Home Equity in Retirement*

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Abstract

Retired homeowners dissave more slowly than renters, which suggests that homeownership affects retirees' saving decisions. We investigate empirically and theoretically the life-cycle patterns of homeownership, housing and nonhousing assets in retirement. Using an estimated structural model of saving and housing decisions, we find, first, that homeowners dissave slowly because they prefer to stay in their house as long as possible, but cannot easily borrow against it. Second, the 1996-2006 housing boom significantly increased homeowners' assets. These channels are quantitatively significant; without considering homeownership, retirees' net worth would be 28-44% lower, depending on age.

JEL classification: D91, J26, E21, G11
Keywords: Housing, Retirement Saving Puzzle, Mortgage, Health, Life-cycle

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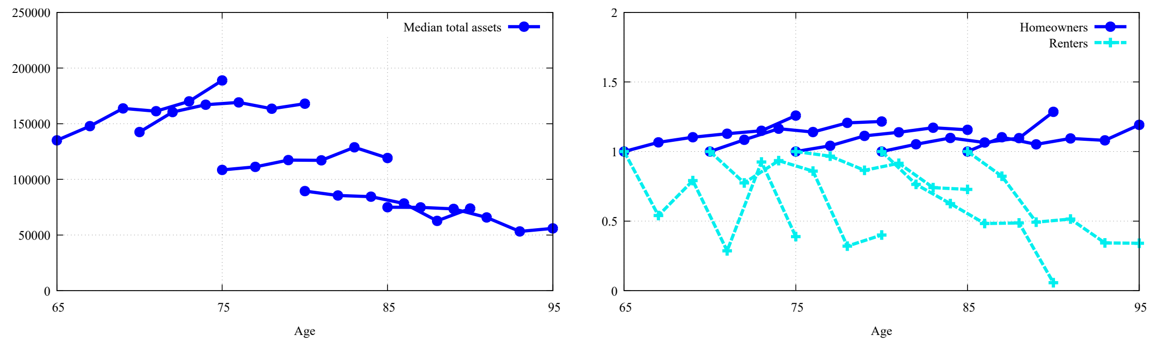


(a) Median Net Worth

(b) Normalized Median Net Worth

Figure 1: Life-Cycle Wealth Profiles. Source: HRS

1 Introduction

An important question in the life-cycle savings literature is why the elderly dissave slowly in the data. As figure 1 shows over the period 1996-2006 for five different cohorts, median net wealth remains high very late into the life cycle. The observation that many people die with significant savings, which is puzzling in the context of a simple life-cycle model, has been termed the "retirement saving puzzle".[1]

The picture changes dramatically if we consider the saving behavior of retirees who own homes, compared to those who do not. Consider figure 1, which documents cohort profiles of median net worth over the same period, normalized by the first observation, for homeowners versus renters.[2] The difference is stark. Homeowners have flat or increasing profiles of net wealth over this period, while renters display a far faster rate of asset decumulation. This suggests that housing may play a major role in determining how retirees save or dissave.

Motivated by this observation, in this paper we examine the role of housing in retirees' (dis)saving behavior. Rather than explaining only the life-cycle profile of household net worth, as the literature has done, we seek to understand several facts about saving in retirement concurrently: we consider both housing and nonhousing assets, as well as homeownership rates and collateralized debt. Our main question is what role housing plays in accounting for the retirement saving puzzle. We find that considering explicitly the nature of housing as a complex asset with properties different from other assets makes an important difference in understanding retiree saving behavior, and changes our conclusions regarding the retirement saving puzzle, relative to

[1]See Section 2 for literature review. De Nardi et al. (2016b) and Suari-Andreu et al. (2019) provide an up-to-date survey of the literature.

[2]In this figure, homeowners are the households that start in our 1996-2006 HRS sample as owners, and remain so throughout the sample; renters are similarly "perpetual" renters.

previous literature. By understanding the nature of homeownership late in life, we also shed new light on the role of bequest motives, uncertainty and precautionary motives in retirement.

We begin by documenting in detail, using the Health and Retirement Study (HRS) over the period 1996-2006, various facts about retirees' financial and housing asset holdings, and about their use of home equity. Because the HRS is a longitudinal survey, it allows us to study life-cycle asset and debt profiles over time. We also document other relevant changes in retirees' lives pertaining to their income, health, medical expenses, marital status and the like, which are all potential drivers of saving decisions late in life.

We then build a model of household saving decisions in retirement with the goal of accounting for the life-cycle facts of interest. The model includes both financial assets and a house, which serves as an asset but also provides utility. Retirees can choose whether to own a home or rent, and homeowners can access their home equity by selling the house or by secured borrowing, with an age-dependent borrowing constraint. Retirees have a warm-glow bequest motive, and face idiosyncratic uncertainty in their health status, medical expenses, and longevity, as well as that of their spouse. They have Social Security and pension income, and access to a government-provided social insurance program which provides a consumption floor for households who run out of assets. Aggregate house price dynamics reflect changes in the U.S. housing market in 1996-2006.

The key potential driving forces of retiree saving behavior in the model are financial and nonfinancial benefits of homeownership, including the housing price boom of 1996-2006, differential liquidity properties of housing and financial assets, as well as bequest motives, longevity risk, medical expense risk and the Medicaid-like government social safety net. While bequest motives, longevity, medical expense risk and Medicaid have been studied and debated in previous literature on the retirement saving puzzle, the housing-related forces have not been considered previously in the context of a structural model; yet, they may matter on their own, and may interact with bequest motives and medical expense risk. We estimate our model, and use it to quantify the role of each of these forces, as well as to understand their interactions.

We estimate the model by a two-step procedure using the HRS. We measure exogenous parameters, such as the shock processes, outside the model, then use the model to estimate other parameters by a minimum-distance estimator, targeting jointly the life-cycle facts mentioned above. Our model successfully replicates these facts, with reasonable resulting parameter values.

To understand the quantitative contribution of the key model features, we conduct a series of experiments using the benchmark model. We shut down these features one at a time, keeping the rest of the model unchanged, and quantify their role based on the resulting changes in outcomes. We find that the high homeownership rate late into the life-cycle that we observe in the data is crucial to take into account if one wants to understand retiree saving behavior. Housing-related channels are significant contributors to the retirement saving puzzle. Retirees stay homeowners late in life, due to financial benefits and attachment to their homes, but become increasingly locked into their home equity; we find that borrowing constraints on retirees tighten considerably as they age. This means, on the one hand, that those who remain homeowners do not decumulate their home equity, thus creating the kind of flat housing and net worth profile that we see in the data, while those who face a large expense may come up against their borrowing constraint and be forced to sell the house. In addition, those who owned a house in the period 1996-2006 became beneficiaries of the housing boom, which further contributes to the flat or increasing net worth profiles of elderly homeowners. These effects together are a big part of what creates the stark difference that we observe between homeowners and renters in the data. The housing-related channels account for between 28 and 44% of median net worth of retirees, depending on age. The effects are robust to perturbation of the parameters of the model around their estimated values, as we show in sensitivity experiments.

We also use the model to understand the relative importance of bequest motives and medical expense risk. In our benchmark estimated model, we show that bequest motives play a quantitatively significant role in accounting for the retirement saving puzzle, contributing between 7 and 28% of median net worth depending on age, while the role of medical expenses and expense risk ranges between 4 and 26%, depending on age, and is a function of the strength of the precautionary motive in the model. We also show in sensitivity experiments that the crucial role of housing is robust to model perturbation. In particular, though perturbation of model parameters can change the relative importance of bequest and precautionary motives in accounting for decumulation of net worth in retirement, this perturbation primarily impacts financial assets, while the role of housing in accounting for net worth in retirement is independent of the relative strength of the other two channels.

In addition to the quantitative decompositions, we conduct an experiment where we allow households to make a decision on whether or not to maintain their home. We evaluate this as an additional, possibly hidden, channel of asset decumulation, consistent with data evidence that homes of elderly owners depreciate more quickly than those of younger owners (Davidoff (2006)). We treat this as a hidden channel because we assume that self-reported housing values of owners who remain in their houses do not take into account the depreciation rate unless they have the house appraised for sale, for example. We find this to be a sizable channel of asset decumulation that increases in importance with age. On average, about 15% of model homeowners choose not to maintain their homes in the 75-85 year old cohort; by age 95, nearly 30% of homeowners choose not to maintain the house.

We thus have three main contributions. First, our careful documentation of the longitudinal data provides a set of facts regarding retirees' saving behavior in more detail than previously studied. In addition to being of empirical interest, we think it is important that these facts should be considered explicitly by a theory that seeks to explain saving behavior in retirement. Second, our model enables us to describe the tradeoff between housing and nonhousing assets in retirement, and to characterize the reasons for homeownership in retirement. To our knowledge, we are the first to do this in the context of a rich structural model. Third, we address the retirement saving puzzle from a new perspective.

The remainder of the paper is organized as follows. Section 2 discusses related literature. Section 3 describes our data and stylized facts. Section 4 develops the model. Section 5 describes the estimation strategy, presents the resulting parameters and assesses the fit of the model. Section 6 describes the experiments we conduct in order to quantify the role of housing and other channels in accounting for the retirement saving puzzle. Section 7 discusses robustness of key results and identification of parameters, based on sensitivity analysis. Section 8 concludes. Some details of data analysis and quantitative experiments are in the appendix.

2 Related Literature

Our paper is related to a number of studies of savings decisions in retirement. On the retirement saving puzzle itself, several answers have been proposed. Hurd (1989) estimates the life-cycle model with mortality risk and bequest motives, and finds that intended bequests are small. Love et al. (2009) analyze the retirement saving puzzle using "annualized comprehensive wealth," which is a measure of total wealth, including annuity-like assets as well as financial and nonfinancial assets. Hubbard et al. (1995) argue that means-tested social insurance programs provide a virtual consumption floor and thus strong incentives for low-income individuals not to save; their paper can thus be seen as reinforcing the retirement saving puzzle. De Nardi et al. (2016a) study the role of Medicaid in accounting for retirees' dissaving decisions. Ameriks et al. (2011) study the relative importance of bequest motives and public care aversion in explaining the related annuity puzzle using a model of retirement and survey data, and find both motives significant in the data. Lockwood (2012) looks at the related decision of whether or not to purchase life insurance in retirement.

The paper by De Nardi et al. (2010) is most closely related to ours in terms of approach. They estimate a life-cycle model of retirees using the AHEAD sub-sample of the HRS, focusing on singles among the oldest old. Like them, we use a life-cycle model of retirees together with the HRS, with health and medical expenditures being a major source of uncertainty for retirees. The key difference between our work and theirs is our focus on housing and home equity borrowing, while they aggregate all the assets in the household portfolio, and study the profile of the consolidated asset position in retirement. In addition, we consider in our sample both single and couple households, while De Nardi et al. (2010) include only singles.

De Nardi et al. (2016b) and Suari-Andreu et al. (2019) conduct comprehensive surveys of existing literature on the retirement saving puzzle, including models with housing. The latter uses this paper's framework as a point of departure, and analyzes data from the Netherlands, to show that there is significant association between housing and bequest motives in accounting for the retirement saving puzzle, and that removing housing from consideration may significantly understate the role of bequests.

The empirical part of our paper is related to Venti and Wise (2004), one of whose main findings, confirmed by our data analysis, is that retirees rarely downsize their houses even in older age, unless a drastic event such as illness or death of a spouse occurs. They also provide evidence from the HRS that some older households move into larger homes; we show that this mostly appears to be the case based on rising house prices, rather than reflecting purchases of larger homes, a possibility pointed out by Skinner (2004).

There is a recent literature that uses cross-country comparison of asset decumulation patterns to shed further light on the key drivers of saving behavior in retirement. Nakajima and Telyukova (2016) compare asset decumulation in retirement in European countries and the U.S. Nakajima and Telyukova (2018) focus on the differences between the U.S. and Sweden to infer the importance of medical expense risk in shaping retirees' wealth decumulation patterns. Blundell et al. (2016) compare the U.S. and the U.K.

Other studies of implications of health and medical expenditure risks on portfolio decisions of retirees is Yogo (2016), which treats health expenses as endogenous investment, and Kopecky and Koreshkova (2014), who focus on nursing home expenses and study the implications on aggregate savings and the wealth distribution. Marshall et al. (2010) revisit the measurement of end-of-life medical expenses in an empirical exercise, and find these expenses to be significant.

More generally, our paper fits with the recently growing body of work that incorporates housing explicitly into a macroeconomic framework. For example, Gervais (2002) studies the effects of the preferential tax treatment of housing on capital accumulation. Fernández-Villaverde and Krueger (2011) use a general equilibrium life-cycle model to study the life-cycle profile of housing and nonhousing consumption. Díaz and Luengo-Prado (2010) investigate housing as an explanation for observed large wealth inequality in the U.S.[3]

3 Facts

We begin by describing the most relevant data facts about homeownership and saving in retirement, which we want to explain using our theory. In addition to the facts already presented, these are retirees' life-cycle profiles of homeownership rates, housing and nonhousing assets, the rate of collateralized debt, and the amount of debt held. We also present some facts that inform our modeling choices, as we describe below. We give much more detail on the mapping between the data and the model in Section 5.

3.1 Data

The Health and Retirement Study (HRS) is a biennial longitudinal survey of households of age 50 and above, conducted by the University of Michigan. The survey began in 1992. Due to issues with the early data on assets (see De Nardi et al. (2010)), we begin our data observation in 1996 and use six waves that span 10 years, through 2006. We use the RAND version of the HRS data, constructing a full merged set from the flat files provided by RAND; in addition, we merge in information from the exit waves of the survey, concerning members of the sample who die between two waves, in order to accurately measure medical expenses at the end of life.

We consider everyone present in the 1996 sample who is of age 63 and above and who reports being retired, either fully or partially. We consider both couples and single households. We subdivide the sample into six cohorts, of ages 63-67, 68-72, 73-77, 78-82, 83-87, and 88-97 in 1996. We follow these cohorts across the waves of the survey and document their life-cycle patterns of asset holding and health, as described below. Because assets are measured in the HRS at household level, while health and other demographics are at the individual level, we adjust the weighting schemes appropriately to construct information for our model households.

The HRS sample is replenished several times over the course of the survey. There are multiple ways to deal with this cohort replenishment: one could only consider those who appear in the survey starting in 1996, or include in later waves everyone who belongs to a given cohort by age, even if they enter the survey after 1996. As a benchmark, we consider only households that appear in the 1996 wave, without cohort replenishment. For robustness, we have considered an alternative in which we replenish the cohorts after the 1996 wave; see Appendix A.

[3] Other studies of housing that use structural models include Davis and Heathcote (2005), who study housing in a business cycle model, and Chambers et al. (2009), who investigate the optimal choice between different types of mortgages in a general equilibrium model. Ortalo-Magné and Rady (2006) study the impact of income shocks and credit constraints for business cycle dynamics of the housing market.

A related issue with the HRS sample is weighting. Each individual in the HRS is assigned a wave-specific weight each year he appears in the sample; however, an individual who lives in a nursing home is assigned a weight of zero. We do not want to lose such individuals from the sample. In order to compute weighted statistics, but not lose nursing home residents, we apply the weight attached to each individual in the initial (1996) wave of our sample, consistent with our choice of unreplenished cohorts. For robustness, we reconstructed all of our analysis with the replenished sample, using the weights specific to each wave; we also constructed unweighted measures, for the purpose of comparing with De Nardi et al. (2010). We discuss these measures in Appendix A. We consider an unbalanced panel in our analysis, since households will drop from the sample due to mortality. This choice is the most consistent with our model, where we will construct an equivalent unbalanced panel, with households dying according to the same probability as in the data.

To allow our data measures to map into the model, we measure financial assets as the sum of non-housing assets (excluding businesses and cars) net of all debt, including home equity debt. We track housing assets separately, including only the primary residence, since other real estate information is not available in all waves of the survey. Finally, we define total assets as the sum of financial and housing assets, net of all debt.[4] Our definition of nonfinancial income includes Social Security, pension, disability, annuity, and government transfer income. Because some of our retirees are only partly retired, we also include labor income in this measure; overall, labor income plays a small role, constituting on average about 6% of total income.

As homeowners in our data, we take everyone who reports owning their residence. In the other category, labeled "renters", we include not only actual renters, but also individuals living in nursing homes, with their children, and in other arrangements not involving homeownership. The results presented here are robust to this aggregation of non-owners. A few of the nursing home residents report owning a home. For such individuals, we set the value of their home to zero, and fold their house value into their financial assets.

3.2 Life-cycle Profiles

To accompany our motivating figure 1, we want to confirm that staying a perpetual homeowner throughout the sample implies different saving behavior than that of anyone who becomes a renter any time in the sample, and that the difference that we observe is not simply a function of being in different wealth quintiles. In figure 2, we plot the normalized median net worth profiles of those who are homeowners perpetually versus those who switch into renting at some point in

[4] We experimented with other definitions of assets and found that the results are not affected.

