inflation target, and y^*_t is a measure of trend output. The parameters ρ_R, ρ_π and ρ_y capture the degree of inertia, and the strength of the interest rate reaction to the deviations of annual inflation from the target and of output from trend.[13]

The capital services market clearing condition is:

$$K_t = \sum_{a=0}^{T} K_{a,t} N_{a,t}$$

where $N_{a,t}$ is the measure of households of age a at time t.

The labor market clearing condition is:

$$L_{u,t} = \sum_{a=0}^{T} \gamma_a l_{a,t} N_{a,t}$$

$$L_{s,t} = \sum_{a=0}^{T} (1-\gamma_a) l_{a,t} N_{a,t}$$

The debt market clearing condition is given by

$$0 = \sum_{a=0}^{T} b_{a,t}$$

[13]The specification was also adopted in Justiniano, Primiceri and Tambalotti (2014).

The aggregate resource constraint is given by

$$Y_t = \sum_{a=0}^{T} c_{a,t} + \sum_{a=0}^{T} I_{a,t} = C_t + I_t$$

where I_t is the aggregate amount of investment in capital:

$$I_t = K_t + (1 - \delta)K_{t-1}$$

6 Implications

7 Robustness

8 Conclusion

9 References

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A Appendix: Life-cycle financial asset holdings

The following graph depicts the holdings of financial assets and debt for U.S. households by age group using data from the U.S. Survey of Consumer Finances.

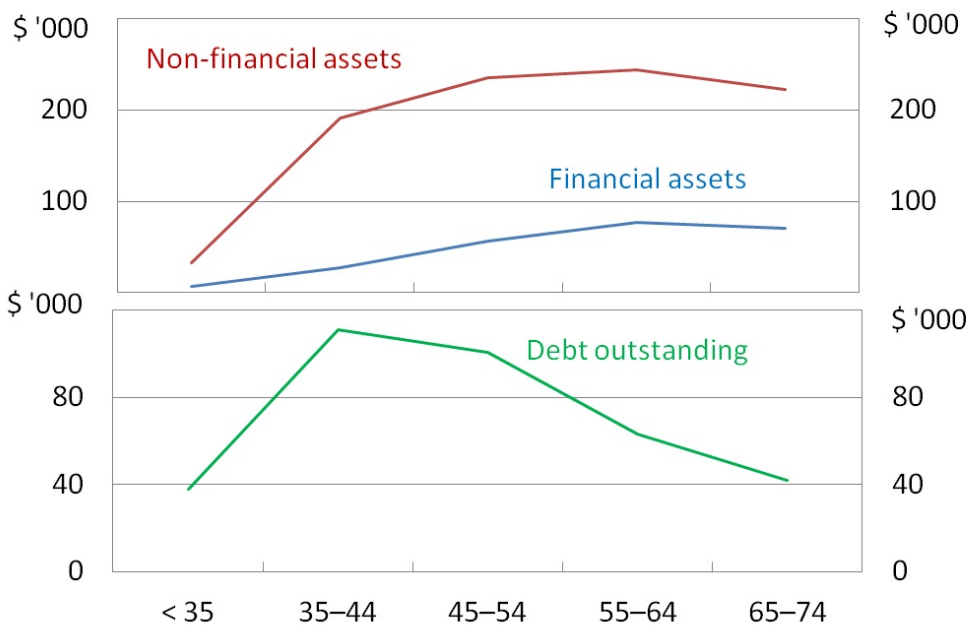

Figure 8: Financial Assets and Debt of Households by Age

B Appendix: Additional Results

This section presents preliminary additional results by demographic splits. I further disaggregate households into groups based on age and college attainment to examine the role of skill in explaining the different in responses by age to monetary policy shocks. The intuition is that individuals that have attained college degrees are more likely to be employed in industries with lower unemployment risk.[14] Figure 9 depicts the impulse response functions of households, grouped by age and college attainment. We see that for all age groups, with the exception of the 55-65 age group, the responses of households by age to a policy shock does not significantly differ by college attainment.

[14]See for example, Jaimovich and Sui (2009), who highlight that individuals employed in routine non-cognitive jobs are more susceptible to unemployment risk at a cyclical basis.

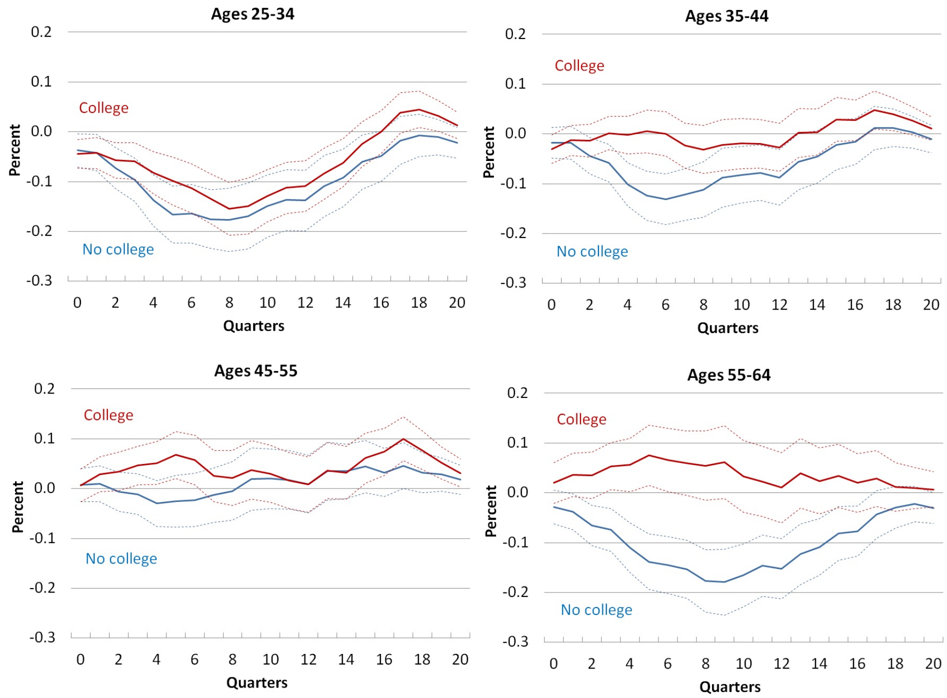

Figure 9: Impulse response of expenditure
by Age and Education after a 1ppt shock

For the 55-65 age group, we observe different responses by college attainment. Households whose head of household do not have a college degree reduce expenditures following a contractionary monetary policy shock, whereas those with a college degree increase their expenditures slightly. One explanation for why college attainment matters for this age group may be due to retirement related savings. Those with college degrees may be more likely to be employed in industries which offer defined benefit retirement schemes, or have substantial personal savings in retirement funds. In contrast, households without college degrees may have less retirement savings, and may therefore respond more by reducing expenditure to save at the higher interest rate for retirement purposes.