Portfolio Choice in Retirement: Health Risk and the Demand for Annuities, Housing, and Risky Assets*

Motohiro Yogo†

Abstract

This paper develops a consumption and portfolio-choice model of a retiree who allocates wealth among four assets: a riskless bond, a risky asset, a real annuity, and housing. Unlike previous studies that treat health expenditures as exogenous negative income shocks, this paper builds on the Grossman model to endogenize health expenditures as investments in health. I calibrate the model to explain the joint evolution of health status and the composition of wealth for retirees, aged 65 to 96, in the Health and Retirement Study. I use the calibrated model to assess the welfare gains of an actuarially fair annuity market. The welfare gain is less than 1% of wealth for the median-health retiree at age 65, and the welfare gain is about 10% of wealth for the healthiest.

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†Finance Department, The Wharton School, University of Pennsylvania, 3620 Locust Walk, Philadelphia, PA 19104 and National Bureau of Economic Research. E-mail: yogo@wharton.upenn.edu.

1 Introduction

As Baby Boomers approach retirement, the merit of retirement financial products, in particular annuities, has been a hot topic of debate in industry and public policy. Yet, little is understood about the asset allocation of retirees. In a world with uncertainty only over the time of death, a retiree should fully annuitize wealth (Yaari 1965). In reality, retirees own more complicated portfolios allocated across four major asset classes: bonds (including cash), risky assets (including private businesses and stocks), annuities (mostly in the form of defined benefit pension plans and Social Security), and housing.

The primary risk that retirees face is health. On the one hand, adverse health shocks require health expenditures to restore health. On the other hand, good health leads to longevity risk, that is, the risk of outliving one's financial wealth. In addition to health risk, a bequest motive may play a role in portfolio choice. Although there is a large literature studying the effects of labor-income risk on portfolio choice for workers, there has been relatively little work on the effects of health risk on portfolio choice for retirees.

This paper develops a consumption and portfolio-choice model to explain the joint evolution of health status and the composition of wealth in retirement. Following the seminal work of Grossman (1972), I model health as a durable consumption good and health expenditures as investments in health. Health insurance is taken into account through the price of health expenditure in relation to consumption. Essentially, I extend the Grossman model to allow for portfolio choice between a riskless bond, a risky asset, a real annuity, and housing. Using data on general health status and asset holdings in the Health and Retirement Study (HRS), I calibrate the model to a population of retired unmarried females, aged 65 to 96. The model explains the cross-sectional distribution of health status together with asset allocation as a function of age and health status.

Previous work has shown that unforseen health expenditures can crowd out the demand for annuities and explain precautionary saving in liquid assets.[1] However, this finding is based

[1] See Hubbard, Skinner, and Zeldes (1994), Palumbo (1999), De Nardi, French, and Jones (2006), and

on a model in which health expenditures are exogenous negative income shocks. When health expenditures are endogenized as investments in health, the precautionary motive to save in liquid assets essentially disappears. This is because the retiree can invest directly in health by accumulating health capital, rather than indirectly by accumulating liquid assets. As a consequence, the bequest motive becomes a relatively important ingredient in explaining the significant holdings of liquid assets that is observed in the data.

Are retirees currently under-annuitized? What would be the demand for annuities in a world with an actuarially fair annuity market? These questions cannot be answered by a model in which health expenditures are exogenous because an alternative market structure can change the endogenous accumulation of health. I use the calibrated Grossman model to assess the welfare gains of an actuarially fair annuity market. I find that the welfare gain is less than 1% of wealth for the median-health retiree at age 65, and the welfare gain is about 10% of wealth for the healthiest. Because the welfare gain is small except for the healthiest retirees, the lack of demand for private annuities is less of a puzzle.

The remainder of the paper proceeds as follows. Section 2 develops a model of consumption and portfolio-choice in retirement. Section 3 describes the relevant measures of health status, health expenditures, and asset holdings in the HRS. Section 4 calibrates and solves the model. Section 5 presents welfare analysis of an actuarially fair annuity market. Section 6 concludes.

Ameriks, Caplin, Laufer, and Van Nieuwerburgh (2007) for an analysis of precautionary saving in bonds due to health expenditure shocks. The analysis has been extended to include portfolio choice between bonds and risky assets (Edwards 2005) as well as bonds and annuities (Turra and Mitchell 2004).

2 A Model of Consumption and Portfolio-Choice in Retirement

2.1 Housing

Although housing is the most important tangible asset for retirees, it has been ignored in previous analysis of portfolio choice in retirement. Cocco (2005), Hu (2005), and Yao and Zhang (2005) develop life-cycle models that incorporate housing in portfolio choice, but they focus on labor-income risk and abstract from health risk that is the main concern for retirees.

Let D_t denote the housing stock at the beginning of period t. The stock D_t incorporates both the size and the quality of the house. In each period t, the house depreciates at a constant rate $\delta \in (0, 1]$. The retiree makes a net investment E_t in the house, which can be negative in the case of disinvestment. The accumulation equation for housing is

$$D_t = (1 - \delta)D_{t-1} + E_t, \tag{1}$$

given an initial stock D_0.

2.2 Health

Following Grossman (1972) and Picone, Uribe, and Wilson (1998), the retiree's health is modeled as a durable consumption good. Let H_t denote the health stock at the beginning of period t. In each period t, health depreciates at a stochastic rate $\omega_t \leq 1$. The retiree dies if $\omega_t = 1$, that is, if her health depreciates entirely. The retiree's maximum possible lifetime is T so that $\omega_{T+1} = 1$ with certainty.

After the health shock is realized in period t, the retiree makes an investment I_t in health if she is still alive.[2] Let $1\{\omega_t < 1\}$ be an indicator function that takes the value one if the

[2] A natural constraint to impose on health is a disinvestment constraint, $I_t \geq 0$. However, this constraint does not bind in practice because health depreciates at a sufficiently high rate for individuals in retirement age. I therefore ignore the constraint, avoiding previous health stock as an additional state variable in the

retiree survives period t, and let $1\{\omega_t = 1\} = 1 - 1\{\omega_t < 1\}$. The accumulation equation for health is

$$H_t = (1 - \omega_t) H_{t-1} + 1\{\omega_t < 1\} I_t, \tag{2}$$

given an initial stock H_0.

2.3 Consumption and Portfolio-Choice Problem

2.3.1 Budget Constraint

The retiree enters each period t with financial wealth W_t. The retiree uses wealth for consumption C_t, housing investment E_t at the relative price P_t, and health investment I_t at the relative price Q_t. The retiree saves the remaining wealth in N financial assets. For each asset i, let A_{it} denote the retiree's savings at the end of period t. Let $R_{i,t+1}$ denote its gross rate of return from period t to $t + 1$. The intraperiod budget constraint is

$$\sum_{i=1}^{N} A_{it} = W_t - C_t - P_t E_t - Q_t I_t. \tag{3}$$

The intertemporal budget constraint is

$$W_{t+1} = \sum_{i=1}^{N} A_{it} R_{i,t+1}, \tag{4}$$

given initial wealth W_1.