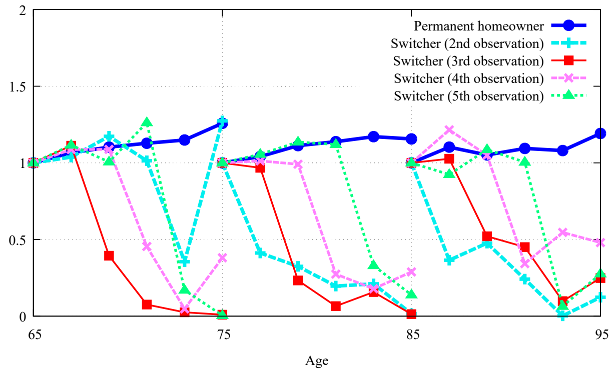
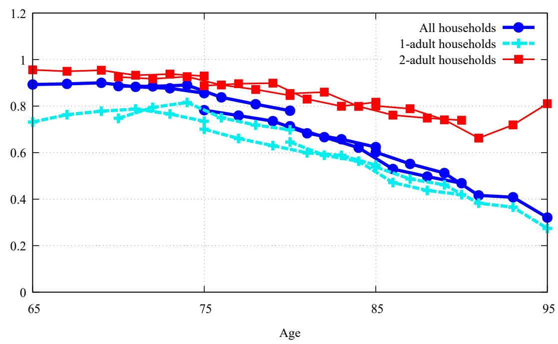
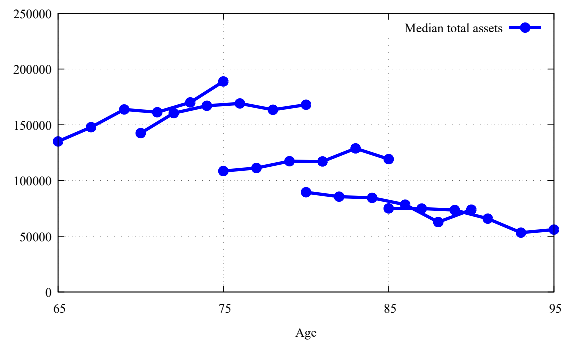


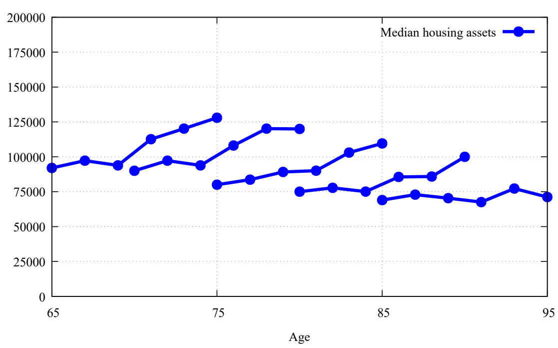
Figure 2: Normalized Median Net Worth, Perpetual Homeowners versus Switchers



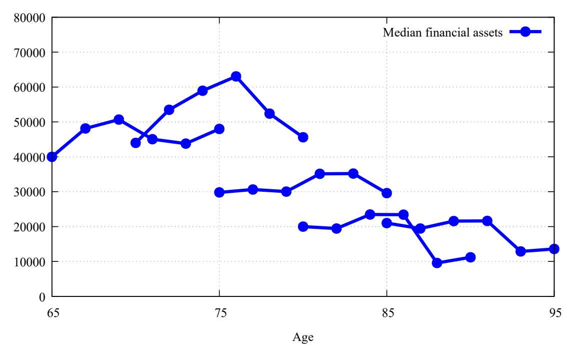
(a) Homeownership Rates



(b) Median Total Assets



(c) Median Housing Assets of Homeowners



(d) Median Financial Assets

Figure 3: Lifecycle Profiles of Homeownership and Assets

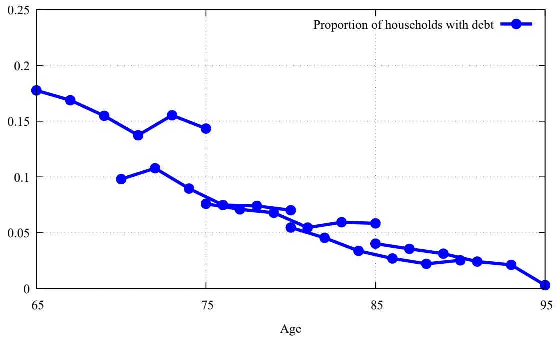
the sample. We designate them by the wave in which they switch, and present only three cohorts to make the figure legible. This figure confirms that when one sells the house, one decumulates assets more quickly than if one stays in the house, and that this behavior is not simply a function of overall wealth; thus, we need to consider housing separately from other assets.

Figure 3, Panel (a), shows the life-cycle profile of homeownership rates among retirees (dark blue solid line). In general, homeownership rates are declining with age, from around 90% at age 65 to just below 40% by age 95. We also break down the rates by the size of the household. The breakdown shows that conditional on household size, the decline is milder than the overall average for 2-adult households, suggesting that the overall decline in homeownership may be driven in part by a transition from a 2-person to a 1-person household. This agrees with the findings of Venti and Wise (2004). Motivated by this finding, we will allow our model households to change size over time, according to probabilities consistent with the data.

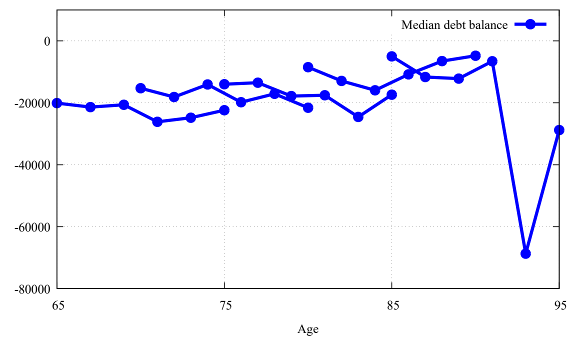
Panel (b) of the figure again plots the life-cycle median net worth profiles of retirees. Panels (c) and (d) break down these profiles into housing and financial assets, as defined above. Total asset holdings are increasing with age for the youngest three cohorts, while they are slightly declining for the older cohorts. The breakdown into housing and non-housing assets shows that the increase in total asset value for the younger cohorts is mainly driven by increasing housing assets, while financial assets are relatively flat for each cohort. Note that the median financial asset profile includes households who sell their house after 1996 and convert it into financial assets; this composition effect is likely important in keeping financial asset profiles flat rather than decreasing.

Panels (a) and (b) of figures 4 plot the shares of retirees who are in debt by our model definition, that is, those who hold a negative financial asset position, as well as the median amount of debt held, conditional on being a debtor. The share of debtors is decreasing with age, from around 18% at age 65 for the first cohort, to nearly zero for the oldest cohort. The conditional debt profile is increasing for the younger cohorts, reflecting that those with more debt stay in debt longer.

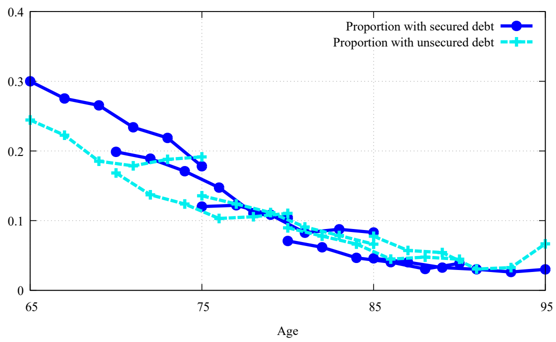
To understand how debt should be modeled, we also consider the profiles of *gross* secured and unsecured debt. The proportion of households with each type of debt in panel (c) decreases with age, in a fashion similar to the negative financial asset position; slightly fewer retired households have unsecured debt than secured debt. Conditional debt levels in panel (d) are similar to the median net debt profiles of panel (b). Instead, the amount of unsecured debt (right scale) is relatively small, at maximum $2,000 for the youngest cohort, compared to $30,000-40,000 in secured debt, decreasing over the lifecycle, and approximately flat for each cohort. Due to low median unsecured debt, and to reduce the computational burden, we will assume unsecured debt away in the model, so that those without a house will not be able to borrow.



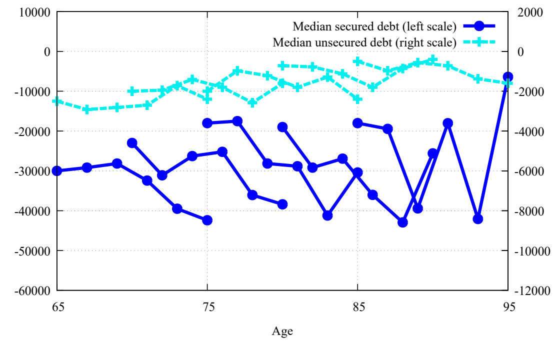
(a) Proportion of Households in Net Debt



(b) Median Net Debt Holding Among Net Debtors



(c) Proportion of Households with Gross Debt



(d) Median Gross Debt for Debt Holders

Figure 4: Lifecycle Profiles of Debt

4 Model

We focus on retiree households, which allows us to abstract from labor supply and retirement decisions. A household in the model starts out either single or as a couple; couple households can become single if one spouse dies, but single households do not re-marry. This assumption is motivated by the data, where the number of remarriages in retirement is small.

A household starts out as a homeowner or a renter. In each period, the household chooses consumption and financial saving, and makes a decision regarding housing. For a homeowner, the housing decision is whether to move out of the house or to stay in it. Homeownership provides utility benefits, in addition to consumption services from the house; these capture factors such as attachment to one's house and neighborhood, the ability to modify one's house to individual taste, but also some financial benefits of ownership that are not explicitly in the model, such as tax exemption of imputed rents of owner-occupied housing, mortgage interest deduction, or insurance against rental rate fluctuation. In addition, homeowners are able to borrow against their home equity; the collateral constraint can change with age, as discussed below. For a renter, the housing choice is only the size of the rental property. We abstract from the decision of a homeowner to move to a different house, or the decision of a renter to buy a house. These abstractions are made to simplify the problem, but are motivated by the observation in the data that the proportion of homeowners making downsizing moves is small, as is the proportion of renters who purchase a home late in life. Finally, renters are not able to borrow due to low unsecured debt among retirees in the data.

The aggregate price of housing in the model is increasing to capture the housing boom of 1996-2006. We assume that households anticipate the increase in a deterministic fashion, and do not face idiosyncratic house price shocks. This last assumption is necessary, given the complexity of the problem. In addition to the household size shock, households are subject to two other types of idiosyncratic shocks: health status, conditioned on age, which includes the probability of death, and out-of-pocket medical expenditures, conditioned on age, size, income and health.

In addition to financial asset income, households have access to pension income. Since in the data nonfinancial income is stable over time conditional on household size, in the model we assume income time-invariant, as long as household size does not change. In addition, households have access to a government-provided consumption floor, which captures insurance programs for the elderly such as Medicaid. Finally, households have a warm-glow bequest motive.

4.1 Preferences

A household is born as a retiree at model age $i = 1$. The household potentially lives up to age I, but dies stochastically; this is discussed more below. The household maximizes its life-time utility. The utility function is time-separable with subjective discount factor β. The period utility function has the following form:

$$u(c, h, s, o) = s\frac{\left(\frac{1}{\mu_s}c^\eta(\omega_o h)^{1-\eta}\right)^{1-\sigma}}{1-\sigma} \tag{1}$$

where c is nonhousing consumption, h is consumption of housing services, $s \in \{1, 2\}$ is the number of adults in the household, and $o \in \{0, 1\}$ is the tenure status, with $o = 0$ representing renting, and $o = 1$ representing owning . We assume a linear technology from the size of the house to the quantity of housing services, which implies that h is the size of the house that the household lives in as well. Consumption is aggregated by a Cobb-Douglas function, with η determining the relative importance of housing and nonhousing consumption. The period utility function applied to the aggregated goods is a standard CRRA function with risk aversion parameter σ. μ_s is the household equivalence scale conditional on household size.[5] In particular, if $\mu_1 = 1$ and $\mu_2 \in (1, 2)$, the *household-size multiplier* for a one-adult household is $\frac{1}{\mu_1^{1-\sigma}} = 1$, while the multiplier for a two-adult household is $\frac{2}{\mu_2^{1-\sigma}} > 1$ for $\sigma > 0$. In other words, the assumption captures the benefits of having multiple adults instead of one adult in the household. ω_o captures the extra utility from owning a house. We normalize the renters' $\omega_0 = 1$.

As in De Nardi et al. (2010), a household gains utility from leaving bequests.[6] When a household dies with consolidated wealth of a, the household's utility function takes the form:

$$v(a) = \gamma \frac{(a + \zeta)^{1-\sigma}}{1 - \sigma}. \tag{2}$$

Here, γ captures the strength of the bequest motive, and ζ affects marginal utility of bequests. A positive ζ makes bequests a luxury good, so that only households with high wealth choose to leave a bequest.

4.2 Nonfinancial Income

We assume that the household's nonfinancial income is $\psi_s b$, where $b \in \{b_1, b_2, b_3, ..., b_B\}$ and ψ_s adjusts the nonfinancial income according to the number of adults in the household, with $\psi_1 = 1$. b is different across households, but is time-invariant for each household. This assumption captures the fact that the main sources of income for retirees are Social Security and other pension benefits, which are fixed at time of retirement and appear constant thereafter in our data.

4.3 Household Structure, Health and Mortality

Households in the model are distinguished demographically in terms of their size and health. The health status of a household is represented by $m \in \{0, 1, 2, ..., M\}$, where $m = 0$ represents death, an absorbing state with with $m_j = 0$ for $\forall j \geq i$ if $m_i = 0$. $m > 0$ indicates that the household is alive and in one of several time-varying health states. We assume that m follows a first-order Markov process. $\pi^m_{i,b,m,m'}$ is the age- and income-dependent transition probability from health m to m', and it includes survival probability of households.

$s \in \{1, 2\}$ represents the number of adults in a household. The transition from $s = 2$ to $s = 1$ can capture the death of a spouse or a divorce; in our estimation, we will abstract from divorces and remarriages, as we find these to be rare in the data. Thus, one-adult households ($s = 1$)

[5] For a more detailed discussion on the household equivalence scale, see Fernández-Villaverde and Krueger (2007). Li and Yao (2007) make a similar assumption with respect to the effect on the household size on utility.

[6] De Nardi (2004) finds that the bequest motive is important in capturing the observed wealth distribution, especially the wealth concentration, using a general equilibrium overlapping-generations model with accidental and intended bequests.

remain single for the rest of their life. In contrast, two-adult households ($s = 2$) stochastically change to one-adult households. Household size transition probabilities are age-dependent and denoted by $\pi^s_{i,s,s'}$. By assumption, $\pi^s_{i,1,1} = 1$, $\pi^s_{i,1,2} = 0$ for all i.

Household size thus affects household decisions as follows. First, two-adult households maximize the sum of the utilities of the two. In order to avoid keeping track of types of each member of a couple, we assume that the two adults have the same utility function, so the utility of a couple is that of a one-adult household multiplied by two, as captured by s in the utility function. Second, consumption is split equally in two-adult households. However, each of the household members enjoys more than half of the consumption because of the positive externality within the household. This is captured by μ_s in the utility function. Third, pension income depends on household size. Finally, two-adult households face the size shock. Together with the mortality shock embedded in $\pi^m_{i,b,m,0}$, this means that in a couple, one spouse can die first via the stochastic shock to s, or both spouses can die at the same time via the household-wide mortality shock.

4.4 Medical Expenditures

Household health introduced above has two effects. First, survival probability is lower for a household in worse health; second, out-of-pocket medical expenses are on average higher for a household in worse health. Both are facts from our data (see Section 5). A household is hit by out-of-pocket (uninsurable) medical expenditure shocks $x \in \{x_0 = 0, x_1, x_2, ..., x_X\}$, which are a function of its age i, health m, income b and size s. The probability that a given x is drawn is denoted by $\pi^x_{i,m,b,s,x}$. Conditional on age, size, income and health, medical expense shocks are i.i.d.; however, because these household characteristics are persistent, so are medical expenses.

4.5 Housing

A household is either a renter ($o = 0$) or a homeowner ($o = 1$). A homeowner with a house $h \in \{h_1, h_2, h_3, ..., h_H\}$ decides whether to move out of the house and become a renter, or to stay in the same house. The value of the house is $p_1 h$, where p_1 is the current house price for owners. If a homeowner sells her house, she receives its value net of any debt, from which she pays a proportional cost κ of moving out, and a capital gains tax. In addition, the homeowner has to pay a proportional maintenance cost δ while she lives in the house. In the benchmark version of the model, we assume that everyone pays this cost, which we will relax later.

The house price p_1 is assumed to have only an aggregate time-varying component; we do not consider heterogeneity of house prices, in order to keep the problem manageable. We further assume that households expect house prices to grow at a constant rate g_1, consistent with the upward price trend in 1996-2006. As an alternative, we have tried the assumption that households expect house prices to stay constant, treating all growth in house prices from the exogenous price trend as a surprise. These two alternatives yield nearly identical results in terms of household behavior; we choose the former specification as it is consistent with rational expectations.

A renter chooses the size of the rental property h each period. Unlike owners, renters can move between properties of different sizes at no moving cost. All rental contracts are for one period. The per-period rental cost of a rental property h is $r_h h p_0$, where p_0 is the value of the rental property and $r_h = r + \delta$ is the rental rate. Here, r is the riskless interest rate, discussed more below. The rental rate captures the competitive cost to an intermediating real estate firm of holding housing and renting it out.[7] Rental properties are evaluated at price p_0, which grows deterministically at a constant rate g_0. This allows us to capture the effect of the 1996-2006 housing boom on the rental market. As dictated by the data, $g_0 < g_1$.

4.6 Saving and Home Equity Borrowing

We use a to denote the household's consolidated financial asset balance. Households can save ($a > 0$) at interest rate r. In addition, home equity borrowing is allowed; homeowners can borrow against the value of their house at the rate of $r + \xi$, where ξ is the mortgage premium. The borrowing limit has the form $a \geq -(1 - \lambda_i)hp_1$: a homeowner can borrow up to a fraction $1 - \lambda_i$ of the value of the house (hp_1) in each period. While the parameter λ_i can most directly be interpreted as a downpayment constraint, in this setup we are agnostic about the exact type of equity loan contracts available and the associated cost types. Therefore, we intend for it to capture parsimoniously all direct costs of borrowing against home equity, e.g. the costs of refinancing, the costs of opening a new home equity line of credit (HELOC), or the upfront costs of a reverse mortgage, and we estimate it from data. We allow this parameter to be age-specific. While there are no overt age requirements for traditional mortgage loans that we are aware of, Caplin (2002) points out that many retired homeowners cannot qualify for conventional mortgages because they fail debt-to-income requirements of such loans. Our specification captures such age variation in borrowing constraints parsimoniously; see Nakajima and Telyukova (2017) for a model that incorporates explicit debt-to-income ratio requirements. As we mentioned above, renters in the model cannot borrow as they do not have collateral. This is consistent with the fact that there is little unsecured debt among retirees in the data.

[7] See Nakajima (2010) for a more detailed discussion about the determination of the competitive rental rate.

4.7 Government Transfers

Following Hubbard et al. (1995) and De Nardi et al. (2010), we assume that the government uses means-tested social insurance, which effectively provides a consumption floor. This is especially important in our model because a large out-of-pocket medical expenditure shock could force a household to negative consumption in the absence of social insurance. The per-adult consumption floor is denoted by $\underline{c}$. Following De Nardi et al. (2010), we assume that the government subsidizes each member of a household up to $\underline{c}$ if the household runs down its financial assets. Homeowners are eligible for the consumption floor so long as the value of their house is below some threshold $\overline{h}p_1$, which captures the Medicaid homestead exemption (De Nardi et al. (2016a)).

4.8 Household Problem

The household problem is recursive, and modeled separately for homeowners and renters. State variables of a household are (i, s, b, m, x, p, h, a): age, size, income, health status, medical expenses, house price, housing size, and financial assets. We use $h = 0$ to represent a renter; $h > 0$ demotes a homeowner with house size of h. House prices are $p = (p_0, p_1)$.

Beginning with the problem of the renter, the Bellman equation is:

$$V(i, s, b, m, x, p, 0, a) = \max_{\tilde{h}, a' \geq 0} \Big\{ u(c, \tilde{h}, s, 0)$$

$$+\beta \sum_{s'} \pi^s_{i,s,s'} \sum_{m'>0} \pi^m_{i,b,m,m'} \sum_{x'} \pi^x_{i+1,m',b,s',x'} V(i+1, s', b, m', x', p', 0, a') + \beta \pi^m_{i,b,m,0} v(a') \Big\} \quad (3)$$

subject to:

$$\tilde{c} + a' + r_h \tilde{h} p_0 + x = (1 + r)a + \psi_s b \quad (4)$$

$$c = \begin{cases} \max\{s\underline{c} - r_h \tilde{h} p_0, \tilde{c}\} & \text{if } a' = 0 \\ \tilde{c} & \text{otherwise} \end{cases} \quad (5)$$

$$p'_i = (1 + g_i)p_i \text{ for } i = \{0, 1\} \quad (6)$$

We use a prime to denote variables in the next period. The renter chooses the level of assets to carry over to the next period (a') and the property that he rents in the current period ($\tilde{h}$) to maximize the sum of three components. The first is the period utility. The second is the discounted expected future value conditional on surviving in the next period ($m' > 0$), with the expectation based on the transition probabilities for the household size, health and medical expense shocks. Income b is constant, and the renter remains a renter ($h' = h = 0$). The third component of (3) is the utility from bequests, in case of death ($m' = 0$). Notice that, for a renter, the only assets left as estate are the financial assets (a'). Equation (4) is the budget constraint, while (5) is the government-provided consumption floor, net of rental expenses, available only when the renter runs down financial assets ($a' = 0$).

A homeowner chooses between staying in his house (V_1) and selling to become a renter (V_0):

$$V(i,s,b,m,x,p,h,a) = \max\{V_0(i,s,b,m,x,p,h,a), V_1(i,s,b,m,x,p,h,a)\} \tag{7}$$

A homeowner who decides to sell the house and become a renter solves:

$$\begin{aligned} &V_0(i,s,b,m,x,p,h,a) = \max_{a' \geq 0} \{u(c,h,s,1) \\ &+\beta \sum_{s'} \pi^s_{i,s,s'} \sum_{m'>0} \pi^m_{i,b,m,m'} \sum_{x'} \pi^x_{i+1,m',b,s',x'} V(i+1,s',b,m',x',p',0,a') + \beta \pi^m_{i,b,m,0} v(a') \Big\} \end{aligned} \tag{8}$$

subject to (6) and:

$$\tilde{c} + a' + x + (\kappa + \delta)hp_1 + q(s,h,p_1) = hp_1 + (1+\tilde{r})a + \psi_s b \tag{9}$$

$$q(s,h,p_1) = \tau_q(hp_1(1-\kappa) - h\overline{p}_1 - \overline{q}s) \tag{10}$$

$$c = \begin{cases} \max\{s\underline{c}, \tilde{c}\} & \text{if } a' = 0 \\ \tilde{c} & \text{otherwise} \end{cases} \tag{11}$$

$$\tilde{r} = \begin{cases} r & \text{if } a \geq 0 \\ r + \xi & \text{if } a < 0 \end{cases} \tag{12}$$

There are four differences from the renter's problem shown above. First, the current tenure status is a homeowner ($o = 1$) with the house size of h, as can be seen in the period utility function. Second, the budget constraint (9) does not include the rental cost (since the household owns in the current period), but includes net income from selling the house. The costs are the current maintenance cost (δ), the selling cost (κ), and capital gains tax $q(s,h,p_1)$, which a homeowner has to pay above exemption level $\overline{q}s$, on capital gains relative to the initial house purchase price $\overline{p}_1$. Third, the interest rate is r for a net saver, but $r + \xi$ for a net borrower. Fourth, the consumption floor does not figure in rental cost. The household then begins the next period as a renter ($h' = 0$).

The problem of the homeowner who decides to stay in his house is characterized by:

$$V_1(i,s,b,m,x,p,h,a) = \max_{a' \geq -(1-\lambda_i)hp_1} \{u(c,h,s,1)$$

$$+\beta \sum_{s'} \pi^s_{i,s,s'} \sum_{m'>0} \pi^m_{i,b,m,m'} \sum_{x'} \pi^x_{i+1,m',b,s',x'} V(i+1,s',b,m',x',p',h,a') + \beta \pi^m_{i,b,m,0} v(hp'_1 + a') \Big\} \quad (13)$$

subject to equations (6), (12) and:

$$c + a' + x + \delta hp_1 = (1+\tilde{r})a + \psi_s b \quad (14)$$

$$c = \begin{cases} \max\{s\underline{c}, \tilde{c}\} & \text{if } h \leq \overline{h}p_1 \text{ and } a' \leq \min(a,0) \\ \tilde{c} & \text{otherwise} \end{cases} \quad (15)$$

First, since a homeowner can borrow against the house, a' is not constrained from below by zero, but by $-(1-\lambda_i)hp_1$. Second, in case the household does not survive to the next period, the estate includes the value of housing (hp'_1) as well as the financial asset position (a'). There is no capital gains taxation on the bequest of a house; by estate taxation laws in the U.S., the exemption level for estate taxes were \$600,000 in 1996, and \$2,000,000 in 2006, so the tax does not apply for any housing bins in our model. For the same reason, we do not model taxation of financial asset bequests. Finally, the homeowner can access the social insurance program subject to the homestead exemption of $\overline{h}p_1$. The condition (15) also states that if the homeowner is in debt, the debt is not written off when the consumption floor is received.

5 Estimation

5.1 Estimation Strategy

Following Gourinchas and Parker (2002) and De Nardi et al. (2010), we use a two-step estimation strategy. In the first step, we estimate the parameters that are directly observable. Parameters associated with all the shocks and prices, as well as the initial conditions, are in this category. In the second step, given these exogenous parameters, we estimate the remaining parameters using a minimum-distance estimator, taking as targets the set of life-cycle profiles described above.

5.2 First Step Estimation

To match the HRS, we set the model period to two years. Each household can live up to 99 years of age, but there is a probability of an earlier death. We look at three cohorts corresponding to ages 63-67, 73-77, and 83-87 in 1996. We call them cohorts 1, 2, and 3, respectively, and define

Table 1: First-Step Estimated Parameters

Parameter	Description	Value[1]
μ_2	Household equivalence scale for 2-adult households	1.340
ψ_2	Income multiplier for 2-adult households	1.500
δ	Maintenance cost of housing	0.017
κ	House selling cost	0.066
r	Saving interest rate	0.040
ξ	Mortgage interest premium	0.016
g_0	Rental rate growth rate	0.011
g_1	House price growth rate	0.045
τ_q	Capital gains tax rate	0.190
$\bar{q}$	Capital gains tax deduction[2]	250,000
$\bar{p}_1$	Purchase price of home (relative to 1996 price)	0.910
$\bar{h}$	Homestead exemption for consumption floor	357,000

[1] Annualized value.
[2] 1996 dollars.

Table 2: Income Levels[1]

	Cohort 1 (age 65)	Cohort 2 (age 75)	Cohort 3 (age 85)
Group 1	5831	6199	5520
Group 2	12049	9977	8055
Group 3	17844	13593	10481
Group 4	25868	18173	13743
Group 5	50227	37869	26090

[1] Annualized income in 1996 dollars.

their age as the center point of each age bin (thus ages 65, 75, 85). For each cohort, we have six data observations that correspond to years 1996, 1998, 2000, 2002, 2004, and 2006. All the values that follow in this section are in 1996 dollars. Individual parameters from the first-step estimation are summarized in table 1.

Preferences. There is a variety of estimates for the household equivalence scale. We use $\mu_2 = 1.34$ for a two-adult household, following Fernández-Villaverde and Krueger (2007). This value is the mean of the existing estimates in the literature, ranging from 1.06 to 1.7.

Nonfinancial Income. In each cohort, we sort the households according to their nonfinancial income in 1996 and classify them into five bins, so that each bin carries approximately one-fifth of the total sample weight in 1996. The value of each bin is the average income of that

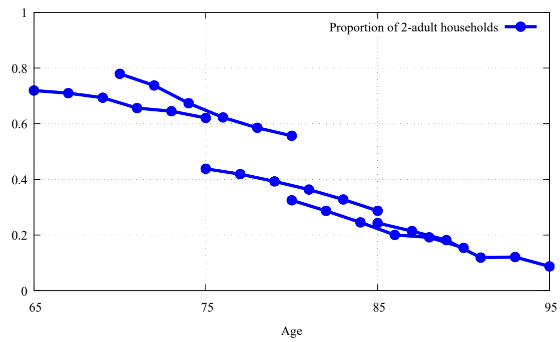


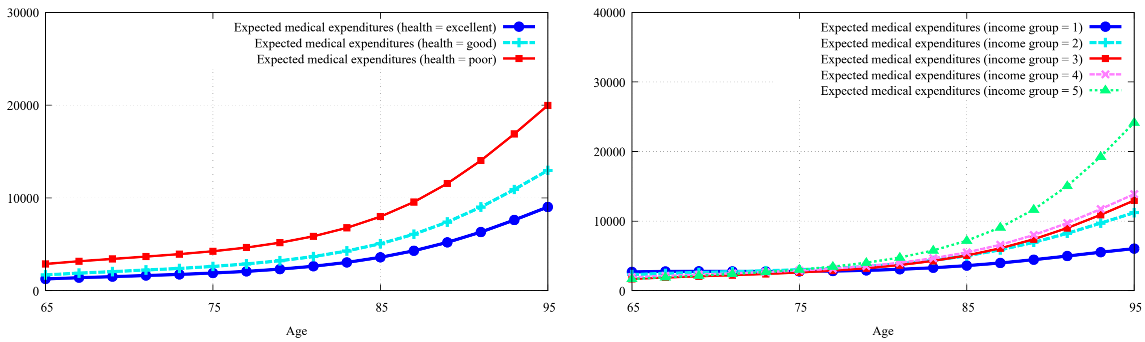
Figure 5: Proportion of Two-Adult Households.

Table 3: Health Status Transition

Age 65, Income Group 1	Dead	Excellent	Good	Poor	**Age 85, Income Group 1**	Dead	Excellent	Good	Poor
Excellent	0.4	71.6	22.5	5.4	Excellent	10.8	39.3	31.5	18.3
Good	3.6	24.8	52.0	19.6	Good	19.3	21.1	46.9	25.4
Poor	9.9	5.0	17.0	68.1	Poor	26.6	5.6	14.2	53.7
Age 65, Income Group 5	Dead	Excellent	Good	Poor	**Age 85, Income Group 5**	Dead	Excellent	Good	Poor
Excellent	1.5	77.2	18.7	2.6	Excellent	8.2	56.3	27.9	7.6
Good	1.4	30.0	53.4	15.3	Good	15.4	15.9	44.0	24.6
Poor	5.9	10.3	32.1	51.7	Poor	26.1	9.2	17.2	47.4

bin's households. Prior to binning, we adjust the income of two-adult households to make it comparable to that of singles. To do this, we use the sample of households who change size from two to one while in the sample, and compute the ratio of income when the household was a couple over the income after it became a one-adult household. The median of this ratio is 1.5, so we set the parameter $\psi_2 = 1.5$. That is, in the median, a two-person household that loses a spouse also loses about one-third of its income. Thus, we divide nonfinancial income of two-adult households by ψ_2. Table 2 summarizes the resulting bins.

Household Size. Figure 5 presents the proportion of two-adult households conditional on age. The proportion is approximately linearly decreasing with age. For all the shock processes, we assume that the household size transition probabilities are time-invariant and estimate them from a pooled sample of all six waves of the HRS. Recall also that we abstract from remarriage, based on its low occurrence among retirees in the data. Finally, we assume that all the transitions from two- to one-adult households are caused by death of the spouse, i.e. are involuntary. That is, we assume away divorce, which appears to be rare in our data.



(a) Middle Income, by Health

(b) Good Health, by Income

Figure 6: Expected Medical Expenses of Singles

Health Status and Mortality Shock Process. We group the five self-reported health categories in the HRS (excellent, very good, good, fair, poor) into three groups, combining the top two and the bottom two. We compute the probability that a respondent of health $m \in \{1, 2, 3\}$ is of health m' two years later, conditional on the respondent's age and income, with income binned into five groups as in table 2. We also compute the probability of death ($m' = 0$). Table 3 presents health transition probabilities for ages 65 and 85, in income bins 1 (lowest) and 5 (highest). First, as expected, the probability of dying is generally higher for older respondents, those in worse health, and those with lower income. Second, health status is persistent. Third, this persistence weakens with age, as probability of death rises. Fourth, persistence of excellent health increases in income, while persistence of poor health decreases in income. Higher-income individuals are also more likely to see reversals of poor health. Both observations are consistent with the intuition that higher-income individuals can afford more and better healthcare.

Medical Expenditures. As we mentioned before, we incorporate into our data the HRS exit waves, which collect medical expenditure information up to the end of life on respondents who die between two waves of the survey. We do not include expenses covered by Medicare, Medicaid or private health insurance since the corresponding model shocks are uninsurable. We estimate out-of-pocket (OOP) medical expenditure shocks by regressing the probability of zero OOP medical expenses, the mean of log-medical expenses, and their standard deviation on household size, income, health status, a quartic in age, as well as interaction terms of age and the other variables. The explanatory variables are similar to those in De Nardi et al. (2010), but we add household size and respective interactions, since we include couples in our data and model. Under the assumption of log-normality, we construct expected OOP medical expenses from this estimation. In figure 6, we plot expected medical expenses for single households, by health status and by income. Medical expenditures increase with age, driven both by a rising mean and rising variability over time; the rise is particularly dramatic for those in poor health.

We then discretize the log-normal distribution using five grid points: zero, the mean, mean plus-minus one log standard deviation, and mean plus two times the log standard deviation. The last grid point captures the right tail of the distribution, emphasized by French and Jones (2004).

Regardless of some differences in terms of sample and methodology, the OOP medical expense shock distribution that we obtain is consistent with related studies, in particular, De Nardi et al. (2010) and Ameriks et al. (2011). De Nardi et al. (2010) report that their estimated medical expense shocks indicate the average medical expenses are low and vary little in income at 75, but they rise and exhibit a large dispersion in income by age 95. Panel (b) of figure 6 is consistent with this description. De Nardi et al. (2010) also report that the average medical expenditures among singles of age 95-100 is \$9,227. According to our estimated medical expense shock process, the average medical expense for singles of age 97 (converted to 1998 dollars to make it comparable) is similar at \$9,317. Finally, De Nardi et al. (2010) report their the overall average variance of medical expense to be 2.53, which is in the middle of implied variance of our estimated medical expense risk, which is 2.08 for age 75 and 3.05 for age 99. Ameriks et al. (2011) report that average OOP medical expenses in the data are \$1,600 for 0-10th income percentile at age 65, and \$2,100 for 70-90th percentile, while average OOP medical expenses at age 95 are \$4,700 for 0-10th income percentile and \$18,700 for 70-90th percentile.[8] In our estimated OOP medical expense shock process, mean medical expenses in bottom and top income quintiles are respectively \$2,119 and \$881 at age 65, and \$4,361 and \$16,754 for age 95.

Housing. We approximate the distribution of house sizes in each cohort using ten grid points. We create this grid by classifying the households in each cohort into bins, each with about 10% of the sample, and using the mean house value within each bin as the grid points. Table 4 summarizes the result. In the model, we also restrict the choice of property values for renters to the same house bins for each cohort.

We set maintenance cost δ at 3.4% per two years (annually 1.7%). This is the value calibrated by Nakajima (2010) using data on depreciation of residential capital in National Income and Product Accounts. The selling cost of a house (κ) is set at 6.6% of the value of the house. This is the estimate obtained by Greenspan and Kennedy (2007). Grueber and Martin (2003) report the median selling cost of 7.0% of the value of the house.

[8]See Table A.1 of their paper. As their numbers are in 2005 dollars, we converted our numbers into 2005 dollars using CPI.

Table 4: House Size Distribution[1]

	Cohort 1 (age 65)	Cohort 2 (age 75)	Cohort 3 (age 85)
Bin 1	21792	18267	16955
Bin 2	44935	37938	35743
Bin 3	63613	50803	47027
Bin 4	77839	64390	51910
Bin 5	88087	77583	62395
Bin 6	101358	88868	75851
Bin 7	125114	103150	88729
Bin 8	152107	137364	108380
Bin 9	195244	183191	148655
Bin 10	360683	345206	266577

[1] Value in 1996 dollars.

Saving and Home Equity Borrowing. The saving interest rate is set at 8% (annually 4%). The mortgage debt premium ξ is set at 3.2% (annually 1.6%), which is the average spread between 30-year mortgages and Treasury bonds of the same maturity between 1977 and 2009.

Housing Prices. For the rate of growth of rents, g_0, we use the primary residence component of the CPI. The rate of growth for 1996-2006 averages at 2.1% per two years. We measure the rate of growth of house prices, g_1, from the house price index (HPI) compiled by the Federal Housing Finance Agency. At 4.5% per year, this rate is just below the price change of 4.8% per year that we compute from self-reported home values in the HRS.

Policy Parameters. The last four parameters in table 1 refer to tax policy and social programs. We set the capital gains tax rate τ_q at 19%, which is the weighted average of marginal tax rates for the 1996-2006 period, during which the legislation changed repeatedly. The capital gains tax deduction $\bar{q}$ is \$250,000, which is similarly averaged over this period. In order to calculate the capital gain, we assume that the house was initially purchased at $\bar{p}_1$=91.9% of the current home value, which is the average in our HRS sample; keeping track of initial house prices at household level is too costly computationally. Finally, we calibrate the homestead exemption level $\bar{h}$ for the consumption floor based on De Nardi et al. (2016a), who describe Medicaid rules state by state in 2009. We average homestead exemption levels, and convert them to 1996 dollars using the HPI.

Initial Distribution We construct the model's initial distribution along the eight-variable state space from the 1996 HRS sample, simulate the model starting from this distribution, and use

Table 5: Initial Distribution, Selected Characteristics – Overall and By Tenure

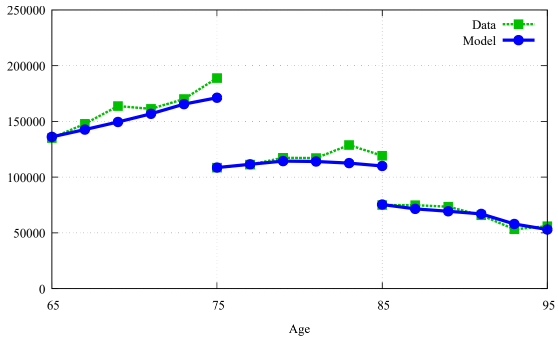
	Cohort 1 (age 65)			Cohort 2 (age 75)			Cohort 3 (age 85)		
	Owner	Renter	All	Owner	Renter	All	Owner	Renter	All
Health Status									
1 (excellent)	0.51	0.30	0.50	0.40	0.34	0.39	0.35	0.33	0.33
2 (good)	0.29	0.29	0.27	0.32	0.30	0.32	0.29	0.25	0.28
3 (poor)	0.21	0.41	0.23	0.28	0.36	0.29	0.36	0.42	0.39
Income Bin									
1st quintile	0.18	0.40	0.20	0.16	0.33	0.20	0.16	0.27	0.20
2nd quintile	0.19	0.26	0.20	0.20	0.21	0.20	0.16	0.28	0.20
3rd quintile	0.21	0.13	0.20	0.21	0.17	0.20	0.22	0.16	0.20
4th quintile	0.21	0.12	0.20	0.22	0.14	0.20	0.24	0.14	0.20
5th quintile	0.21	0.09	0.20	0.21	0.15	0.20	0.22	0.16	0.20
Tenure									
Homeowner			0.89			0.78			0.60
Renter			0.11			0.22			0.40
Household Size									
One-adult	0.23	0.70	0.28	0.50	0.77	0.56	0.68	0.88	0.76
Two-adult	0.77	0.30	0.72	0.50	0.23	0.44	0.32	0.12	0.24
Saver or Borrower									
Saver	0.80	1.00	0.82	0.91	1.00	0.92	0.94	1.00	0.96
Borrower	0.20	0.00	0.18	0.09	0.00	0.08	0.06	0.00	0.04

the simulation outcome to estimate the structural parameters in the second estimation step. Table 5 shows aspects of the initial distribution not described previously, overall and by housing tenure. There is correlation between the dimensions of the state space which is built into the initial distribution, and hence into the model. For example, homeowners are on average in better health, have higher income, and are significantly more likely to live in a two-adult household.