2.3.2 Intraperiod Utility

In each period that the retiree is alive, her utility flow is given by

$$U(C, D, H) = [(1 - \alpha)(C^{1-\phi} D^{\phi})^{1-1/\rho} + \alpha H^{1-1/\rho}]^{1/(1-1/\rho)}, \tag{5}$$

solution.

where $\phi \in (0,1)$ and $\alpha \in (0,1)$. The parameter $\rho \in (0,1]$ is the elasticity of substitution between consumption and health. The restriction $\rho \leq 1$ assures that the marginal utility of health becomes unbounded as the health stock approaches zero, so that the retiree never desires intentional death.

2.3.3 Utility Maximization Problem

If the retiree survives period t, she experiences a utility flow $U(C_t, D_t, H_t)$. If she dies in period t, she leaves behind *tangible wealth*,

$$\overline{W}_t = W_t + (1-\delta)P_t D_{t-1}, \tag{6}$$

which is the sum of financial and housing wealth. The retiree has joy-of-giving bequest utility over tangible wealth. Abel and Warshawsky (1988) show that a joy-of-giving bequest motive can be interpreted as a reduced form for an altruistic bequest motive.

The retiree maximizes the objective function

$$\mathbf{E}_1 \left[\sum_{t=1}^{T+1} \beta^{t-1} \prod_{s=2}^{t-1} 1\{\omega_s < 1\} \left(1\{\omega_t < 1\} \frac{U(C_t, D_t, H_t)^{1-\gamma}}{1-\gamma} + 1\{\omega_t = 1\} \frac{(\overline{u}\overline{W}_t)^{1-\gamma}}{1-\gamma} \right) \right]. \tag{7}$$

The parameter $\beta \in (0,1)$ is the subjective discount factor, and $\gamma > 1$ is the relative risk aversion. The parameter $\overline{u} > 0$ controls the strength of the bequest motive, which disappears as $\overline{u} \to \infty$.

2.4 Transforming the Problem in Terms of Total Wealth

As stated above, financial wealth, housing stock, and health stock are all state variables of the consumption and portfolio-choice problem. The problem can be simplified significantly by collapsing the three state variables into one state variable called *total wealth*. The retiree's total wealth at the beginning of period t is

$$\widetilde{W}_t = W_t + (1-\delta)P_t D_{t-1} + (1-\omega_t)Q_t H_{t-1}. \tag{8}$$

In words, total wealth is the sum of financial wealth, housing wealth, and health capital. In the period in which she dies, the retiree's total wealth is equal to tangible wealth, that is, $\widetilde{W}_t = \overline{W}_t$.

Define savings in housing and health in period t as

$$A_{Dt} = P_t D_t, \tag{9}$$

$$A_{Ht} = Q_t H_t. \tag{10}$$

Then the intraperiod budget constraint (3) can be rewritten as

$$\sum_{i=1}^{N} A_{it} + A_{Dt} + A_{Ht} = \widetilde{W}_t - C_t. \tag{11}$$

Define the gross rates of return on housing and health from period t to $t+1$ as

$$R_{D,t+1} = (1-\delta)\frac{P_{t+1}}{P_t}, \tag{12}$$

$$R_{H,t+1} = (1-\omega_{t+1})\frac{Q_{t+1}}{Q_t}. \tag{13}$$

Then the intertemporal budget constraint (4) can be rewritten as

$$\widetilde{W}_{t+1} = \sum_{i=1}^{N} A_{it} R_{i,t+1} + A_{Dt} R_{D,t+1} + A_{Ht} R_{H,t+1}. \tag{14}$$

Let $A_t = \{A_{1t}, \ldots, A_{Nt}, A_{Dt}, A_{Ht}\}$ be the set of savings in all assets, including housing and health. The utility flow (5) in period t can be rewritten as

$$U_t(C_t, A_{Dt}, A_{Ht}) = C_t \left[(1-\alpha)\left(\frac{A_{Dt}}{P_t C_t}\right)^{\phi(1-1/\rho)} + \alpha\left(\frac{A_{Ht}}{Q_t C_t}\right)^{1-1/\rho}\right]^{1/(1-1/\rho)}. \tag{15}$$

The Bellman equation is

$$\begin{aligned} J_t(\widetilde{W}_t) &= \max_{C_t, A_t} \frac{U_t(C_t, A_{Dt}, A_{Ht})^{1-\gamma}}{1-\gamma} \\ &\quad +\beta \mathbf{E}_t \left[1\{\omega_{t+1} < 1\} J_{t+1}(\widetilde{W}_{t+1}) + 1\{\omega_t = 1\} \frac{(\overline{u}\widetilde{W}_{t+1})^{1-\gamma}}{1-\gamma}\right]. \end{aligned} \tag{16}$$

2.5 Financial Assets

To complete the model, I specify the retiree's trading universe and portfolio constraints. The trading universe consists of three financial assets, which capture the key economic features of actual assets held by retirees.

2.5.1 Riskless Bond

The first asset is a bond, which has a constant gross rate of return $R_{1t} = \overline{R}_1$. For the period 1971 to 2006, the average real return (in excess of the CPI inflation rate) on the one-year Treasury bond was 2.6%. Based on this estimate, I set $\overline{R}_2 = 1.026$.

The retiree can short the bond up to a fraction $\lambda \in [0, 1)$ of the value of the house. A short position on the bond can be interpreted as a mortgage or a home equity line of credit. Therefore, the portfolio constraint for savings in the bond is

$$A_{1t} \in [-\lambda P_t D_t, W_t - C_t - P_t E_t - Q_t I_t]. \tag{17}$$

I calibrate the borrowing limit to be 20% of the value of the house. This value is consistent with the evidence that retirees are less able to tap into their home equity than younger workers (Sinai and Souleles 2007).

2.5.2 Risky Asset

The second asset is a risky asset, which has a stochastic gross rate of return

$$R_{2t} = \overline{R}_2 \nu_{2t}, \tag{18}$$

where $\log \nu_{2t} \sim \mathbf{N}(-\sigma_2^2/2, \sigma_2^2)$ is independently and identically distributed (i.i.d.). For the period 1971 to 2006, the real return (in excess of the CPI inflation rate) on the Center for Research in Securities Prices value-weighted index had a mean of 7.9% and a standard deviation of 17.2%. Based on these estimates, I set $\overline{R}_2 = 1.056$ and $\sigma_2 = 0.172$. In the life-cycle consumption and portfolio-choice literature, models are commonly calibrated with an equity premium that is lower than the historical average excess stock returns (e.g., Cocco, Gomes, and Maenhout (2005)). This practice is justified through stock-market participation costs, whether they are actual or psychological costs.