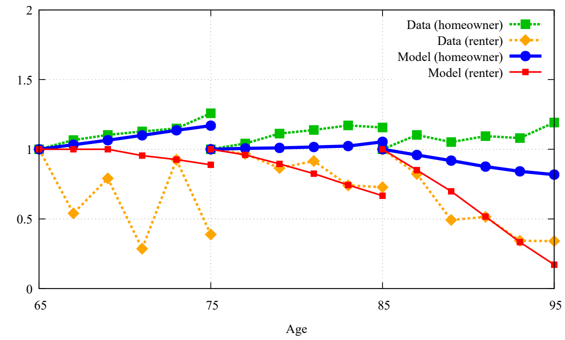
5.3 Second Step Estimation

In the second-step estimation, we choose parameters to fit the life-cycle profiles in Section 3, using a minimum-distance estimator. The targets are cohort profiles of the homeownership rate, median total, financial and housing assets, proportion of households in debt, and median debt of debtors. We also target the normalized median net worth profiles for homeowners and renters, as in figure 1, as well as net worth by income bin and Medicaid participation rates by age.

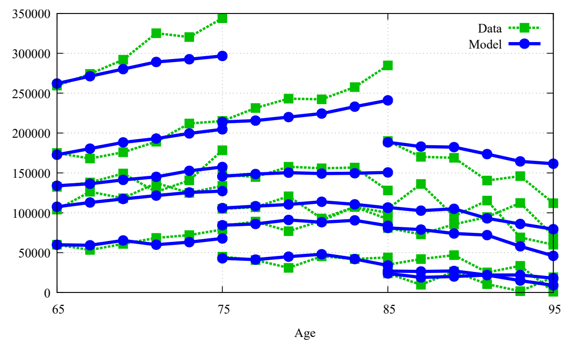
Figure 7 gives the asset profiles of the three cohorts, comparing the model and data. Panel (a) presents median total asset profiles of each cohort, which is the classic statement of the retirement saving puzzle; the model matches these profiles well. Panel (b) compares owners and



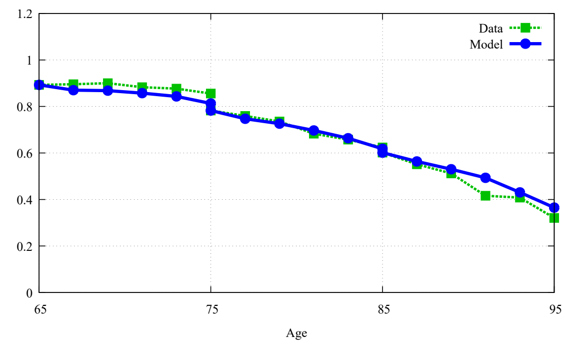
(a) Median Total Assets



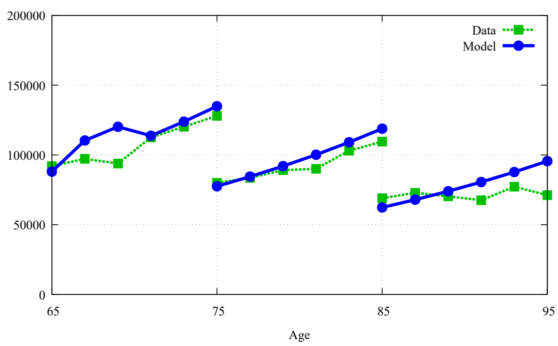
(b) Median Total Assets: Owners vs. Renters



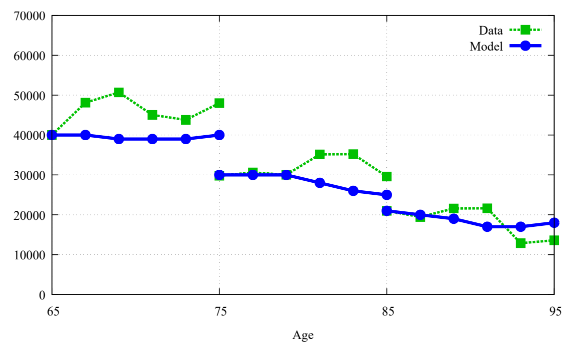
(c) Total Assets by Income Bin



(d) Homeownership Rate



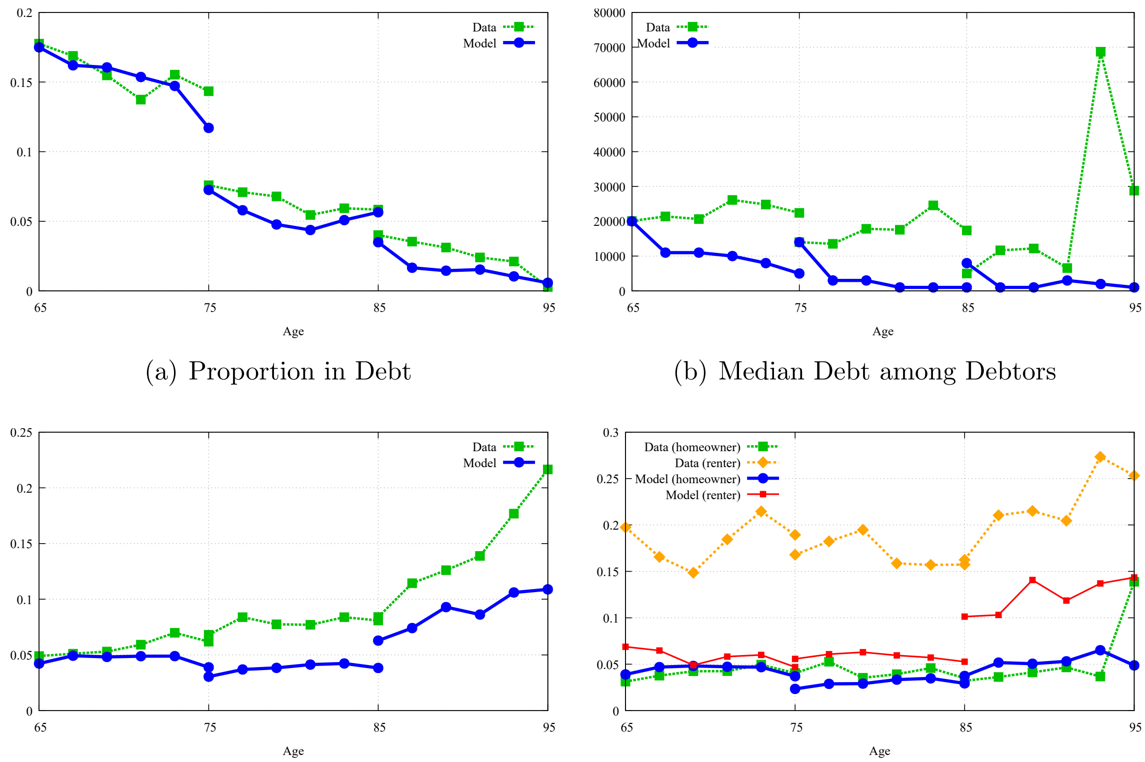
(e) Median Housing Assets



(f) Median Financial Assets

Figure 7: Benchmark Model Fit - Asset Profiles

renters in the model to those groups in the data, in terms of normalized median total asset profiles. For the first two cohorts, the model matches the data profiles fairly well, with the exception of the youngest cohort's renters – but this group is small in the data and the profile is noisy. For the oldest cohort, the model underpredicts somewhat the extent of asset accumulation of owners, but generates close to the full empirical difference in the behavior of the two groups. Panel (c) shows total assets by income group. The model does well on these. For the youngest



(a) Proportion in Debt

(b) Median Debt among Debtors

(c) Medicaid Rate

(d) Medicaid Rate by Tenure

Figure 8: Benchmark Model Fit - Debt and Medicaid Profiles

cohort, it underpredicts net worth accumulation of the top tail, while it overpredicts it somewhat for the oldest cohort. The remaining panels of the figure show that the model replicates well homeownership rates, median housing assets of homeowners, and median financial assets in the model relative to data.

Panels (a) and (b) of figure 8 present the proportion of households in debt and median debt among indebted households. Given our parsimonious modeling of equity borrowing costs, we cannot match both the extensive and intensive margins of debt. The model matches the rate of indebtedness very well, but does less well on debt levels. In the data, the few households that do continue to borrow late in life appear to borrow quite a bit, although the data are noisy; in our model, the estimated tight collateral constraints shown below make that impossible. Matching the intensive margin would require a more flexible model of mortgage contracts, as in Nakajima and Telyukova (2017), at the cost of additional computational burden. Here, the intensive-margin discrepancy is acceptable, as it concerns a small subset of the population.

Panels (c) and (d) of figure 8 show the rate of Medicaid recipiency for the sample as a whole, and by homeownership status. For the whole sample (panel (c)), the model slightly

Table 6: Second-Step Parameter Estimates

Parameter	Description	Value
β	Discount factor[1]	0.9606
η	Consumption aggregator	0.8340
σ	Coefficient of RRA	2.757
ω_1	Extra-utility from ownership	2.508
γ	Strength of bequest motive	6.756
ζ	Shifter of bequest utility	61,812
$\underline{c}$	Consumption floor per adult[1]	8,800
λ_{65}	Collateral constraint for age-65	0.6389
λ_{70}	Collateral constraint for age-70	0.8268
λ_{75}	Collateral constraint for age-75	0.9608
λ_{80}	Collateral constraint for age-80	0.9899
λ_{85}	Collateral constraint for age-85	0.9901
λ_{90}	Collateral constraint for age-90	0.9903
λ_{95}	Collateral constraint for age-95	0.9983

[1] Biennial value.

underpredicts the Medicaid take-up rate, especially for older cohorts. From panel (d), it is clear that the discrepancy in Medicaid rates is due to renters rather than owners in the model. This is important, because in the model, as in the data, there is a homestead exemption for Medicaid eligibility that could motivate some homeowners to stay in the house longer. The graph shows that we do not overstate the influence of Medicaid on homeownership. The model underpredicts the share of renters on Medicaid partly because we only have five income bins; by design, we cannot replicate the lowest tail of the income distribution, a key source of Medicaid claims in the data.

The resulting parameters from the second-step estimation are in table 6. First, the estimated collateral constraints imply that upon retirement, households' ability to borrow against home equity quickly becomes limited. Retirees of age 65 can borrow up to 36% of their home equity. The constraint tightens considerably by the time they are 75, to just 4% of home equity, and to just 1% for homeowners who are 85 years old. These numbers should not be interpreted literally as downpayment constraints; rather, these constraints capture the overall increase of costs of equity borrowing, such as binding debt-to-income ratio requirements, as discussed above. While reverse mortgages are instruments available specifically to relax the borrowing constraints of the elderly, in Nakajima and Telyukova (2017) we find these to be very costly, due to insurance costs, and hence rarely optimal to use. This is consistent with our interpretation of λ_i as capturing high costs of borrowing in retirement. See also the discussion in section 4.6.

Based on the Medicaid recipiency rates, we estimate the consumption floor to be about \$4,400 per person per year in 1996 dollars. Our estimate lines up well with Hubbard et al. (1994), who measure the non-Social-Security consumption floor for the elderly to be \$6,893 per *household* per year in 1984 dollars. Our estimated parameter of extra utility from homeownership is 2.5, which means that it is 3.5 times more appealing to own a home than it is to rent. As we mentioned before, this parameter captures all possible nonfinancial benefits of homeownership, as well as those financial benefits that are not explicitly in the model. The estimate that we have is consistent also with the findings in Venti and Wise (2004), who find strong support in the data, based on an AARP survey, that retirees like to stay in their homes as long as possible.

The relative risk aversion parameter that we estimate is $\sigma = 2.76$. This is in the middle of the range typically used in consumption-saving literature, and thus our model does not require a high degree of risk aversion to match the slow rate of asset decumulation in the data. The estimated strength of the bequest motive is 6.76. The interpretation of this and remaining parameters will be clear in the next sections in the context of our experiments.

6 Experiments: Decomposing the Retirement Saving Puzzle

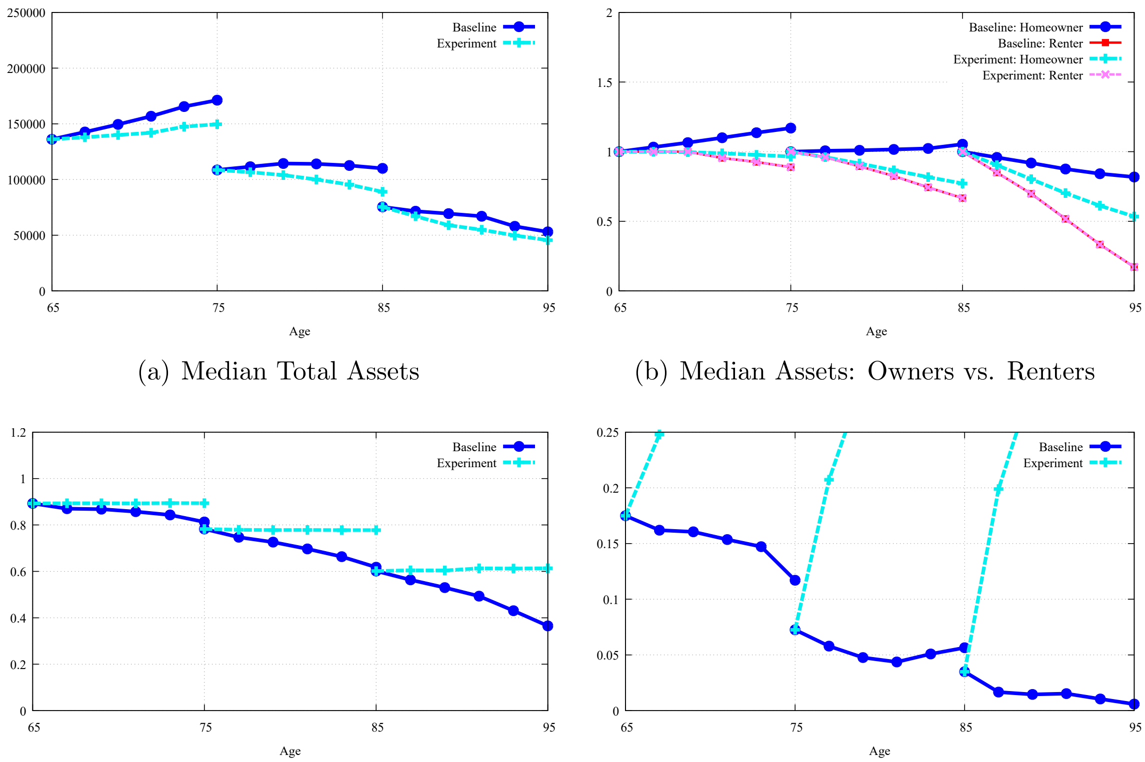
We use the estimated model to evaluate the quantitative contribution of key model features to retiree saving behavior, by shutting down these mechanisms one at a time, and comparing the results to the benchmark model outcome. The housing channels that we focus on are extra utility of homeownership, collateral constraints, and the housing boom of 1996-2006. We also evaluate the role of home maintenance as a potential hidden channel of asset decumulation. Finally, we evaluate the impact of medical expenses and bequest motives. We focus on the most salient results for each experiment; the full set of results is available upon request.

6.1 Role of Housing

6.1.1 Collateral Constraints

For this experiment, we relax the collateral constraints on homeowners, making them uniform across age. For this purpose, we set everyone's collateral constraint λ to 0.2, allowing all homeowners to borrow up to 80% of their equity, which is a standard feature of conventional mortgage contracts.

As panel (c) of figure 9 shows, the illiquidity of housing is sufficient to create most of the observed decline in the homeownership rate, all else equal. This implies that homeowners in our model sell their homes largely when they are forced against their borrowing constraint. The



(a) Median Total Assets

(b) Median Assets: Owners vs. Renters

(c) Homeownership Rate

(d) Debt Rate

Figure 9: Decomposition Experiment – Relaxed Collateral Constraints

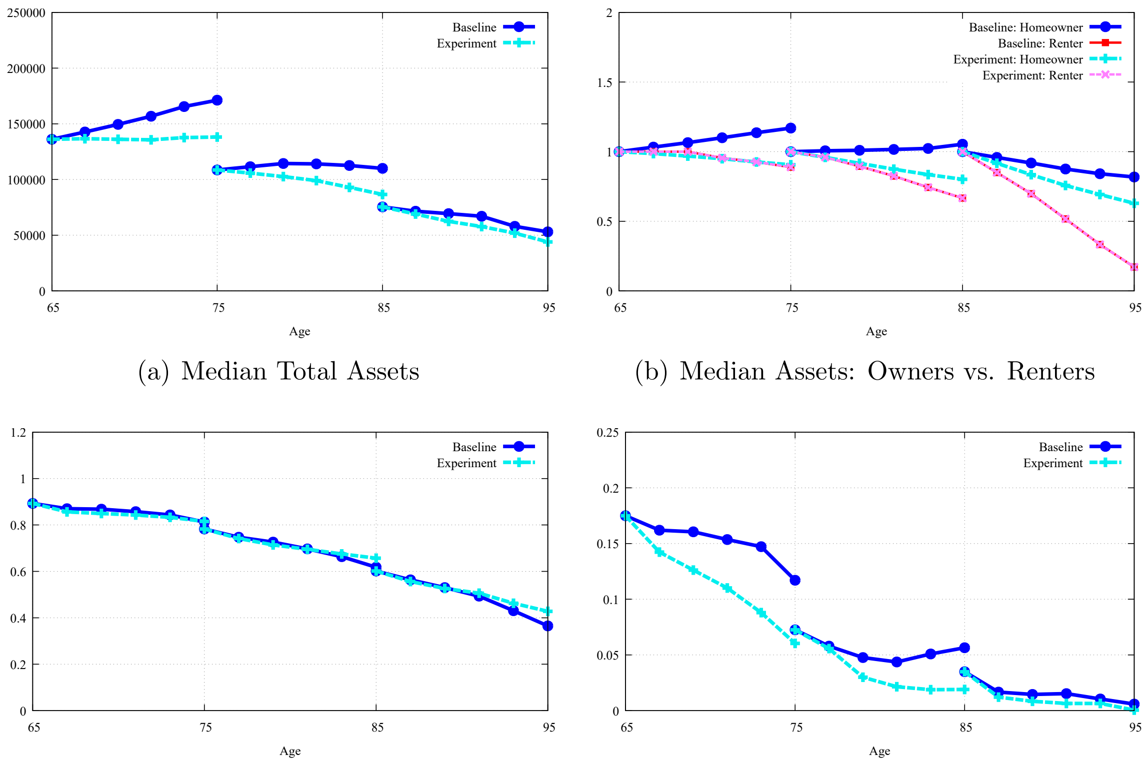
borrowing constraints depress borrowing (panel (d));[9] if homeowners were able to access their equity freely, they would hold on to their house, motivated by the utility benefit and housing boom, and borrow against their equity instead, decumulating their housing asset more quickly.

This in turn is reflected visibly in the median net worth in panel (a), suggesting that collateral constraints contribute to the retirement saving puzzle in a significant way, especially for younger cohorts. In addition, illiquidity of housing contributes significantly to the difference in dissaving rates between homeowners and renters, as shown in panel (b). Only for the oldest cohort there remains a noticeable difference even when borrowing constraints are relaxed.

6.1.2 Housing Boom

To evaluate the role of the 1996-2006 housing boom, we shut down exogenous increases to the aggregate housing price, making it constant instead. The obvious impact is the flattening of median net worth profiles in panel (a) of figure 10, which happens through two channels. First,

[9]For ease of comparison, we keep the scale of the graphs constant, at the cost of having this graph partially off the scale.



(a) Median Total Assets

(b) Median Assets: Owners vs. Renters

(c) Homeownership Rate

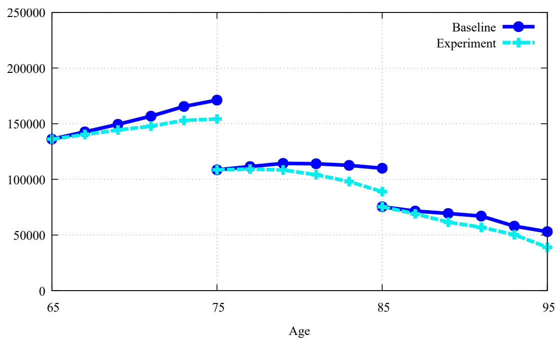
(d) Debt Rate

Figure 10: Decomposition Experiment – No Housing Boom

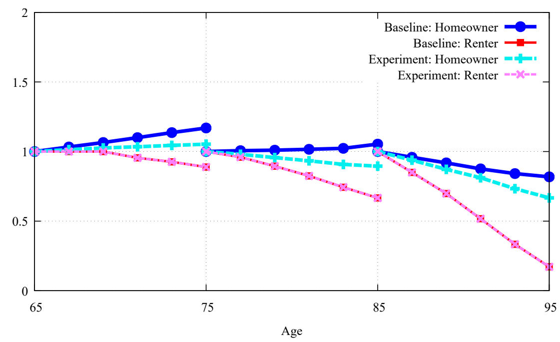
there is a significant flattening of median housing asset profiles (not shown). In addition, panel (d) shows a decline in the debt rate when there is no housing boom; the median amount of debt, especially in the younger cohort, also declines somewhat. (See online appendix). This is intuitive: a housing boom increases the amount of home equity that households can extract, and some households take advantage of that. The overall impact of the housing boom is an increase in the median net worth for all cohorts; this impact is least pronounced for the oldest cohort. Note also that the housing boom, like collateral constraints, plays an important role in creating the differences in the dissaving behavior of homeowners versus renters (panel (b)), with the oldest cohort being the biggest exception.

6.1.3 Extra Utility of Homeownership

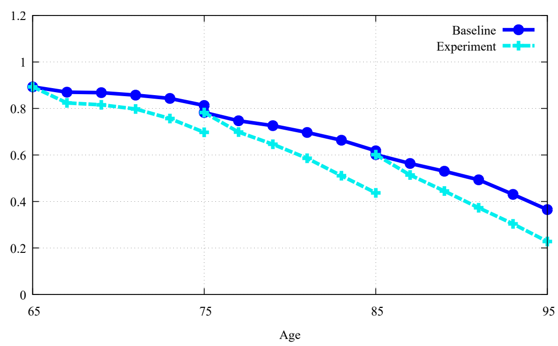
To evaluate the role of nonfinancial and additional financial benefits of homeownership in retiree saving decisions, we set $\omega_1 = \omega_0 = 1$, so that owned and rented homes are the same in terms of utility. Panels (c) and (d) of figure 11 shows that, not surprisingly, the utility benefit of homeownership encourages retirees to own homes, to a similar extent across cohorts, and decreases the



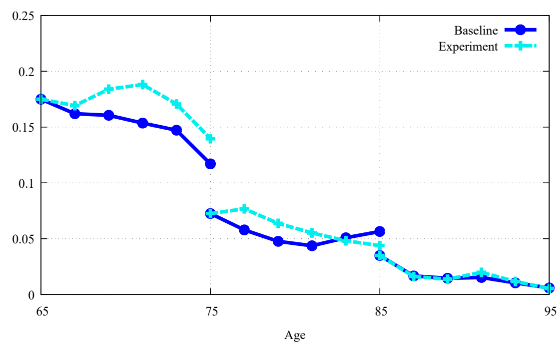
(a) Median Total Assets



(b) Median Assets: Owners vs. Renters



(c) Homeownership Rate



(d) Debt Rate

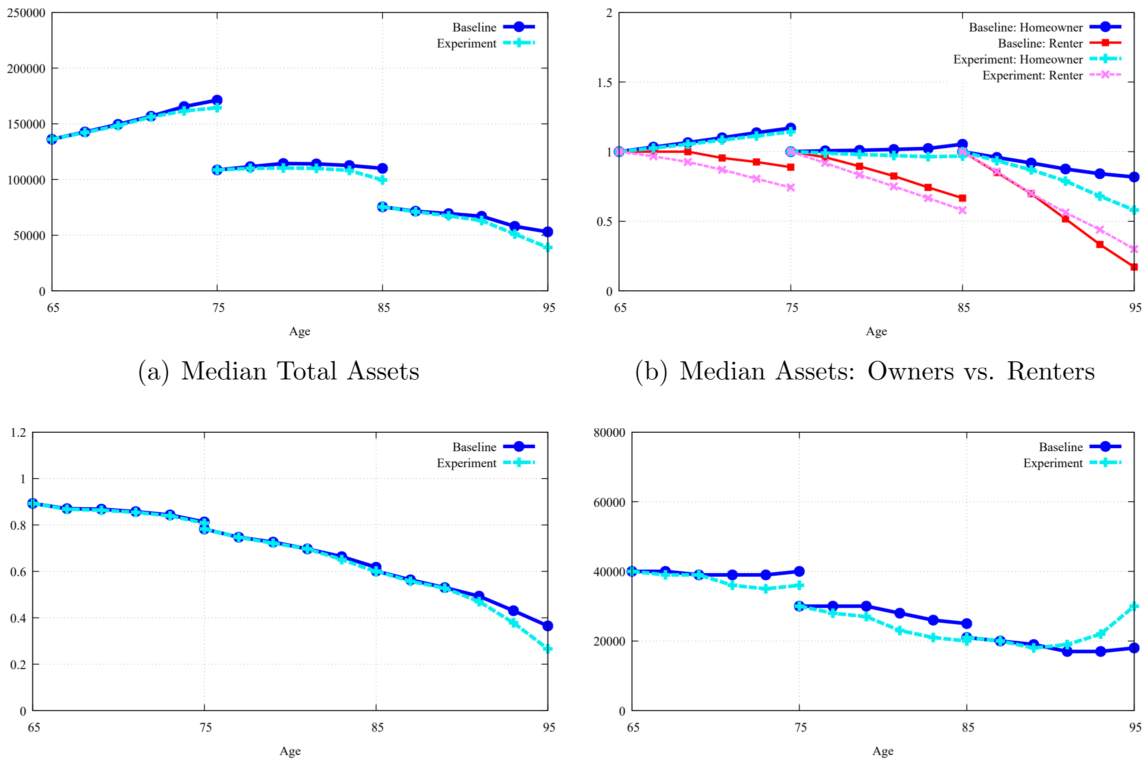
Figure 11: Decomposition Experiment – No Extra Ownership Utility

share of retirees who borrow against home equity, particularly in the youngest cohort. Through extra homeownership, the utility benefit raises median net worth (panel (a)), and contributes to the difference in the rate of dissaving between owners and renters (panel (b)), albeit to a smaller extent that the other two housing channels.

6.2 Role of Medical Expenses

In this section we perform two experiments. First, we shut down all medical expense risk by setting everyone's expenses to the overall mean, and eliminating dependence of medical expenses on health and household size. Thus, medical expenses in this experiment depend only on age and income, both of which are deterministic. In the second experiment, we remove medical expenses altogether, setting $x = 0$.

Panel (c) of figure 12 shows that medical expense risk does not impact homeownership rate, except for the oldest retirees, a small fraction of whom would sell their homes if we shut down medical expense risk. This effect comes from the homestead exemption of Medicaid. In the presence of medical expense risk, some of the oldest homeowners have an incentive to hold on to



(a) Median Total Assets

(b) Median Assets: Owners vs. Renters

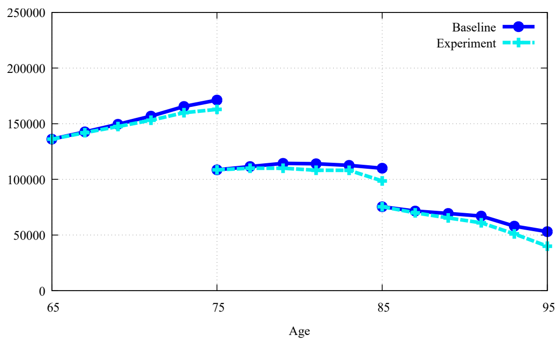
(c) Homeownership Rate

(d) Median Financial Assets

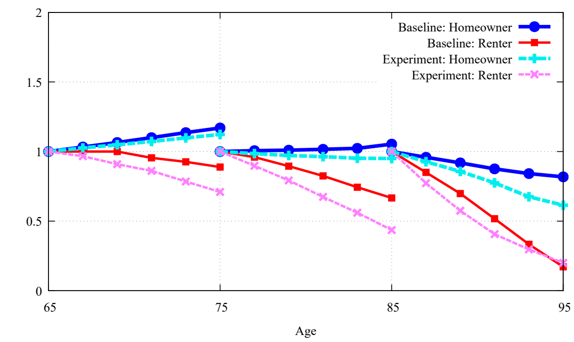
Figure 12: Decomposition Experiment – No Medical Expense Risk

their home and use Medicaid if a big medical expense shock realizes, rather than to sell the home and use home equity to pay for the expense. As panels (b) and (d) show, both homeowners and renters decumulate their financial assets more rapidly in the absence of medical expense risk, but the difference between owners and renters remains large and even increases for all the cohorts except the oldest one; the Medicaid channel described above does account for some of that difference for the oldest retirees. The impact on financial assets points to a moderate precautionary motive in saving for medical expense risk, while there is no impact on median housing assets, and the overall effect on median net worth is fairly small (panel (a)).

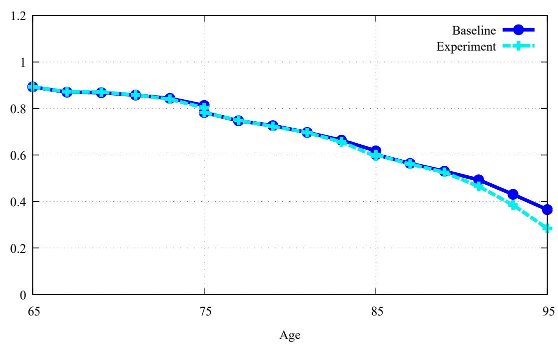
When medical expenses are shut down altogether, the results are similar in spirit to those just described, and slightly stronger in magnitude for older retirees. See figure 13. Homeownership rates and housing assets are still not impacted for younger retirees, but a mild impact is observed from age 82 forward. Financial asset decumulation is slightly more pronounced for the middle and oldest cohorts, with a resulting drop in net worth for those cohorts that is somewhat larger than in the previous experiment. This is not surprising because the mean and variance of medical expenses remain low until about age 80. Homeowners and renters both decumulate wealth more



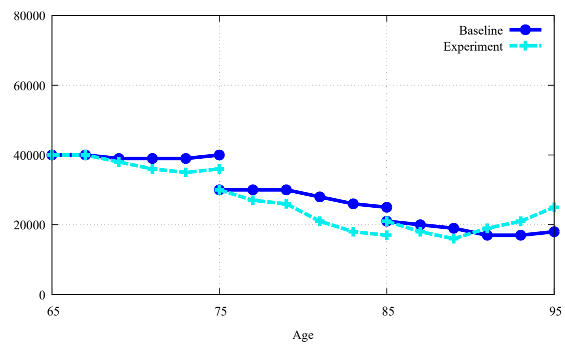
(a) Median Total Assets



(b) Median Assets: Owners vs. Renters



(c) Homeownership Rate



(d) Median Financial Assets

Figure 13: Decomposition Experiment – Zero Medical Expenses

quickly, but a significant difference between them remains. When medical expenses are removed altogether, retirees decumulate wealth more quickly not only because they don't need to self-insure against future medical expense risk, but also because they are not setting aside assets even for expected medical expenses. Some older retirees sell their homes faster because housing is illiquid late in life, while a small fraction of retirees prefers to continue spending down their wealth.

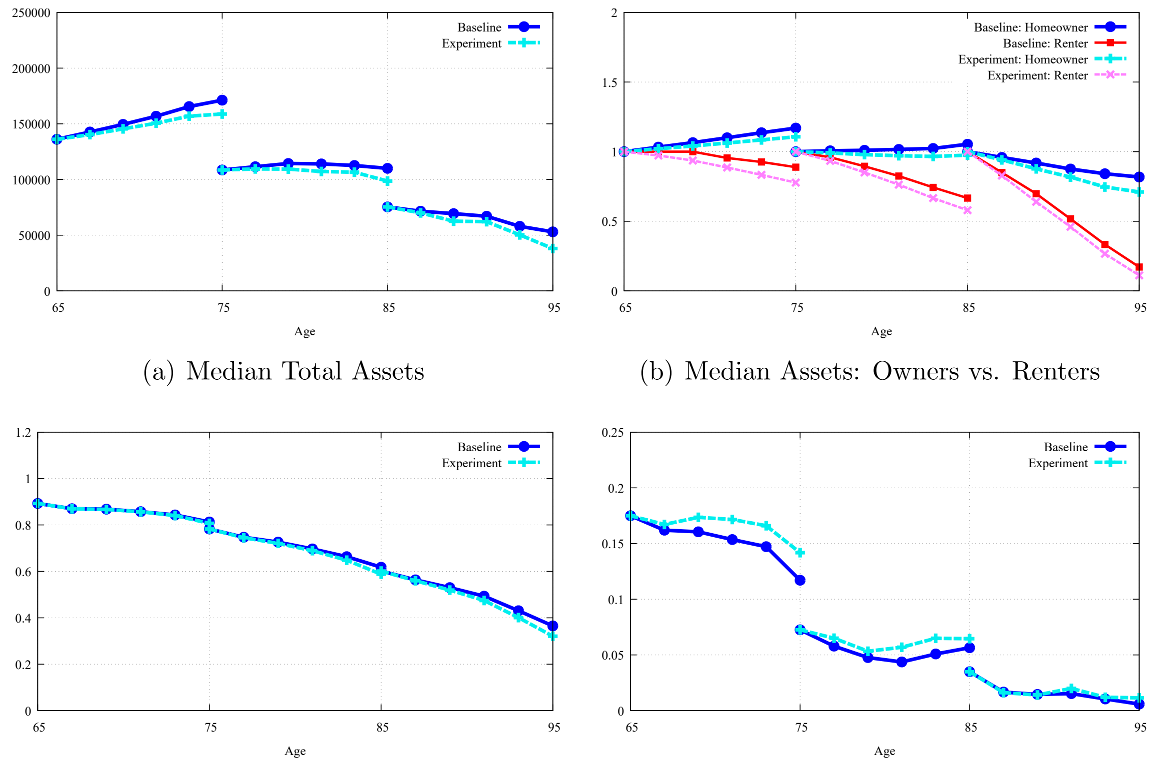
In our model, the role of medical expenses is noticeable, but much lower relative to previous literature, particularly De Nardi et al. (2010), who find that medical expenses account for a large portion of the retirement saving puzzle in a one-asset life-cycle model. A key reason for this difference is in the structure of the model: our model includes housing, which fundamentally changes the nature of saving in retirement. When housing is added, its illiquidity and financial characteristics play a significant role in the dissaving patterns of retirees, and once this role is taken into account, medical expenses necessarily play a reduced role. Even though there is some interaction between housing and medical expenses – e.g. large medical expense shocks may force some retirees to sell their house – this interaction is not large enough to make medical expenses the dominant explanatory variable for the retirement saving puzzle. A second reason for the differences is that De Nardi et al. (2010) only consider single households in their sample, while we include all households. Since couple households tend to hold housing, and are likely to save more and to leave bequests, estimation that includes couple households naturally will assign lower importance to medical expense risk. Finally, the role of medical expenses is partly a function of the coefficient of relative risk aversion σ. As we show below, the identification of σ is challenging in life-cycle models, especially if the model has only one asset and does not include housing.

Like in our model, De Nardi et al. (2010) find that removing all medical expenses has a stronger effect than just removing medical expense risk, although in their case the difference in impacts is larger. In addition to the role of housing in our model, this difference in our results may be due to the fact that De Nardi et al. (2010) do not remove dependence of medical expenses on stochastic health in their risk experiment, which we do remove. In our model, the impact of health expense *risk* thus appears larger than in theirs, but the role of medical expenses overall is significantly reduced.

To conclude this section, we investigate the aforementioned interaction of housing, health, and medical expenses in more detail by conducting an additional counterfactual experiment. At the beginning of retirement, homeowners and renters are different in terms of health status – renters tend to be in poorer health. It is possible that people may be driven to sell their homes when their health deteriorates and medical expenses increase, so that the differences between owners and renters are driven by health and medical expenses. Our model allows for this to happen, and as we just showed it does to a small extent, when some homeowners that are hit by a large medical expense shock sell their homes. We conduct an additional experiment where we allow homeowners at age 65 to have the same health status distribution as renters, to see if they sell their homes and dissave more quickly. We find that the overall effect on median net worth is small. The impact is mainly on the oldest retirees, who in some cases decumulate wealth more quickly when hit by the largest medical expense shocks, including by selling their home. See Appendix B.