The retiree may not take a short or a leveraged position in the risky asset. Therefore, the portfolio constraint for savings in the risky asset is

$$A_{2t} \in [0, W_t - C_t - P_t E_t - Q_t I_t]. \tag{19}$$

2.5.3 Real Annuity

The third asset is a real annuity, which has a gross rate of return that is contingent on survival,

$$R_{3t} = \begin{cases} \overline{R}_3/p_t & \text{if } \omega_t < 1 \\ 0 & \text{if } \omega_t = 1 \end{cases}. \tag{20}$$

In this specification, p_t is an actuarially fair survival probability in period t, which is a deterministic function of gender, birth cohort, and age. If a unit of the annuity is defined as a claim that pays off one unit of consumption in every period until death, its actuarially fair price in period t is

$$P_{3t} = \sum_{s=1}^{T-t} \frac{\prod_{u=1}^{s} p_{t+u}}{\overline{R}_3^s}. \tag{21}$$

I use equation (20) to calibrate the return on the annuity, using $\overline{R}_3 = 1.026$ to match the real return on the one-year Treasury bond. The survival probabilities are those for a female born in the 1940 cohort, which are reported by the Social Security Administration (Bell and Miller 2005, Table 7). Similarly, I use equation (21) to calibrate the price of the annuity, setting T to age 96.

Almost all individuals enter retirement with implicit holdings in annuities, either through a defined benefit pension plan or Social Security, and subsequently do not increase their holdings of annuities. I model this situation as follows. Let B_{3t} be the holdings in the annuity at the end of period t, so that savings in the annuity is $A_{3t} = P_{3t}B_{3t}$. The individual enters retirement with an endowment B_0 of the annuity. For all periods $t \geq 1$, the portfolio constraint for the annuity is $B_{3t} = B_{3,t-1}$. In Section 5, I relax this constraint and allow the retiree to purchase additional units through an actuarially fair annuity market, which corresponds to the constraint $B_{3t} \geq B_{3,t-1}$.

2.6 Relative Price of Housing

I model the gross rate of return on housing as

$$R_{Dt} = \overline{R}_D \nu_{Dt}, \tag{22}$$

where $\log \nu_{Dt} \sim \mathbf{N}(-\sigma_D^2/2, \sigma_D^2)$ is i.i.d. The dynamics of the relative price of housing is then determined by equation (12), normalizing the initial price level at $P_1 = 1$.

Using equation (12) and the Bureau of Economic Analysis's depreciation rate of 1.14% on residential capital, I compute the return on the Case-Shiller Composite-10 Home Price

Index. For the period 1988 to 2006, the real housing return (in excess of the CPI inflation rate) had a mean of 2.2% and a standard deviation of 7.0%. Based on these estimates, I set $\overline{R}_D = 1.022$ and $\sigma_D = 0.070$.

3 Health and Retirement Study

The HRS is a panel survey designed to study the health and wealth of the elderly in the United States. I use the RAND HRS data files, which is a version of the HRS cleaned and processed by the RAND Center for the Study of Aging. I use the first six waves of the HRS, which includes the initial HRS cohort (born 1931 to 1941), the Study of Assets and Health Dynamics Among the Oldest Old cohort (born before 1924), the Children of Depression cohort (born 1924 to 1930), and the War Baby cohort (born 1942 to 1947).

Respondents in the HRS are asked to report their health status and health expenditures every two years. The relevant measure of health for my study is the self-reported general health status, which is categoried as poor, fair, good, very good, or excellent. The RAND HRS data contain a measure of total health expenditures on hospitals, nursing homes, doctor visits, dentist visits, outpatient surgery, prescription drugs, home health care, and special facilities. It also contains a measure of out-of-pocket health expenditures, that is, the part of total health expenditures paid for by the respondent.

3.1 Sample

I focus my analysis on the sample of retired unmarried females, born 1901 to 1940 and aged 65 to 96. The focus on unmarried individuals is dictated by the fact that married individuals maximize a more complicated objective function that depends on the health and survival of the spouse. Lillard and Weiss (1997) provide an analysis of married households. The focus on females is dictated by the fact that females live longer than males, and hence, have a longer (and arguably more interesting) retirement cycle. The focus on retirees younger than

96 is dictated by the fact that there are very few survivors in the data set beyond that age.

Because respondents are interviewed every two years, I code age in groups of two years from the 65–66 to the 95–96 age group. Hence, there are a total of 16 periods in the retirement cycle, indexed as $t = 1, \ldots, 16$.

3.2 Transition Probabilities for Health Status

In order to implement the model, I must estimate the transition dynamics of health implied by the accumulation equation (2). I use data on self-reported general health status and an ordered probit model to estimate the transition dynamics. In each period t, the respondent reports her health status H_t^*. The health status depends on a latent variable, H_t, through

$$H_t^* = \begin{cases} 0 \text{ Deceased} & \text{if } \quad H_t < H_P \\ 1 \text{ Poor} & \text{if } H_P \leq H_t < H_F \\ 2 \text{ Fair} & \text{if } H_F \leq H_t < H_G \\ 3 \text{ Good} & \text{if } H_G \leq H_t < H_{VG} \\ 4 \text{ Very Good} & \text{if } H_{VG} \leq H_t < H_E \\ 5 \text{ Excellent} & \text{if } H_E \leq H_t \end{cases}. \tag{23}$$

I model $\log H_t$ as a function of cohort dummies, health status at $t-1$, age, and the interaction of health status at $t-1$ with age. I also control for log total health expenditure at t, where expenditures below \$1,000 are truncated at \$1,000.

Table 1 reports the estimated model. As is expected, health status at t is positively related to health status at $t-1$. In other words, retirees in poor health on average remain in poor health. The coefficient on age is negative, which implies that health status declines in age. The coefficient on total health expenditures is positive, which implies that health expenditures are indeed investments that improve health status.

Using the estimated ordered probit model, I compute the transition probabilities for health status, $\Pr(H_t^*|H_{t-1}^*)$, in the absence of health expenditures. The predicted probabilities are those for the 1931–1940 cohort with health expenditures below $1,000. Figure 1 plots the transition probabilities by age for each category of health status. Mortality is related to health status in the expected way. Conditional on being in poor health, death is the most likely outcome in the subsequent period. Conditional on being in excellent health, death is the least likely outcome in the subsequent period.

3.3 Relative Price of Health Expenditure

For each respondent, I compute the out-of-pocket health expenditure share as a ratio of out-of-pocket health expenditures to total health expenditures. I use a censored regression model to estimate the out-of-pocket health expenditure share as a function of cohort dummies, health status, age, and the interaction of health status with age.

Table 2 reports the estimated model. The out-of-pocket health expenditure share is essentially constant in age for respondents in good health. The out-of-pocket health expenditure share rises in health status. This relation suggests that medical procedures that keep the unhealthy alive are more subsidized by insurance than those that marginally improve the health of the already healthy.

I model health insurance through the price of health expenditure in relation to consumption. Let $\widehat{Q}_t(H_t^*) \in [0, 1]$ denote the predicted health expenditure share for the 1931–1940 cohort as a function of age and health status. I model the relative price of health expenditure as

$$Q_t = Q_1 e^{qt} \widehat{Q}_t(H_t^*), \tag{24}$$

normalizing the initial price level at $Q_1 = 1$. For the period 1971 to 2006, the average log growth rate of the CPI for medical care relative to that for all items less medical care was 1.9%. Based on this estimate, I set $q = 0.019$.

3.4 Asset Allocation in Retirement

Respondents in the HRS report holdings of four major asset classes. The first asset class is "bonds", which consists of checking, savings, and money market accounts; CD, government savings bonds, and T-bills; bonds and bond funds; and the safe part of IRA and Keogh accounts. From the value of bonds, I subtract the value of liabilities, which consists of all mortgages for primary residence; all mortgages for secondary residence; other home loans for primary residence; and other debt.

The second asset class is "risky assets", which consists of businesses; stocks, mutual funds, and investment trusts; and the risky part of IRA and Keogh accounts. Following Hurd (2002), I assume that half of the value of IRA and Keogh accounts is safe, and the other half is risky.

The third asset class is "annuities", which consists of employer pension or annuity; Social Security disability and supplemental security income; and Social Security retirement. Following Gustman, Mitchell, Samwick, and Steinmeier (1997), I use data on pension and Social Security income to impute its asset value in each respondent's portfolio. The asset value of annuities is defined simply as the total pension and Social Security income times the price of a real annuity (21). This imputation abstracts from the fact that not all pension income is indexed to the CPI.

The fourth asset class is "housing", which consists of primary residence and secondary residence.

I use a censored regression model to estimate the portfolio share in each of the four assets as a function of cohort dummies, health status, age, and the interaction of health status with age. Table 3 reports the estimated models. Older retirees have a higher share of their portfolio in bonds, a higher share in risky assets, a lower share in annuities, and a higher share in housing. Healthier retirees have a higher share of their portfolio in bonds, a higher share in risky assets, a lower share in annuities, and a higher share in housing.[3]

[3] Coile and Milligan (2006) and Hurd (2002) also document asset allocation in the HRS, but they ignore

For ease of comparison to the model in later analysis, Figure 2 plots the portfolio shares in each of the four assets as a function of age and health status. The predicted portfolio shares are those for the 1931–1940 cohort. Retirees allocate a significant share of their wealth to bonds and stocks, even late in the retirement cycle. This fact has been attributed to both a bequest motive and a precautionary saving motive in response to health shocks.

Housing remains a significant share of the portfolio, even late in the retirement cycle. Venti and Wise (1989, 2004) find that retirees are unlikely to discontinue home ownership, and on average, increase their home equity when they move. Based on this evidence, Venti and Wise conclude that the large home equity in the retirement portfolio is not a consequence of transactions costs that prevent retirees from downsizing their homes.

4 Benchmark Calibration of the Model

4.1 Calibration of Preferences

Table 4 summarizes the key parameters in the benchmark calibration. Following a standard practice in the life-cycle consumption and portfolio-choice literature, I set the subjective discount factor to $\beta = 0.96$. Because of the large premium on risky assets, the relative risk aversion must be fairly large in order to match the asset allocation between bonds and risky assets. I therefore set $\gamma = 7$. These choices are consistent with the structural estimates in De Nardi, French, and Jones (2006).

If $\rho < 1/\gamma$, consumption and health are complements in the sense that the marginal utility of consumption rises in the health stock. If $\rho > 1/\gamma$, consumption and health are substitutes. Introspection suggests that consumption and health must be complements at an extremely low level of health stock that approaches death. Viscusi and Evans (1990) analyze a survey of chemical workers and find that consumption and health are complements. Based

the asset value of annuities in their analysis. Rosen and Wu (2004) document evidence that the portfolio share in risky assets is positively related to health.

on this evidence, I set the elasticity of substitution to $\rho = 0.1$. As discussed below, I calibrate the remaining preference parameters to match certain empirical moments describing health accumulation and asset allocation.

I discretize the health stock as a grid over five values, corresponding to the five categories of health status. I normalize the initial distribution of health at age 65–66 so that $\log H_1 \sim \mathbf{N}(0, 1)$. By inverting the lognormal distribution function, I obtain the health stock for each category of health status, which are reported in Table 4.

4.2 Consumption and Portfolio Policy

I solve the model through numerical dynamic programming as described in Appendix A. In each period t, the state variables of the consumption and portfolio-choice problem are total wealth $\widetilde{W}_t$, initial annuity holdings B_0, and the relative price of housing P_t. For the purposes of solving the problem, it is convenient to replace total wealth with the health stock H_t as a state variable.

Figure 3 shows the consumption policy function, as a share of total wealth, at age 65–66. Holding initial annuity holdings constant, the retiree consumes a higher share of total wealth when she is healthier. This is explained by the fact that consumption and health are complements in the retiree's utility function.

Figure 3 also shows the portfolio policy functions, as a share of total savings, at age 65–66. The policy functions for bonds and stocks mirror that for the annuity. At high health and low initial annuity holdings, the portfolio shares in bonds and stocks are high. At low health and high initial annuity holdings, the portfolio share in the annuity is high. When the retiree cannot purchase additional units of the annuity, she holds a portfolio of bonds and stocks as an imperfect substitute to insure against longevity risk.

4.3 Distribution of Health Status

In order to calibrate the model, it is useful to first document the cross-sectional distribution of health status in the HRS. I use an ordered probit model to estimate the distribution of health status as a function of cohort dummies and age. The left panel of Figure 4 plots the cross-sectional distribution of health status at each age for the 1931–1940 cohort.

Using the optimal consumption and portfolio policies, I simulate a population of retirees as described in Appendix A. In the simulation, I set the initial distribution of health status at age 65–66 to exactly match the empirical distribution of health status. The parameter α plays a role in determining the share of health in the retiree's portfolio, and consequently, the accumulation of health over the retirement cycle. A higher value of α implies greater accumulation in health. I calibrate this parameter to match, as closely as possible, the cross-sectional distribution of health status at age 91–92. The right panel of Figure 4 plots the cross-sectional distribution of health status at each age for the simulated model.

4.4 Asset Allocation of Simulated Retirees

Figure 5 shows the asset allocation of simulated retirees as a function of age and health status. The figure compares favorably to that of actual retirees in the HRS, shown in Figure 2. With a limited set of parameters, it is impossible to match all the empirical moments describing asset allocation. I therefore focus on those at the beginning of retirement, at age 65–66, and those at the end of retirement, at age 91–92. For ease of comparison to the data, Table 5 reports the portfolio shares in each of the four tangible assets at age 65–66. Table 6 reports the same at age 91–92.

For each health status, I calibrate the initial annuity holdings B_0 to match the portfolio share in annuity at age 65–66. Upon death, the retiree leaves behind only bonds, stocks, and housing. Therefore, the bequest motive plays a key role in determining the portfolio share in annuity as the retiree approaches death. I choose the value $\overline{u} = 0.18$ to match the portfolio share in annuity for the median-health retiree at age 91–92.

The parameter ϕ plays a key role in determining the portfolio share in housing. I choose the value $\phi = 0.1$ to match the portfolio share in housing for the median-health retiree at age 91–92. In the model, housing is an attractive asset because the retiree can enjoy its utility flow while alive and also leave it as a bequest.