6.3 Role of Bequest Motive

Figure 14 shows that bequest motives have a mild effect on net worth or homeownership in our model. A bequest motive causes retirees to save more, both as homeowners and renters, and causes some older homeowners to hold on to their homes longer, while discouraging borrowing against home equity. Bequest motives account for a small portion of the difference between



(a) Median Total Assets

(b) Median Assets: Owners vs. Renters

(c) Homeownership Rate

(d) Debt Rate

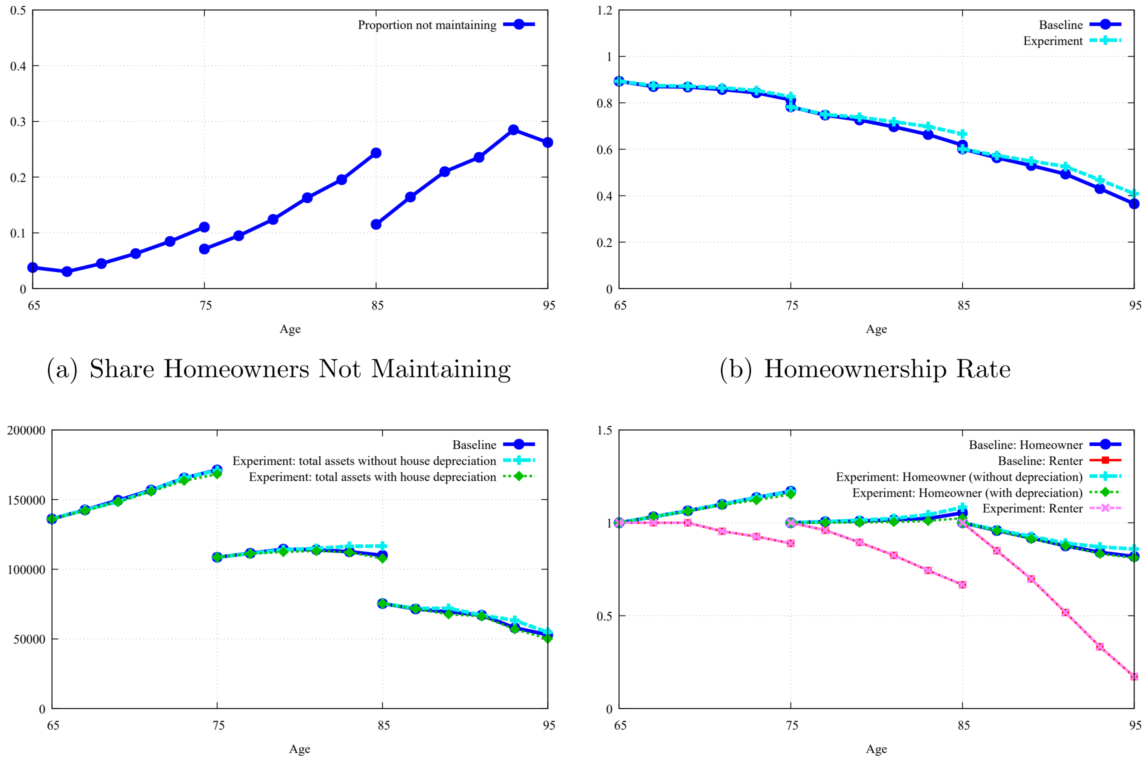
Figure 14: Decomposition Experiment – No Bequest Motive

homeowners and renters, and are strongly dominated by the housing channels.

6.4 Role of Home Maintenance

We conduct one more experiment to evaluate the role of home maintenance as a possible "hidden" channel of asset decumulation. We are motivated by the study of Davidoff (2006), who finds that elderly homeowners spend on average 0.8% less per year on home maintenance than younger owners of similar houses, and that similar houses sell at lower prices if the seller is older than 75.

In order to conduct this experiment, we add a choice margin to our model. Whereas in the benchmark, we assume that all households pay the maintenance cost (1.7% of house value per year) and as a result the house does not depreciate, now we give the households a choice: they can continue to pay the cost, or they can choose not to pay it, but the house will depreciate as a result at the rate of 4.25% per year. The calibration for this experiment came from the maintenance spending number in Davidoff (2006) mentioned above. In addition, he calculates that houses of older homeowners appreciate at a rate of 2 percentage points per year lower than houses of younger owners. These two numbers together, in addition to the maintenance cost



(a) Share Homeowners Not Maintaining

(b) Homeownership Rate

(c) Median Total Assets

(d) Median Assets: Owners vs. Renters

Figure 15: Experiment – Home Maintenance Decision

parameter, give us the parameters specified here.

An additional important point is that in order to conduct this experiment, we make the assumption that self-reported home values do not take into account depreciation of the house. That is, we assume that homeowners who stay in their homes do not have their house appraised and are not aware of the rate at which their home depreciates. This assumption is supported by Venti and Wise (2004), who find that self-reported home values are exaggerated. Still it may be an extreme assumption, and thus the results of this experiment should be treated with this caveat in mind. On the other hand, the empirical findings of Davidoff (2006) appear to be that the maintenance margin is an important one, and we can use our model to get a sense of how much it might contribute to the retirement saving puzzle in a "hidden" way.[10]

Figure 15 shows the results of the experiment. First, the proportion of homeowners who

[10]In this experiment, it would be valid to re-estimate all of the parameters, since we change a choice margin in the model. We do not do that here for feasibility reasons, but since the resulting experiment wealth profiles are very similar to the benchmark, we expect that the parameters would not change significantly relative to benchmark. Absent this re-estimation, the results can be treated as an approximation of the total effect of maintenance.

choose not to maintain grows steadily with age (panel (a)), which is consistent with empirical findings in the literature, from 3% at age 65 to nearly 30% by age 93-95. Intuitively, the older a homeowner gets, the more likely she is to be borrowing-constrained. Choosing not to maintain gives her an alternative way to tap into some of her equity indirectly while staying in the house. This is mirrored in panel (b), where more older homeowners are able to keep their homes compared to the benchmark model. However, as shown in panels (c) and (d), we find that the effects of maintenance decision on median net worth is small. Here we show total asset profiles calculated with and without accounting for depreciation. Total assets profiles, especially for homeowners (see panel (d)), rise as some homeowners retain their house while decumulating its value by not maintaining, but if depreciation is taken into account, total asset profiles are very similar to the benchmark case, as depreciation and consequent decline of house values bring the profiles back down.

6.5 Summary: Individual Decomposition Results

Table 7: Decomposition: Percent Contributions to Median Net Worth

Model	Age 75 (cohort 1)	Age 85 (cohort 2)	Age 95 (cohort 3)
Simple life-cycle with longevity risk, no med. exp.	51.3	66.4	84.9
Housing	28.3	35.6	43.9
House price growth	19.3	21.3	17.0
Extra-utility of owning	12.6	19.1	14.0
Collateralized borrowing	9.9	19.1	26.4
Medical expenditure risk	4.0	9.4	26.4
Zero medical expenditures	4.9	10.3	24.5
Bequest motive	7.2	10.3	28.3

Table 7 summarizes and quantifies the results of the individual experiments just presented. The first row shows how much the observed net worth profiles decline if we shut down all of the uncertainty in the model, except for longevity risk, and set medical expenses to zero. From the second row on, each number represents the magnitude of decline of median net worth as a result of removing the respective model feature, relative to the estimated full model. That is, the table shows how much each of the model features contributes to the net worth profiles observed in the data.

This strip-down model which is close to the canonical life-cycle model of retirement, shows that housing, medical expenses, and bequest motives together account for between 51% of net worth for age-75 retirees and 85% for age-95 retirees, and this contribution continues to increase through age 99. The fact that many households are homeowners well into their old age turns out to be crucial to explain the retirement saving puzzle. The contribution of the three housing-related features ranges from 28% of net worth for age-75 retirees to 44% for retirees above age 95. Retired homeowners choose to remain owners late in life due to a combination of financial and nonfinancial benefits of ownership, as well as the expected house price growth. The benefits of ownership, expressed in our utility parameter ω_1, account for between 13% and 14% of net worth profiles. Once retirees choose to stay in their homes, they become beneficiaries of the housing boom, which contributed between 17% and 21% to the retirement saving puzzle over the period 1996-2006. Finally, as homeowners age, they become increasingly locked into their home equity because of tightening borrowing constraints; this accounts for between 10% and over 26% to the observed net worth profiles. On the flip side, retirees can hit their borrowing constraints – due to medical and other expenses – and can be forced to sell the house as a result, becoming renters instead.

Medical expense risk accounts for a moderate portion of the puzzle, and this contribution grows with age. At age 75, medical expenses account for between 4% and 5% of net worth, this contribution is between 9% and 10% at age 85, and 25-26% at age 95. Finally, bequest motives account for 7-28% of median net worth at the three ages. As we showed above, medical expense risk does not impact homeownership until later in life (age 84 and above), while bequest motives have a very minor impact on homeownership rates.

In Appendix C we show additional experiments that demonstrate possible interactions between the model channels that we are concerned with, by sequentially removing features of housing, medical expenses, and bequest motives in different orders. We find that the role of housing remains strong and quantitatively similar regardless of the relative order in which housing-related channels are removed. The relative roles of bequest motives and medical expenses can increase or decrease depending on the order in which they are removed from the model, though both remain secondary to the housing channels regardless of the order.

7 Identification and Sensitivity

In this section we use sensitivity analysis to show how each parameter maps to the central model targets. We show that our key result, quantitative role of housing, is robust to parameter perturbations. We also show that the two parameters that determine bequest and precautionary motives are difficult to disentangle. Graphs and tables with details of these experiments are in Appendix D.

7.1 The Role of Housing and Parameter Identification

The role of housing in our model is determined by three channels, not counting the maintenance channel, which correspond to three parameters. The first is the collateral constraint, with the age-dependent parameter λ_i, which is identified by the debt rate profile. The second is the housing boom, which is driven by the house price p with the growth rate g_1, both of which are exogenous, and are not tested here. The third channel is the utility benefit of homeownership, with parameter ω_1, which helps determine the homeownership rate in the model. Since ω_1 affects only homeowners and not renters, it also helps separate the normalized net worth profiles of owners versus renters. While λ_i and g_1 are identified nearly one-for-one with the respective endogenous or exogenous targets, we cannot claim such identification for ω_1 or the remaining parameters. In a series of experiments here, we perturb one parameter at a time, holding all others fixed, to show how the model fit is affected, and how the role of housing responds to the change. For each parameter, we pick two values on either side of the benchmark estimate.

Perturbing λ_i demonstrates the close relationship between borrowing constraints and the debt rate (see Appendix D.1). The experiment tests two scenarios, either decreasing or increasing λ_i by 10 percentage points relative to benchmark for each age. The effect on the debt rate of an increase in λ_i is large, and for the youngest cohort, results in a slight deterioration of the homeownership rate and median net worth, as well as all the other targets for all cohorts. However, the contribution of housing to net worth profiles is nearly unaffected by these changes in the borrowing constraint, ranging between 27% for age-75 retirees and 43-44% for age-95 retirees in both experiments.

The value of ω_1, as discussed above, is mainly identified by two estimation targets. Given the benchmark value of $\omega_1 = 2.5$, we test values of 1.5 and 3.5. For age 75, the impact of housing on net worth as a result of this perturbation ranges between 26% and 29%, while for age 95 the range is 38-46%. As the graphs show, setting ω_1 to 1.5 results in a slightly better fit of the homeownership rate, at the cost of a deterioration in the normalized net worth profiles of homeowners.

The aggregator of housing and non-housing consumption in the utility function, η, changes the balance between housing and financial assets. In particular, a lower η yields a higher homeownership rate, a higher total asset profile of homeowners, and a lower financial asset profile. We test the values of eta of 0.8 and 0.87, given the benchmark estimate of 0.83. The value of 0.87 slightly improves the fit of the homeownership rate and median financial asset profiles, but performance for all other targets deteriorates. For the two values of η, housing remains robust, contributing 26-30% of median net worth at age 75, and 38-45% of net worth at age 95.

Perturbing γ, the warm-glow bequest motive parameter, 20% up or down from its benchmark value, leaves the contribution of housing largely unaffected, accounting for 28-28.7% of net worth for age-75 retirees, and 42-43% at age 95. The higher value of γ, 8.11, slightly improves the fit of financial asset profiles for older retirees, but model fit along other targets deteriorates.

The bequest shifter ζ affects the difference in bequest motives between wealthy and less wealthy households. We test the range of ζ 20% above and below the benchmark value. For the lower value, we see an improvement once again in financial asset profiles, but a deterioration of fit along the other dimensions. This perturbation does not noticeably shift the role of housing, which contributes 27-29% of the youngest cohort's median net worth, and 38-43% of the oldest cohort's median net worth.

The discount factor β helps replicate the total and financial asset holdings, especially of younger cohorts. We test β in the range of 0.93 to 0.99. For the higher value, we see a slight improvement in median financial assets and net worth, particularly for the younger cohorts, at the expense of other targets such as renters' net worth profiles, as raising the discount factor makes all agents in the model save more. The role of housing remains robust to this change, at 26-30% of median net worth at age 75, and 40-43% at age 95.

The consumption floor parameter $\underline{c}$ determines the proportion of households who use Medicaid in the model. $\underline{c}$ also helps generate the separation between homeowners' and renters' net worth profiles, since renters rely on the consumption floor more often, and thus are more sensitive to changes in $\underline{c}$. We test values of $\underline{c}$ of 20% above and below the benchmark value. Unsurprisingly, the higher value ($10,560) significantly improves the fit of the model for Medicaid claim rates, which were underpredicted in the benchmark, but this leads to counterfactual declines of renters' assets and of median financial assets overall. The three housing channels still account for 28-30% of median net worth at age 75, and for 43-44% at 95.

In sum, these experiments show that each parameter plays a distinct role in fitting the benchmark model to the estimation targets, and the result of each perturbation is a noticeable deterioration of fit. The role of housing remains robust to the perturbations of these parameters.

7.2 Strength of Bequest and Precautionary Motives

The second set of our benchmark results concerns the role of bequest motives and medical expenses, two contributors to the retirement saving puzzle emphasized in previous literature, in generating the observed median net worth profiles. This role is primarily determined by the parameters σ, the curvature of the utility function, and γ, the strength of the bequest motive. It is difficult to make a formal argument about identification of these two parameters, unless data on the strength of bequest motives are used for estimation in addition to asset profile data, as in Ameriks et al. (2011). The above experiments suggest that we may be able to use age and wealth heterogeneity to identify them, because bequest motives and medical expenses affect the young and old, high- and low-income households differently. For example, bequest motives seem to impact older and higher-income households more, while precautionary motives impact the young more. However, it is also clear that these parameters interact. This is an issue that would affect any standard life-cycle model.

In order to demonstrate the sensitivity of our results to the parameters σ and γ, here we perform two extreme experiments. First, we set $\sigma = 3.8$, as in De Nardi et al. (2010), a value that is nearly 38% above our estimated value. Then, holding all other parameters constant, we re-estimate γ such that the sum of squared residuals (SSR) is minimized along all the estimation targets. In this case, we find that $\gamma = 0$ is required (indeed $\gamma < 0$ performs even better), and this model has worse fit than the benchmark (Appendix D.2). The same is true for the second experiment, where we again raise σ to 3.8, but now we keep γ at its benchmark estimated value, and instead let β adjust to minimize SSR. In this case, we get $\beta = 0.94$. The deterioration in fit concerns all the estimation targets to some extent: for example, the fit of older retirees' net worth and homeownership rates deteriorates, as does the fit of median financial assets for younger and oldest individuals. Net worth fit of the middle cohort, as well as homeowners, is matched slightly better in these two experiments, but the fit of renters' net worth profiles is noticeably worse.

Importantly, these two altered models still predict a robust and strong role for housing. In the first experiment, housing accounts for 34-44% of median net worth profiles across age groups. However, with the quantitative role of bequests removed, the role of medical expense risk rises to a range of 9-37% across age groups. The results are similar for the second experiment: the role of housing ranges between 32% and 44% of net worth across cohorts, while medical expense risk accounts for between 7.5% and 39%, with a very small role left to bequests.

These results are not surprising. In the first experiment we increase relative risk aversion, thereby increasing precautionary saving motive, while removing the bequest motive. Absent the bequest motive, we would expect more people to sell their homes and/or to borrow against their homes, but the increased risk aversion counters and dominates this; overall saving goes up in the model. In the second experiment, with higher relative risk aversion, we decrease the households' patience. Similarly, we might expect less saving and more borrowing with more impatient households, but this is countered by a significant increase in the precautionary saving motive. Moreover, less-patient households are less responsive to the bequest motive.

The message of these experiments is, first, that our main result regarding the role of housing is robust to the changes of parameters σ, γ and β in the model, even though in each case, the model fit deteriorates. Second, in life-cycle models of retirement with warm-glow bequest motives, it may be difficult to disentangle the strength of bequest motives from precautionary motives. This is especially true for life-cycle models with just one asset; when matching net worth profiles alone, without accounting for homeownership, if one of the parameters changes value, the other counters to provide an overall similar match of net worth profiles. This point was also made by Ameriks et al. (2011). Thus, future research will need additional strategies for identification, which may involve, for example, more detailed modeling of bequests, or the use of data from multiple countries, or both. Nakajima and Telyukova (2018) take a step in that direction.

8 Conclusion

In this paper, we study homeownership in retirement, to understand what role it plays in accounting for the retirement saving puzzle. We do so by estimating a model of retiree saving that is explicit about differentiating between housing and nonhousing assets, targeting jointly in estimation not only median net worth lifecycle profiles of retirees, but also profiles of homeownership rates, housing and financial assets separately, renters' and homeowners' net worth separately, as well as debt rates and amounts. In our estimated model, housing plays a key role in accounting for the retirement saving puzzle, through a combination of utility benefits of homeownership, illiquidity of housing, and the housing boom of 1996-2006. Moreover, bequest motives and medical expenses account for moderate and similar shares of the puzzle, once housing assets and homeownership are explicitly taken into account. We demonstrate also, however, that the relative roles of bequest motives and medical expenses are difficult to identify separately in this class of models. The quantitative role of housing is not significantly affected by these two channels, and is robust to perturbation of the other parameters. Relative to previous literature, conclusions regarding the retirement saving puzzle change if one considers housing and motives for homeownership late in life explicitly, and separately from overall net worth of retirees.

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Appendix (Not for Publication)

Appendix A Data Analysis Robustness: Weighting and Panel Balancing

In this section, we demonstrate how our choices regarding the weight scheme that we use, as well as the way we treat panel balancing, impact the data facts. To remind the reader, in our data analysis, we chose to use 1996 weights for the households in the sample, which means that the households in our analysis have to be present in the first wave, and that thereafter, we are looking at an unbalanced panel. The choice of first-wave weights was motivated by the fact that we do not want to lose nursing-home residents from our sample, while the unbalanced panel is the most natural mapping of the model to the data, since in the model, we will also generate an unbalanced panel, with empirical mortality rates conditioned on all the state variables of the model.

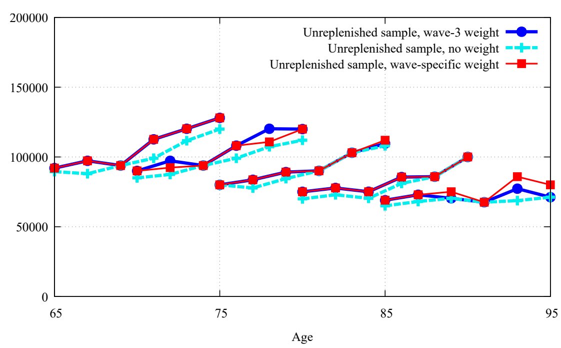


Figure A1: Median Housing Assets: Weight Comparison.

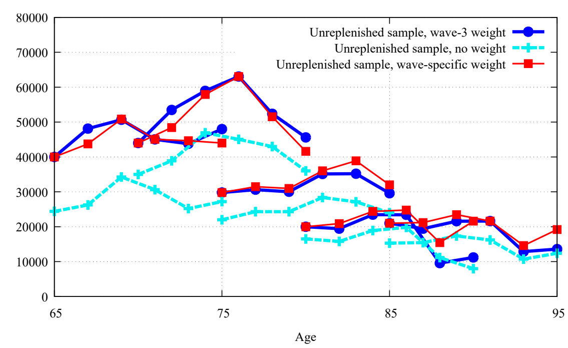


Figure A2: Median Financial Assets: Weight Comparison.

First, we compute the cohort profiles of median housing and financial assets using alternative weighting schemes. Figures A1 and A2 compare profiles of median housing and financial assets, with (i) the baseline assumptions (using 1996 weights on the sample, with no subsequent cohort replenishment, labeled wave-3 weights in the graphs), (ii) the same sample, with no sample weighting, and (iii) cohort replenishment and using wave-specific weights, which implies losing nursing home residents. We check the case without sample weighting to compare our results with De Nardi et al. (2010), who do not use sample weighting in their data analysis; our results align with theirs well, given that they use only singles in their analysis, while we also use couples. The profiles that we found under the baseline assumptions, i.e. upward-sloping housing asset profiles for all cohorts and approximately flat financial asset profiles, are roughly maintained under alternative assumptions. Using weights – either 1996 or cohort-specific – elevates the levels of assets, especially for younger cohorts. We prefer to use the weighted sample, but in such a way that it still allows us to account for nursing home residents with positive weights.

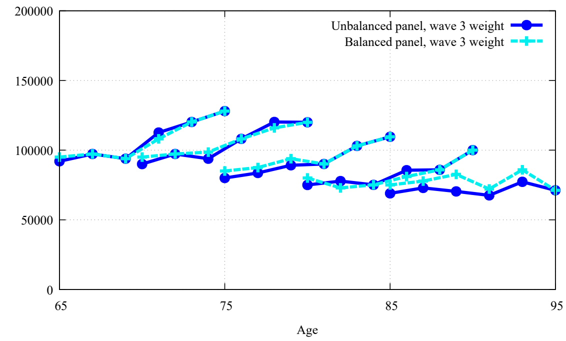


Figure A3: Median Housing Assets: Balanced vs Unbalanced Panel.

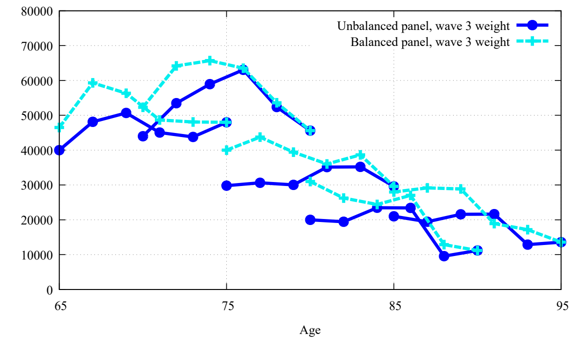


Figure A4: Median Financial Assets: Balanced vs Unbalanced Panel.

We also demonstrate the impact of choosing to work with the entire sample (those who were present in 1996), which creates an unbalanced panel, versus working with only those who start in 1996 and survive into the eighth wave of the survey (a balanced panel). Figures A3 and A4 plot median housing and financial asset profiles in the balanced and unbalanced panels. We find that especially for financial assets, using the balanced panel makes the asset profiles steeper, so that asset decumulation over the life cycle looks more pronounced. This confirms what De Nardi et al. (2010) called the mortality bias: including non-survivors in the sample alters the sample composition toward those in poorer health, who also tend to have less wealth, so that the median profiles look flatter as a result.

Appendix B Interaction of Housing, Health and Medical Expenses

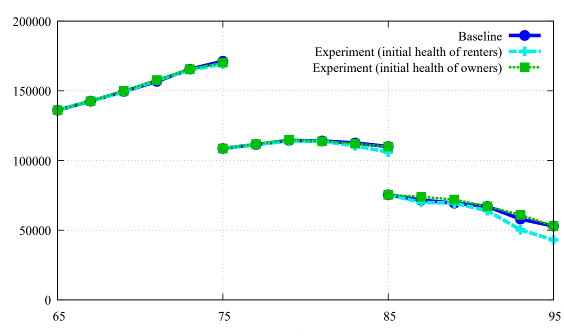


Figure A5: Median Total Assets: Health and Housing Counterfactual Experiment

In this section we conduct a counterfactual experiment to assess how homeownership, health, and medical expenses interact in the model. While experiments in Section 6.2 already demonstrate some impact on homeownership when medical expense risk or medical expenses are removed, we also want to investigate the role that the initial distribution of health among retirees plays in determining asset decumulation behavior in retirement.

To do this, we conduct two versions of the experiment. In the first, we change the health distribution of homeowners at age 65 to look like that of renters. In the second, we change the health distributions of renters at age 65 to look like homeowners. For example, when homeowners' health deteriorates to look like renters, we want to assess whether they sell homes and decumulate net worth more quickly than in the benchmark model, thus indicating that health and medical expenses impact homeownership and asset decumulation behavior.

We do find some interaction between health, medical expenses, and saving, but the impact on homeownership and median net worth is small, and mainly impacts the oldest retirees. Figure A5 shows the effect of both changes on median total assets. The more noticeable impact is from reducing the health of homeowners. Here, some of the oldest retirees encounter significantly larger medical expense shocks, and choose to sell their house sooner than in the benchmark. Overall, the impact is small enough to conclude that health and medical expenses are not a key driver of homeownership behavior in retirement.

Appendix C Sequential Quantitative Assessment of Retirement Saving Puzzle

The experiments in Section 6 reveal the roles of individual model channels in accounting for the retirement saving puzzle. However, since multiple parameters impact the same targets, the experiments imply possible interactions between the model channels that we are concerned with. For example, bequest motives and utility benefits of homeownership may interact and reinforce each other in creating motives for homeownership; medical expenses may interact with borrowing constraints and cause some homeowners to sell. In order to shed more light on such possible interactions, we next conduct experiments where we remove the relevant model features one at a time in succession. We do this in several different orders, to highlight the interactions of interest.

For these sequential experiments, we focus on the most standard statement of the retirement saving puzzle – the median net worth of each age group. Taking the benchmark net worth median as 100%, we quantify how much of it, relative to the benchmark, is generated for each cohort by each model mechanism. We present results for selected age groups in table A1. Each numbered panel shows a different order of removal of key model features, and all housing features (collateral

Table A1: Contribution of Each Channel to Median Net Worth – Sequential Decompositions and Incremental Contributions[1]

	Features Turned Off	Age 75 (cohort 1)	Age 85 (cohort 2)	Age 95 (cohort 3)
1	Bequest motive	7.2	10.3	28.3
	All housing features	34.9	36.0	32.1
	Medical expenditure risk	6.5	10.1	4.3
2	Bequest motive	7.2	10.3	28.3
	Medical expenditure risk	2.9	6.9	7.5
	All housing features	38.5	39.2	28.8
3	Medical expenditure risk	4.0	9.4	26.4
	Bequest motive	6.1	7.8	9.4
	All housing features	38.5	39.2	28.8
4	Medical expenditure risk	4.0	9.4	26.4
	All housing features	25.9	30.9	24.5
	Bequest motive	18.7	16.1	13.7
5	All housing features	28.3	35.6	43.9
	Medical expenditure risk	1.7	4.8	7.0
	Bequest motive	18.7	16.1	13.7
6	All housing features	28.3	35.6	43.9
	Bequest motive	13.9	10.8	16.4
	Medical expenditure risk	6.5	10.1	4.3
7	All (housing, bequest, med. exp. risk)	48.6	56.5	64.7

[1] Each number in table represents the percentage by which net worth drops relative to benchmark net worth, i.e. it is a direct measure of the contribution of the given feature to the retirement saving puzzle.

[2] "All housing features" includes (1) utility benefits of homeownership, (2) collateral constraints, and (3) housing boom.

constraints, housing boom, and utility of homeownership) are grouped together. The overview is that housing plays an important quantitative role for the retirement saving puzzle, accounting for between 28 and 44% of the observed median net worth, depending on age and order. In addition, there is visible interaction of the bequest motive with housing channels, because its quantitative contribution changes depending on the order in which it is removed. The bequest motive accounts for 6-28% of median net worth of retirees, depending on age. Finally, the quantitative role of medical expenses is moderate, 1.7-26% depending on age, and there is moderate interaction with housing for the oldest cohort.

The role of the three housing channels together ranges between 26% and 39% for the youngest group, depending on whether their preferences have a bequest motive at the time of removal of housing, and between 25 and 44% for the oldest households. The role of bequest motives ranges from 6 to 19% for the youngest cohort, and from 9 to 28% for the oldest cohort.

The order in which housing is removed is important, especially relative to the bequest motive. If the bequest motive is removed first, with the housing channels still operative in the model (see panels 1 and 2 of the table), the role of housing is higher and the role of bequests is lower for the two younger cohorts, than if housing is removed first (panels 5 and 6). For the oldest cohort, this is reversed: the role of bequests is stronger if housing is still operative in the model, and the role of housing is stronger if removed while bequest motives still operate in the model. Both show an interaction or complementarity between housing and bequests. Bequest motive affects the behavior of homeowners, and the decision to own a home for the oldest cohort.

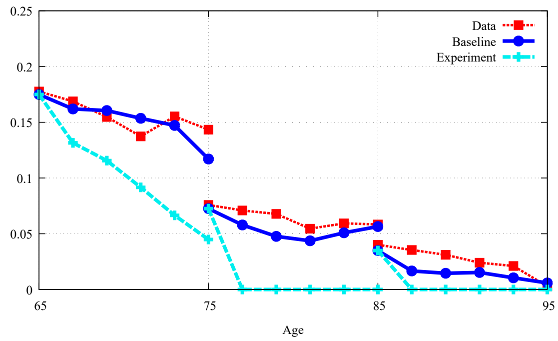
Medical expense risk accounts for 6.5% of median net worth of the youngest cohort, 10% of the middle cohort, and 4% of the oldest cohort in a model with no bequest motives or housing (panels 1 and 6). In a model with bequest motives (and no housing), the contribution of medical expense risk is only 1.7% for the youngest cohort, and goes up to 7% for the oldest cohort (panel 5). That is, with bequest motives present, medical expense risk plays a relatively larger role for the oldest old than it does for the youngest retirees. In a model with housing and no bequest motives, i.e. if medical expense are removed before housing but after bequests, medical expense risk contributes between 3 and 8% of median net worth (panel 2); instead, in the model with both housing and bequests, the contribution of medical expense risk is moderate at 4% and 9% for the youngest cohorts, but rises to 26% for age-95 retirees (panels 3 and 4). Again, the interactions of medical expense risks with the other channels differs depending on age.

In the stripped-down model, the only source of saving is precautionary motive against longevity risk. In this model, the median age-75 household would have 49% less net worth, or 51% of the empirical and benchmark-model net worth (panel 7). At age 85, net worth reduces by 57% relative to the benchmark, and by age 95, the median net worth reduces by 65%. These numbers quantify the cumulative contribution to the retirement saving puzzle of housing-related channels, bequest motives, and medical expense risk.

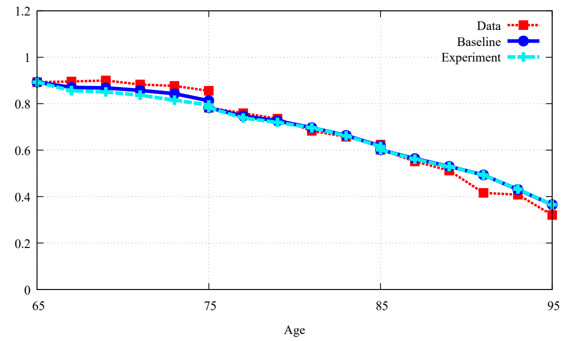
Appendix D Parameter Sensitivity Experiments

D.1 Role of Housing and Parameter Identification

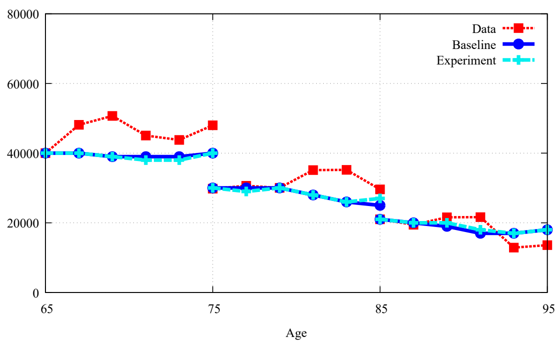
In this section, we show a series of graphs (figures A6 - A12) for each sensitivity experiment, associated with one of the two values of the parameter tested, as specified in the caption. Panel (a) of each graph shows the dimension that is improved with the choice of the given parameter perturbation, while the remaining panels show some of the dimensions that deteriorate as a result of the perturbation. Table A2 gives the quantitative role of housing for each of the experiments, showing its robustness to parameter perturbation.



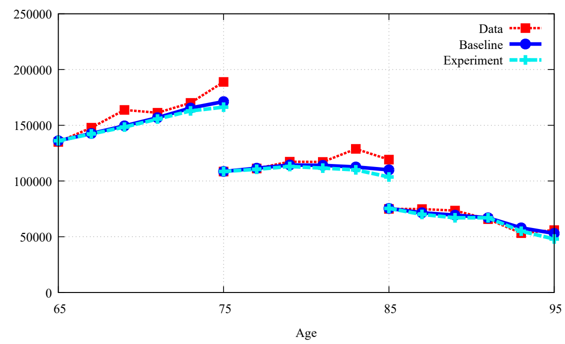
(a) Debt Rate



(b) Homeownership Rate

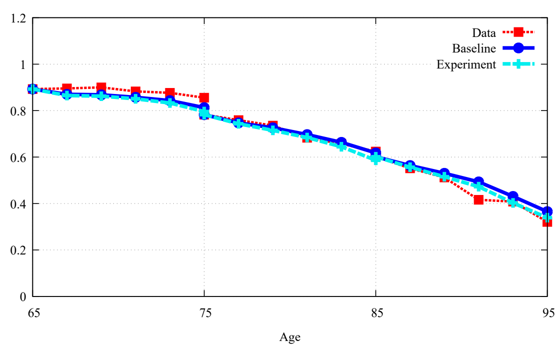


(c) Financial Assets

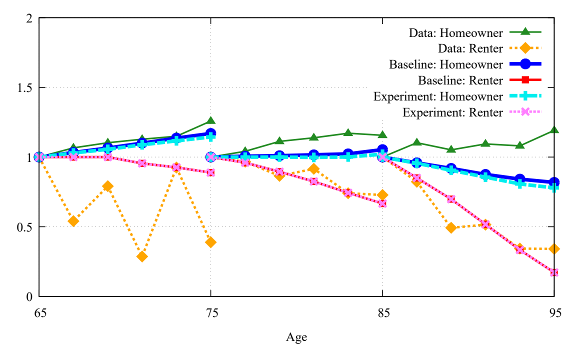


(d) Median Net Worh

Figure A6: Sensitivity Experiment – λ_i increase by 10 percentage points, cap of 1

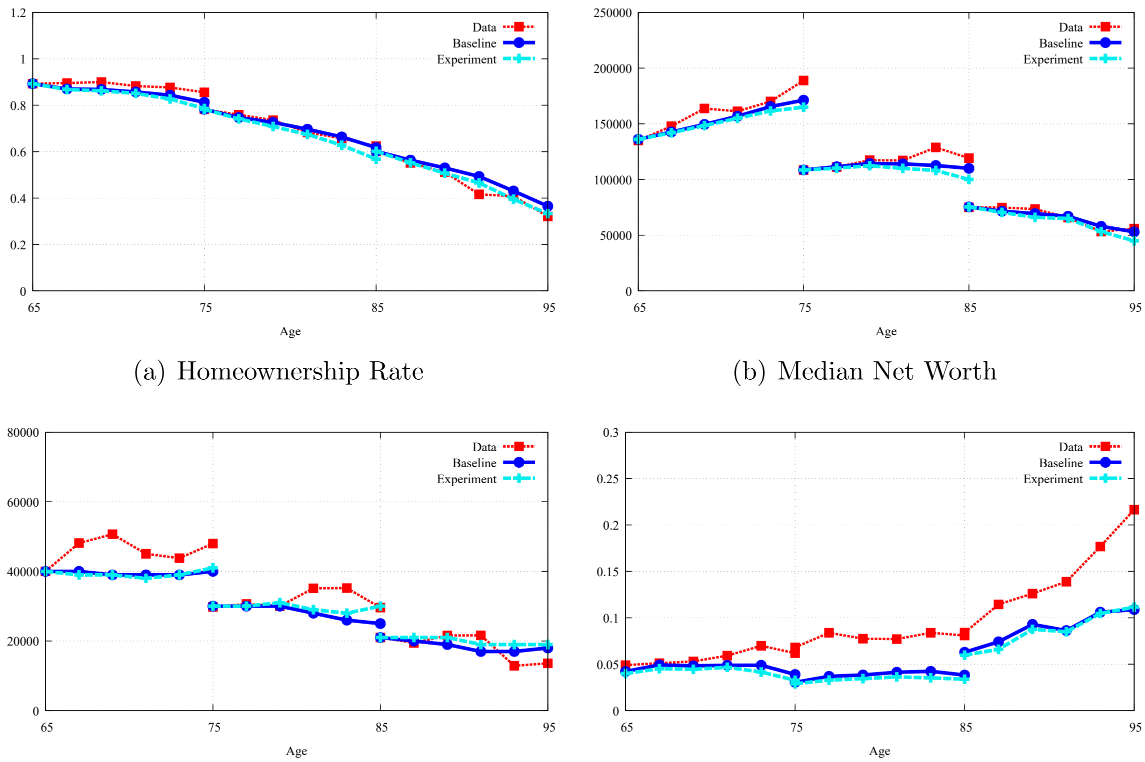


(a) Homeownership Rate



(b) Median Assets: Owners vs. Renters

Figure A7: Sensitivity Experiment – $\omega_1 = 1.5$



(a) Homeownership Rate

(b) Median Net Worth

(c) Median Financial Assets

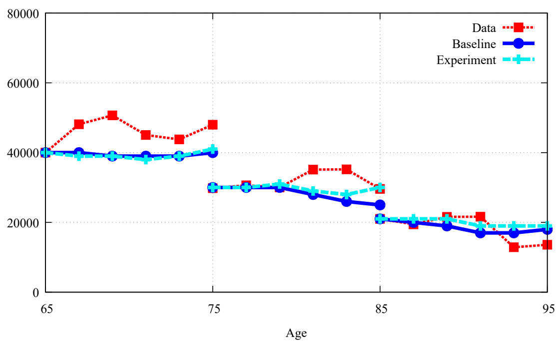
(d) Medicaid Claim Rates

Figure A8: Sensitivity Experiment $-\ \eta = 0.87$

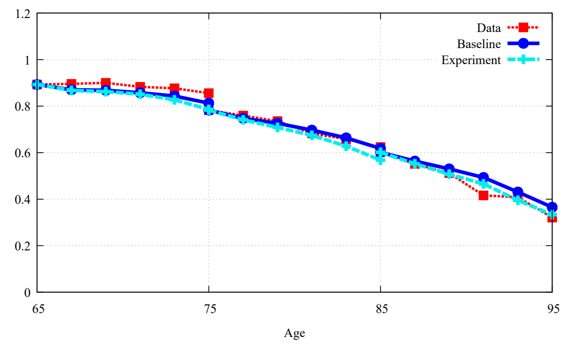
D.2 Bequest and Precautionary Motives

As described in the text, we run two experiments: in both, we raise σ to 3.8, which is the point estimate in De Nardi et al. (2010), then re-estimate first γ and then β to minimize the sum of squared residuals (SSR). As figures A13 and A14 show, model performance deteriorates along key target dimensions in similar ways.