One potentially important feature of housing that is from missing from the model is illiquidity, that there may be transactions costs involved in selling the house.[4] Transactions costs would make liquid assets such as bonds and risky assets more attractive relative to housing. Although this extension can change the relative asset allocation between bonds, risky assets, and housing, the overall level of precautionary savings in these assets should not be affected.

4.5 What is the Role of a Bequest Motive?

In order to assess the importance of the bequest motive, I solve the model without a bequest motive, setting the parameter $\overline{u} = \infty$. I keep the other parameters of the model the same as those in the benchmark calibration. Figure 6 shows the asset allocation of simulated retirees as a function of age and health status. A comparison to Figure 5 shows that the absence of a bequest motive drastically alters the retirement portfolio. In addition to her endowment in the annuity, a healthy retiree holds mostly risky assets and housing. An unhealthy retiree holds mostly housing. Most retirees hold a small short position in bonds, representing a loan against their home equity.

This analysis suggests that the bequest motive is the primary reason that retirees hold bonds and risky assets. This finding is in contrast to earlier work that emphasized a precautionary motive driven by unforseen health expenditures (Hubbard, Skinner, and Zeldes 1994, Palumbo 1999, De Nardi, French, and Jones 2006). The conclusions of the earlier work relied on the assumption that health expenditures are exogenous and unavoidable. When health expenditures are endogenized as investments in health, the precautionary motive to

[4] See Cocco (2005), Hu (2005), and Yao and Zhang (2005) for an analysis of housing and portfolio choice with transactions costs.

save in liquid assets essentially disappears. This is because the retiree can invest directly in health by accumulating health capital, rather than indirectly by accumulating liquid assets.

5 Welfare Analysis of an Actuarially Fair Annuity Market

In the analysis so far, the retiree is constrained to hold a constant endowment of the annuity throughout retirement. I now relax this constraint and allow the retiree to purchase additional units through an actuarially fair annuity market. In terms of the model, this amounts to relaxing the portfolio constraint on the annuity to be $B_{3t} \geq B_{3,t-1}$.

Figure 7 shows the asset allocation of simulated retirees as a function of age and health status. A comparison to Figure 5 shows that the presence of an actuarially fair annuity market causes a relatively small change in the retirement portfolio. The biggest change occurs for retirees of excellent health, who substitute bonds with the annuity.

How much additional wealth does a retiree require at age 65 to achieve the same level of expected utility over retirement as in a hypothetical world with an actuarially fair annuity market? I evaluate the welfare gains of an annuity market by comparing the solution in the benchmark model with that in the model with an actuarially fair annuity market. The welfare gains, as a percentage of initial wealth in the benchmark model, is 0.87% for poor health, 0.39% for fair health, 0.02% for good health, 8.92% for very good health, and 10.19% for excellent health.

This calculation should be considered an upper bound on the welfare gains from a private annuity market. Because of adverse selection and transactions costs, the private annuity market offers a lower rate of return than an actuarially fair annuity market based on Social Security life tables and the Treasury bond rate (Warshawsky 1988, Mitchell, Poterba, Warshawsky, and Brown 1999). Because the welfare gain is small except for the healthiest retirees, the lack of demand in the private annuity market is less of a puzzle.

6 Conclusion

This paper has shown that a standard model of health accumulation is surprisingly good at capturing wealth decumulation in retirement. In a model with endogenous health accumulation, the retiree can invest directly in health through health expenditures, rather than indirectly by holding liquid assets. Consequently, a fairly strong bequest motive is necessary to explain the lack of annuitization, especially late in the retirement cycle (Friedman and Warshawsky 1990). These findings imply that previous studies, based on a model with exogenous health expenditures, overstate the importance of the precautionary motive to save in liquid assets.

I use the calibrated model to assess the welfare gains from an actuarially fair annuity market. The welfare gain is fairly small for most retirees, and even for healthiest, the welfare gain is only about 10% of wealth at age 65. Because the implicit holdings in annuities through defined benefit pension plans and Social Security are already large, the low demand for private annuities is a rational choice for the median-health retiree. In future work, I intend to use the model to explore the welfare implications of other retirement financial products, such as variable annuities and reverse mortgages.

Appendix A Solution of the Consumption and Portfolio-Choice Problem

A.1 Rescaling the Model by Total Wealth

Because the utility function is homothetic, the consumption and portfolio-choice model can be rescaled by total wealth. Define rescaled consumption as $c_t = C_t/\widetilde{W}_t$. For each asset $i = 1, \ldots, N, D, H$, define the portfolio share of total savings as $a_{it} = A_{it}/(\widetilde{W}_t - C_t)$.

The intraperiod budget constraint (11) can be rewritten as

$$\sum_{i=1}^{N} a_{it} + a_{Dt} + a_{Ht} = 1. \tag{25}$$

The intertemporal budget constraint (14) can be rewritten as

$$\widetilde{W}_{t+1} = R_{t+1}(\widetilde{W}_t - C_t), \tag{26}$$

where

$$R_{t+1} = \sum_{i=1}^{N} a_{it} R_{i,t+1} + a_{Dt} R_{D,t+1} + a_{Ht} R_{H,t+1} \tag{27}$$

is the gross rate of return on total wealth.

The portfolio constraints are

$$a_{1t} \in [-\lambda a_{Dt}, 1 - a_{Dt} - a_{Ht}], \tag{28}$$

$$a_{2t} \in [0, 1 - a_{Dt} - a_{Ht}], \tag{29}$$

$$a_{3t} \in \left[\frac{P_{3t} B_{3,t-1}}{\widetilde{W}_t(1 - c_t)}, 1 - a_{Dt} - a_{Ht}\right], \tag{30}$$

$$a_{Dt} \in \left[0, \frac{1}{1 - \lambda}\right], \tag{31}$$

$$a_{Ht} \in [0, 1]. \tag{32}$$

In the benchmark model without an actuarially fair annuity market, the lower bound on portfolio constraint (30) is binding. Portfolio constraint (28) and the intraperiod budget constraint can be combined as an inequality constraint,

$$a_{2t} + a_{3t} + (1-\lambda)a_{Dt} + a_{Ht} \leq 1.$$

Define rescaled utility as

$$u_t(c_t, a_{Dt}, a_{Ht}) = c_t V_t(c_t, a_{Dt}, a_{Ht}), \tag{33}$$

where

$$V_t(c_t, a_{Dt}, a_{Ht}) = \left[(1-\alpha)\left(\frac{a_{Dt}(c_t^{-1}-1)}{P_t}\right)^{\phi(1-1/\rho)} + \alpha\left(\frac{a_{Ht}(c_t^{-1}-1)}{Q_t}\right)^{1-1/\rho}\right]^{1/(1-1/\rho)}. \tag{34}$$

The marginal utility of consumption is

$$\begin{aligned} u_{ct}(c_t, a_{Dt}, a_{Ht}) &= V_t - \frac{V_t^{1/\rho}}{1-c_t}\left[(1-\alpha)\phi\left(\frac{a_{Dt}(c_t^{-1}-1)}{P_t}\right)^{\phi(1-1/\rho)}\right. \\ &\quad \left. +\alpha\left(\frac{a_{Ht}(c_t^{-1}-1)}{Q_t}\right)^{1-1/\rho}\right]. \end{aligned} \tag{35}$$

Let $a_t = \{a_{2t}, \ldots, a_{Nt}, a_{Dt}, a_{Ht}\}$ be the set of portfolio shares on all assets, including housing and health. The value function (16) can be rescaled as

$$\begin{aligned} j_t = \frac{J_t(\widetilde{W}_t)}{\widetilde{W}_t^{1-\gamma}} &= \max_{c_t, a_t} \frac{u_t(c_t, a_{Dt}, a_{Ht})^{1-\gamma}}{1-\gamma} \\ &\quad +\beta \mathbf{E}_t\left[R_{t+1}^{1-\gamma}(1-c_t)^{1-\gamma}\left(1\{\omega_{t+1}<1\}j_{t+1} + 1\{\omega_{t+1}=1\}\frac{\overline{u}^{1-\gamma}}{1-\gamma}\right)\right]. \end{aligned} \tag{36}$$

The derivative of the value function with respect to consumption is

$$\frac{\partial j_t}{\partial c_t} = u_t^{-\gamma}u_{ct} - \beta(1-\gamma)\mathbf{E}_t\left[R_{t+1}^{1-\gamma}(1-c_t)^{-\gamma}\left(1\{\omega_{t+1}<1\}j_{t+1} + 1\{\omega_{t+1}=1\}\frac{\overline{u}^{1-\gamma}}{1-\gamma}\right)\right]. \tag{37}$$

The derivatives of the value function with respect to the portfolio shares in financial assets are

$$\begin{aligned}\frac{\partial j_t}{\partial a_{it}} &= \beta(1-\gamma)\mathbf{E}_t[R_{t+1}^{-\gamma}(R_{i,t+1}-R_{1,t+1})(1-c_t)^{1-\gamma} \\ &\quad \times \left(1\{\omega_{t+1}<1\}j_{t+1}+1\{\omega_{t+1}=1\}\frac{\overline{u}^{1-\gamma}}{1-\gamma}\right)\right], \end{aligned} \tag{38}$$

for $i=2,\dots,N$. The derivative of the value function with respect to the portfolio share in housing is

$$\begin{aligned}\frac{\partial j_t}{\partial a_{Dt}} &= \frac{u_t^{-\gamma}(1-\alpha)\phi c_t V_t^{1/\rho}}{a_{Dt}}\left(\frac{a_{Dt}(c_t^{-1}-1)}{P_t}\right)^{\phi(1-1/\rho)} \\ &\quad +\beta(1-\gamma)\mathbf{E}_t[R_{t+1}^{-\gamma}(R_{D,t+1}-R_{1,t+1})(1-c_t)^{1-\gamma} \\ &\quad \times \left(1\{\omega_{t+1}<1\}j_{t+1}+1\{\omega_{t+1}=1\}\frac{\overline{u}^{1-\gamma}}{1-\gamma}\right)\right]. \end{aligned} \tag{39}$$

Finally, the derivative of the value function with respect to the portfolio share in health is

$$\begin{aligned}\frac{\partial j_t}{\partial a_{Ht}} &= \frac{u_t^{-\gamma}\alpha c_t V_t^{1/\rho}}{a_{Ht}}\left(\frac{a_{Ht}(c_t^{-1}-1)}{Q_t}\right)^{1-1/\rho} \\ &\quad +\beta(1-\gamma)\mathbf{E}_t[R_{t+1}^{-\gamma}(R_{H,t+1}-R_{1,t+1})(1-c_t)^{1-\gamma} \\ &\quad \times \left(1\{\omega_{t+1}<1\}j_{t+1}+1\{\omega_{t+1}=1\}\frac{\overline{u}^{1-\gamma}}{1-\gamma}\right)\right]. \end{aligned} \tag{40}$$

A.2 Solution in the Last Period with No Bequest Motive

A special case of the model is when the retiree has no bequest motive, which corresponds to the parameterization $\overline{u}=\infty$. In this case, the policy functions in the last period can be derived in closed form. This known solution serves as a useful starting point for numerically computing the solution even when the retiree has a bequest motive.

The value function in the last period T is

$$j_T = \max_{c_T, a_T} \frac{u_T(c_T, a_{DT}, a_{HT})^{1-\gamma}}{1-\gamma}. \tag{41}$$

Because it is optimal to consume all financial wealth, the optimal portfolio shares in financial assets are

$$a_{1T} = -\lambda a_{DT}, \tag{42}$$

$$a_{2T} = 0, \tag{43}$$

$$a_{3T} = (Z_T - 1)a_{HT}, \tag{44}$$

where $Z_T = 1 + P_{3T}B_{3,T-1}/(Q_T H_T)$.

The problem is now reduced to that of maximizing the value function subject to the constraint

$$(1-\lambda)a_{DT} + Z_T a_{HT} = 1. \tag{45}$$

The first-order conditions imply that

$$c_T = \frac{(1-\phi)(1-Z_T a_{HT})}{1-(1-\phi)Z_T a_{HT}}, \tag{46}$$

$$a_{DT} = \frac{1-Z_T a_{HT}}{1-\lambda}, \tag{47}$$

$$a_{HT} = \left[Z_T + \frac{\phi^{1-\phi(1-\rho)}}{(1-\phi)^{(1-\phi)(1-\rho)}} \left(\frac{(1-\alpha)Z_T}{\alpha} \right)^{\rho} \left(\frac{(1-\lambda)^{\phi} P_T^{\phi}}{Q_T} \right)^{1-\rho} \right]^{-1}. \tag{48}$$

A.3 Solution by Numerical Dynamic Programming

I discretize the state space as

$$\{H_j\}_{j=1}^{J} = \{H_P, H_F, H_G, H_{VG}, H_E\},$$

$$\{B_k\}_{k=1}^{K} = \{B_1, \ldots, B_K\},$$

$$\{P_l\}_{l=1}^{L} = \{P_1, \ldots, P_L\}.$$

Table 4 reports the grid for the health stock. The grid for annuity holdings is equally spaced on a logarithmic scale, based on $K = 20$, $B_1 = 0.1$, and $B_K = 10$. The grid for the relative price of housing is equally spaced on a logarithmic scale, based on $L = 5$, $P_1 = 1$, and $P_L = 5$. I discretize the lognormal shock to risky assets, ν_{2t}, as five points of equal probability.

Starting with the solution in period T, I solve the problem recursively for periods $t = T-1, \ldots, 1$ through the following algorithm.

1. For each point on the discretized state space, find the policy functions that maximize the value function $j_t(H_j, B_k, P_l)$.