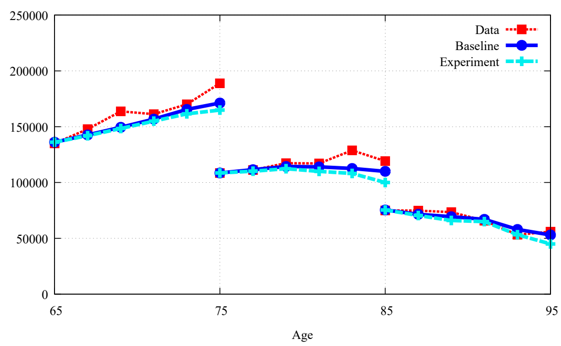
Table A3 gives the quantitative decomposition of each of the salient model channels. We observe similar interactions to what we saw in the previous experiments. Notably, in spite of the changing relative roles of medical expenses and bequest motives, the role of housing overall remains robust, and the role of individual housing channels (not shown) is equally robust.



(a) Median Financial Assets

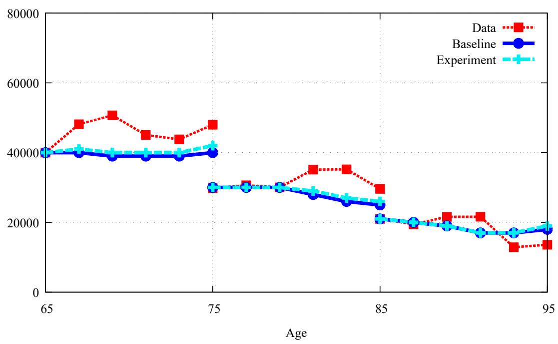


(b) Homeownership Rate

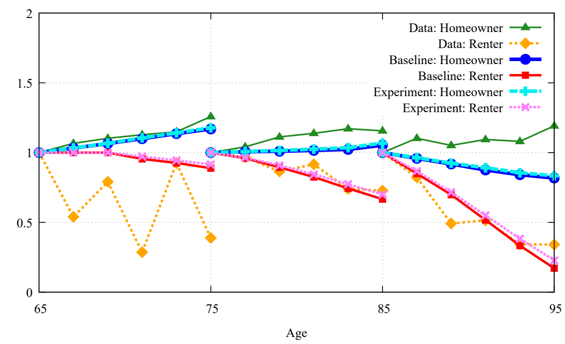


(c) Median Net Worth

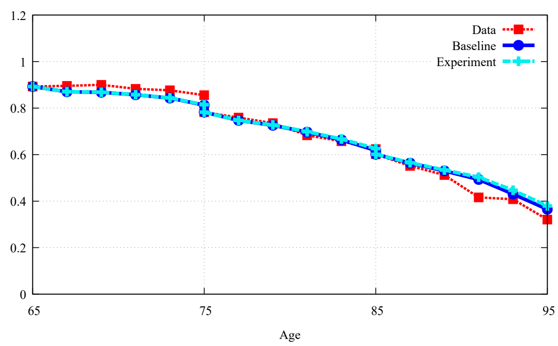
Figure A9: Sensitivity Experiment – $\gamma = 8.11$



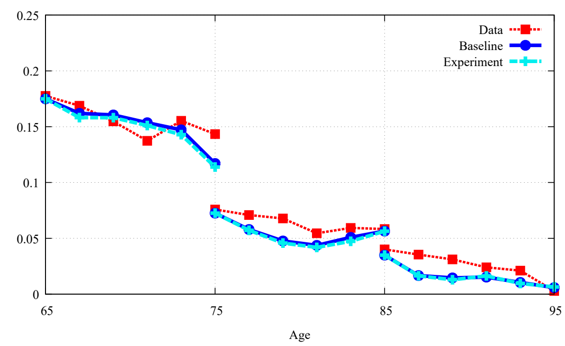
(a) Median Financial Assets



(b) Median Assets: Owners vs. Renters

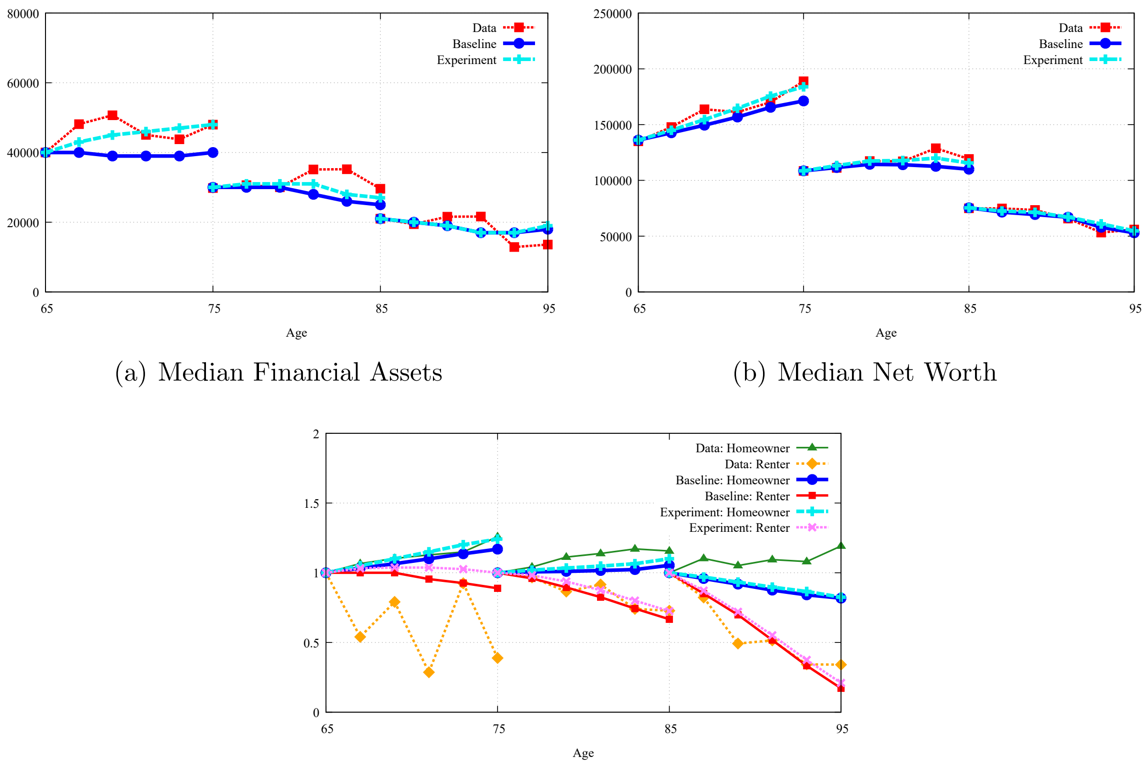


(c) Homeownership Rate



(d) Debt Rate

Figure A10: Sensitivity Experiment – $\zeta = 49,450$

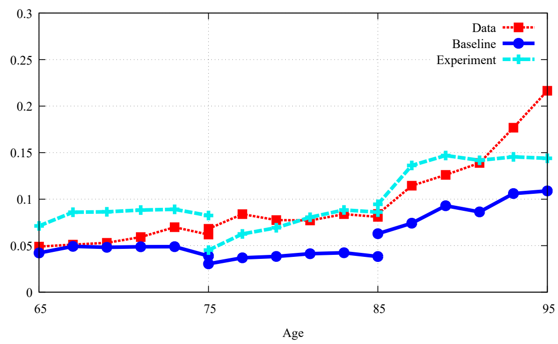


(a) Median Financial Assets

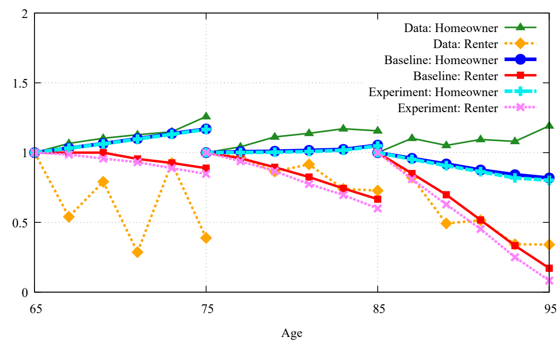
(b) Median Net Worth

(c) Median Assets: Owners vs. Renters

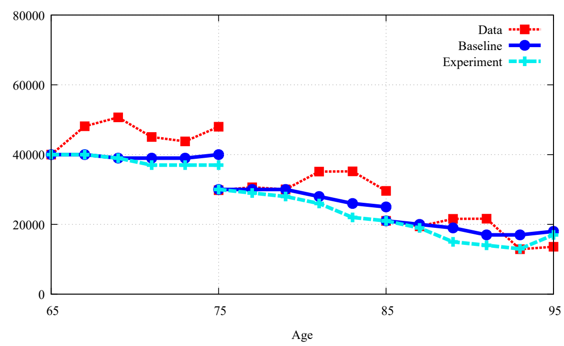
Figure A11: Sensitivity Experiment – $\beta = 0.99$



(a) Medicaid Claim Rates

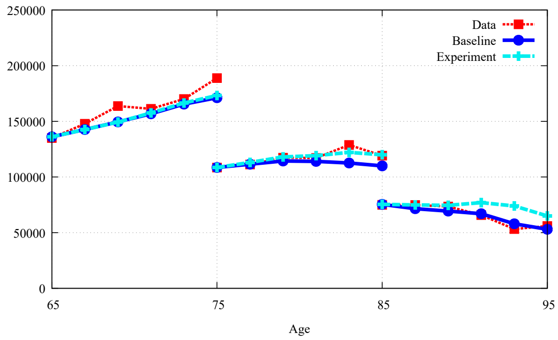


(b) Median Assets: Owners vs. Renters

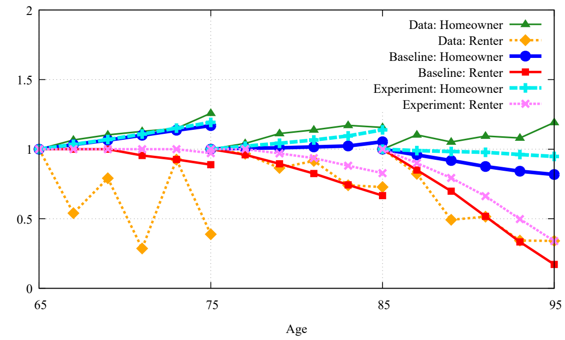


(c) Median Financial Assets

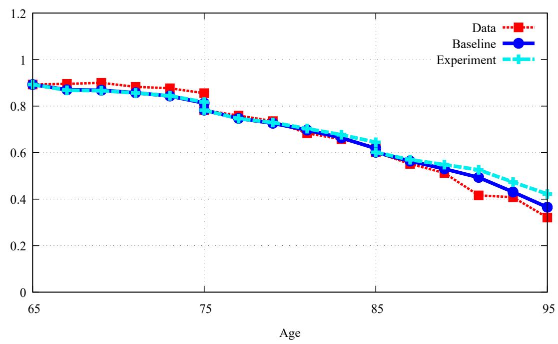
Figure A12: Sensitivity Experiment – $\underline{c} = 10,560$



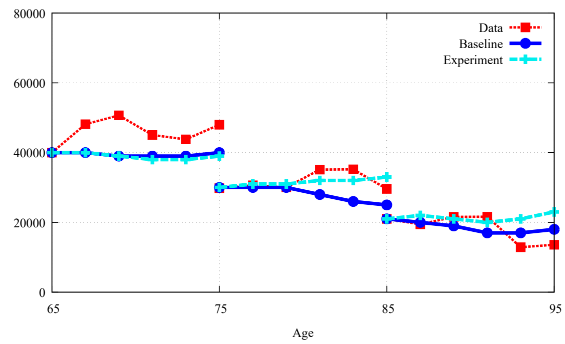
(a) Median Total Assets



(b) Median Assets: Owners vs. Renters

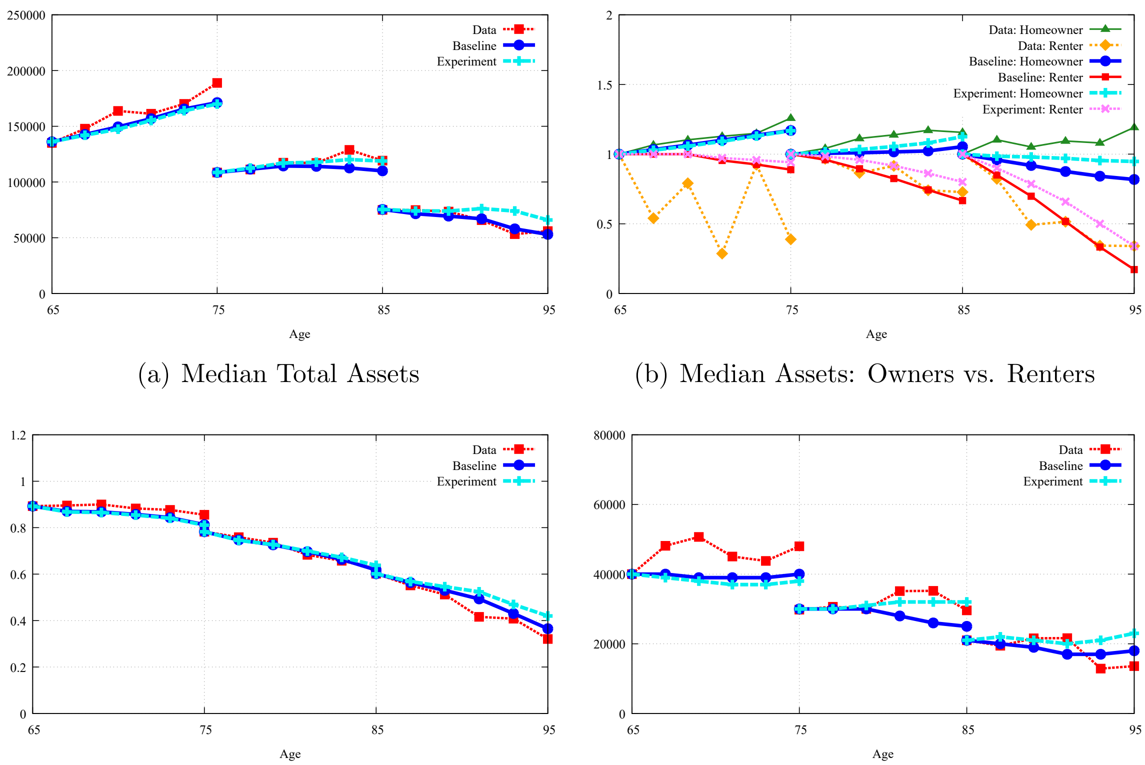


(c) Homeownership Rate



(d) Median Financial Assets

Figure A13: Sensitivity Experiment – $\sigma = 3.8$, γ reestimated to minimize SSR ($\gamma = 0$)



(a) Median Total Assets

(b) Median Assets: Owners vs. Renters

(c) Homeownership Rate

(d) Median Financial Assets

Figure A14: Sensitivity Experiment – $\sigma = 3.8$, β **reestimated minimize SSR** ($\beta = 0.942$)

Table A2: Percent Contribution of Housing to Median Net Worth – Sensitivity Experiments

Parameter	Baseline value	Experiment range	Age 75 (cohort 1)	Age 85 (cohort 2)	Age 95 (cohort 3)
λ_i	0.64-1.00[1]	0.54-0.74[1]	27.2-27.7	34.9-35.4	42.8-43.9
ω	2.508	1.50-3.50	26.1-29.4	31.6-37.1	38.1-45.7
η	0.8340	0.80-0.87	26.4-29.9	29.1-38.4	37.8-45.2
γ	6.756	5.40-8.11	28.0-28.7	34.4-35.9	41.8-43.2
ζ	61,812	49,450-74,174	27.1-29.0	34.1-36.0	38.4-43.8
β	0.9606	0.93-0.99	26.6-30.3	34.3-35.4	40.2-42.6
$\underline{c}$	8,800	7,040-10,560	27.5-30.2	34.6-39.1	41.1-50.0

In experiments, λ_i is shifted up or down by 10 percentage points for each age group, with the upper bound of 1.0 imposed. Corresponding graph shows the case of increasing λ_i.

Table A3: Contribution of Each Channel to Median Net Worth – Sensitivity Experiment with $\sigma = 3.81$

Model	Age 75 (cohort 1)	Age 85 (cohort 2)	Age 95 (cohort 3)
$\boldsymbol{\sigma = 3.81}$ **and** $\boldsymbol{\gamma = 0}$			
Simple life-cycle model with longevity risk[1]	44.0	50.8	54.1
Bequest motive	0.0	0.0	0.0
Total housing	34.1	35.3	44.0
Medical expenditure risk[1]	9.2	17.8	36.9
$\boldsymbol{\sigma = 3.81}$ **and** $\boldsymbol{\beta = 0.942}$			
Simple life-cycle model with longevity risk[1]	46.7	52.9	57.7
Bequest motive	2.2	0.8	0.5
Total housing	32.3	35.2	44.1
Medical expenditure risk[1]	7.5	17.0	39.4

[1] When medical expense risk is shut off, medical expense is fixed for a given age and income level, removing its dependence on health status and household size.