2. Compute the total wealth corresponding to the optimal portfolio share in health through the relation

$$\widetilde{W}_t(H_j, B_k, P_l) = \frac{Q_t(H_j)H_j}{a_{Ht}(H_j, B_k, P_l)(1 - c_t(H_j, B_k, P_l))}.$$

A.4 Simulation of the Model

I simulate the retirement cycle for 100,000 retirees, starting at age 65–66. I set the initial price of housing at $P_1 = 1$ for all retirees. The initial distribution of health status is drawn from the cross-sectional distribution of health status in the HRS at age 65–66. For each category of health status, $H_1 = \{H_P, H_F, H_G, H_{VG}, H_E\}$, I compute $B_0(H_1)$ such that

$$\frac{a_{31}(H_1, B_0(H_1), P_1)}{1 - a_{H1}(H_1, B_0(H_1), P_1)}$$

matches the allocation to annuities, as a share of tangible wealth, in the HRS at age 65–66.

For periods $t = 2, \ldots, T$, I simulate the retirement cycle for each retiree, until death, through the following algorithm.

1. Simulate the shocks to risky asset returns, housing returns, and the health stock.

Compute the gross return on total wealth,

$$R_t = \sum_{i=1}^{3} a_{i,t-1} R_{it} + a_{D,t-1} R_{Dt} + a_{H,t-1} R_{Ht}.$$

2. Update the total wealth through the relation

$$\widetilde{W}_t = R_t \frac{Q_{t-1} H_{t-1}}{a_{H,t-1}}.$$

3. If there is an actuarially fair annuity market, update the annuity holdings through the relation

$$B_{t-1} = \frac{a_{3,t-1} Q_{t-1} H_{t-1}}{P_{3,t-1} a_{H,t-1}}.$$

4. Update the health stock through a closest neighbor interpolation of H_t as a function of $\widetilde{W}_t(H_t, B_{t-1}, P_t)$.

5. Compute the optimal consumption and portfolio policies at (H_t, B_{t-1}, P_t).

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Table 1: Estimation of the Transition Probabilities for Health Status

The table reports estimates of an ordered probit model for health status in the subsequent period. The latent variable depends on cohort dummies, current health status, age, and the interaction of current health status with age. The latent variable also depends on log total health expenditure in the subsequent period, where expenditures below $1,000 are truncated at $1,000. The sample consists of retired unmarried females, born 1901 to 1940 and aged 65 to 96, in the HRS.

Regressor	Coefficient	t-statistic
Cohort:		
1901–1910	-0.13	-0.92
1911–1920	0.05	0.53
1921–1930	0.09	1.48
Health Status:		
Poor	-1.43	-15.29
Fair	-0.71	-9.08
Very Good	0.83	10.06
Excellent	1.51	10.84
$(\text{Age} - 65)/10$	-0.17	-2.85
× Poor	0.18	2.54
× Fair	0.03	0.48
× Very Good	-0.16	-2.47
× Excellent	-0.15	-1.38
Medical Expenditure	0.06	5.47
Intercept:		
Poor	-1.31	-10.97
Fair	-0.73	-6.50
Good	0.09	0.79
Very Good	1.03	9.72
Excellent	2.17	19.68

Table 2: Estimation of the Out-of-Pocket Health Expenditure Share

The table reports estimates of a censored regression model for the out-of-pocket health expenditure share. The latent variable depends on cohort dummies, health status, age, and the interaction of health status with age. Health expenditures include the cost of hospitals, nursing homes, doctor visits, dentist visits, outpatient surgery, prescription drugs, home health care, and special facilities. The sample consists of retired unmarried females, born 1901 to 1940 and aged 65 to 96, in the HRS.

Regressor	Coefficient	t-statistic
Cohort:		
1901–1910	0.00	0.09
1911–1920	-0.02	-0.46
1921–1930	0.00	-0.07
Health Status:		
Poor	-0.19	-4.18
Fair	-0.06	-1.81
Very Good	0.09	2.67
Excellent	0.07	1.56
$(\text{Age} - 65)/10$	0.01	0.48
× Poor	0.04	1.36
× Fair	0.01	0.60
× Very Good	-0.04	-1.70
× Excellent	-0.07	-2.09
Intercept	0.42	17.04

Table 3: Estimation of Asset Allocation in the HRS

The table reports estimates of a censored regression model for the portfolio share in each of the four asset classes. The latent variable depends on cohort dummies, health status, age, and the interaction of health status with age. Bonds include checking, savings, and money market accounts; CD, government savings bonds, and T-bills; bonds and bond funds; and the safe part of IRA and Keogh accounts. The value of liabilities is subtracted from the value of bonds, which include all mortgages for primary residence; all mortgages for secondary residence; other home loans for primary residence; and other debt. Risky assets include businesses; stocks, mutual funds, and investment trusts; and the risky part of IRA and Keogh accounts. Housing includes primary residence and secondary residence. Annuities include employer pension or annuity; Social Security disability and supplemental security income; and Social Security retirement. The sample consists of retired unmarried females, born 1901 to 1940 and aged 65 to 96, in the HRS.

Regressor	Bonds		Risky Assets		Annuity		Housing	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Cohort:								
1901–1910	0.03	1.73	-0.15	-3.93	0.12	3.99	-0.12	-3.38
1911–1920	0.00	-0.05	-0.11	-4.07	0.09	4.70	-0.05	-2.08
1921–1930	0.00	-0.33	-0.01	-0.55	0.05	3.46	0.00	0.07
Health Status:								
Poor	-0.04	-2.45	-0.18	-4.50	0.12	4.63	-0.07	-2.21
Fair	-0.03	-2.77	-0.12	-4.57	0.09	4.48	-0.03	-1.16
Very Good	0.03	2.40	0.11	4.77	-0.10	-5.35	0.06	2.74
Excellent	0.02	1.15	0.14	4.59	-0.16	-6.24	0.14	4.47
(Age − 65)/10	0.06	6.50	0.05	3.04	-0.13	-9.77	0.04	2.50
× Poor	0.00	0.20	0.00	-0.18	0.00	0.05	0.00	0.04
× Fair	0.01	1.15	0.01	0.65	-0.01	-1.00	0.00	-0.23
× Very Good	-0.01	-0.71	-0.04	-2.30	0.04	2.69	-0.04	-2.19
× Excellent	0.00	-0.07	-0.05	-2.10	0.05	2.85	-0.05	-2.37
Intercept	0.03	3.08	-0.13	-6.81	0.69	48.84	0.14	8.08

Table 4: Parameters in the Benchmark Calibration

The table reports the key parameters in the benchmark calibration. The model is solved at a two-year frequency to match the frequency of interviews in the HRS. The parameter values are reported in annualized units. The grid for health stock is based on the normalization that the initial distribution of health at age 65–66 is $\log H_1 \sim \mathbf{N}(0, 1)$.

Parameter	Symbol	Value
Preferences:		
Discount factor	β	0.96
Relative risk aversion	γ	7
Utility weight on housing	ϕ	0.10
Utility weight on health	α	0.80
Elasticity of substitution between consumption and health	ρ	0.10
Joy-of-giving bequest motive	$\overline{u}$	0.18
Asset returns:		
Bond return	$\overline{R}_1 - 1$	2.6%
Average stock return	$\overline{R}_2 - 1$	5.6%
Standard deviation of stock return	σ_2	17.2%
Average annuity return	$\overline{R}_3 - 1$	2.6%
Housing:		
Borrowing limit	λ	20%
Depreciation rate	δ	1.14%
Average housing return	$\overline{R}_D - 1$	2.2%
Standard deviation of housing return	σ_D	7.0%
Health:		
Poor health	H_P	0.18
Fair health	H_F	0.42
Good health	H_G	0.90
Very good health	H_{VG}	1.99
Excellent health	H_E	5.06
Growth rate of the relative price of medical expenditure	q	1.9%

Table 5: Asset Allocation of Simulated Retirees at Age 65–66

The table reports the portfolio share in each of the four tangible assets for the 65–66 age group. From left to right, the columns correspond to retirees in the HRS, simulated retirees in the benchmark calibration, and simulated retirees in an economy with an actuarially fair annuity market. The portfolio shares in the HRS, based on the estimated censored regression model in Table 3, are those for the 1931–1940 cohort.

Health Status	HRS	Simulated Model	
		Benchmark	Annuity Market
Panel A: Bonds (% of Tangible Wealth)			
Poor	2	9	10
Fair	1	2	6
Good	3	6	6
Very Good	2	6	1
Excellent	1	13	-4
Panel B: Risky Assets (% of Tangible Wealth)			
Poor	3	5	4
Fair	5	8	6
Good	8	11	11
Very Good	13	16	15
Excellent	14	16	13
Panel C: Annuity (% of Tangible Wealth)			
Poor	76	76	76
Fair	74	74	74
Good	67	67	67
Very Good	58	58	64
Excellent	53	53	73
Panel D: Housing (% of Tangible Wealth)			
Poor	18	10	10
Fair	20	16	15
Good	22	17	17
Very Good	26	20	20
Excellent	32	18	18

Table 6: Asset Allocation of Simulated Retirees at Age 91–92

The table reports the portfolio share in each of the four tangible assets for the 91–92 age group. From left to right, the columns correspond to retirees in the HRS, simulated retirees in the benchmark calibration, and simulated retirees in an economy with an actuarially fair annuity market. The portfolio shares in the HRS, based on the estimated censored regression model in Table 3, are those for the 1931–1940 cohort.

Health Status	HRS	Simulated Model	
		Benchmark	Annuity Market
Panel A: Bonds (% of Tangible Wealth)			
Poor	21	23	23
Fair	21	21	22
Good	19	21	20
Very Good	22	16	14
Excellent	20	27	7
Panel B: Risky Assets (% of Tangible Wealth)			
Poor	7	8	8
Fair	10	9	9
Good	14	12	10
Very Good	15	12	9
Excellent	15	17	13
Panel C: Annuity (% of Tangible Wealth)			
Poor	48	47	48
Fair	42	47	45
Good	37	38	44
Very Good	37	45	54
Excellent	36	25	48
Panel D: Housing (% of Tangible Wealth)			
Poor	25	21	21
Fair	27	23	24
Good	30	28	26
Very Good	27	28	24
Excellent	29	31	31

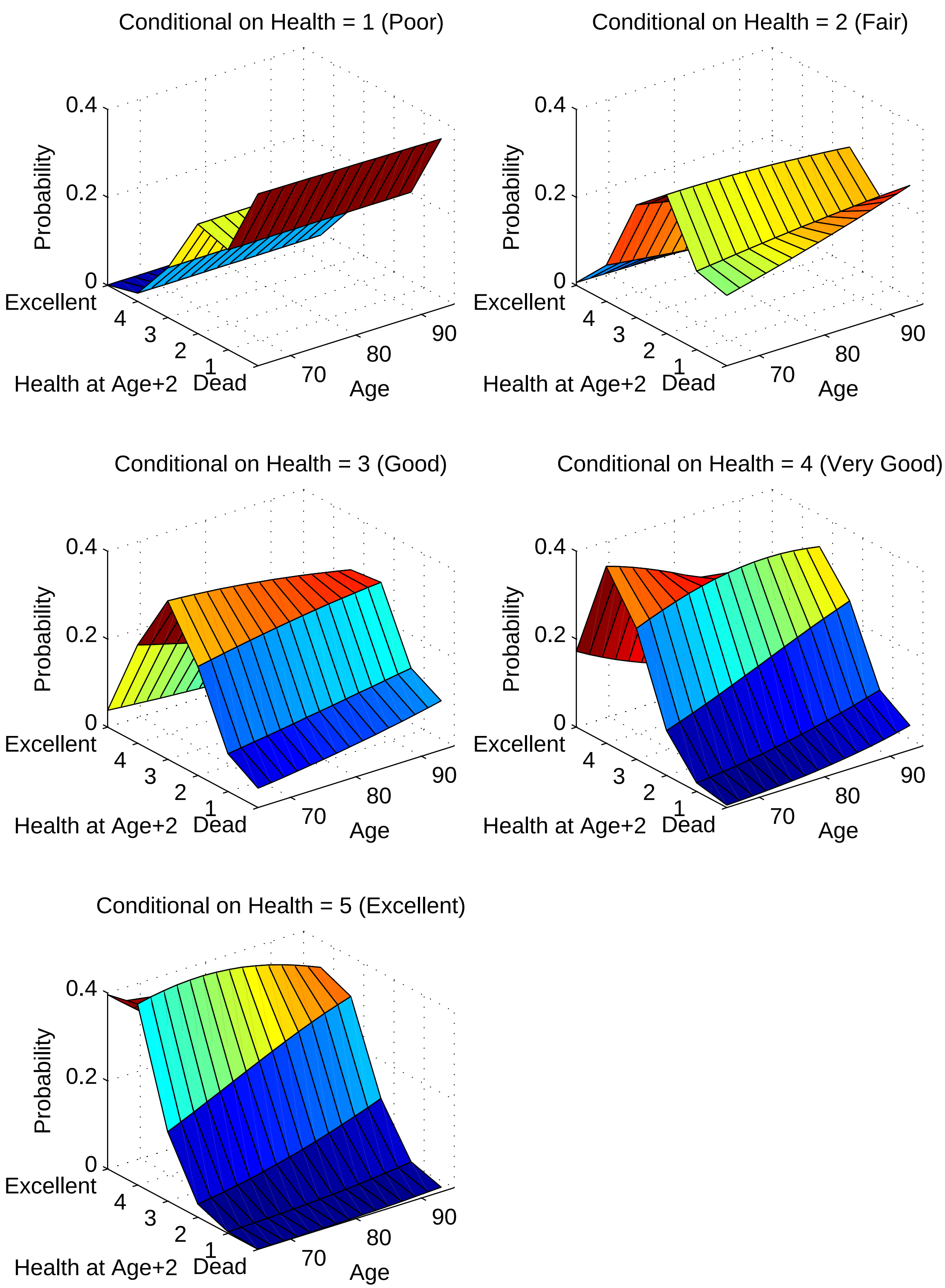

Figure 1: Transition Probabilities for Health Status
The ordered probit model, reported in Table 1, is used to predict the transition probabilities for health status. The predicted probabilities are those for retired unmarried females, born in the 1931–1940 cohort, with medical expenditures below $1,000.

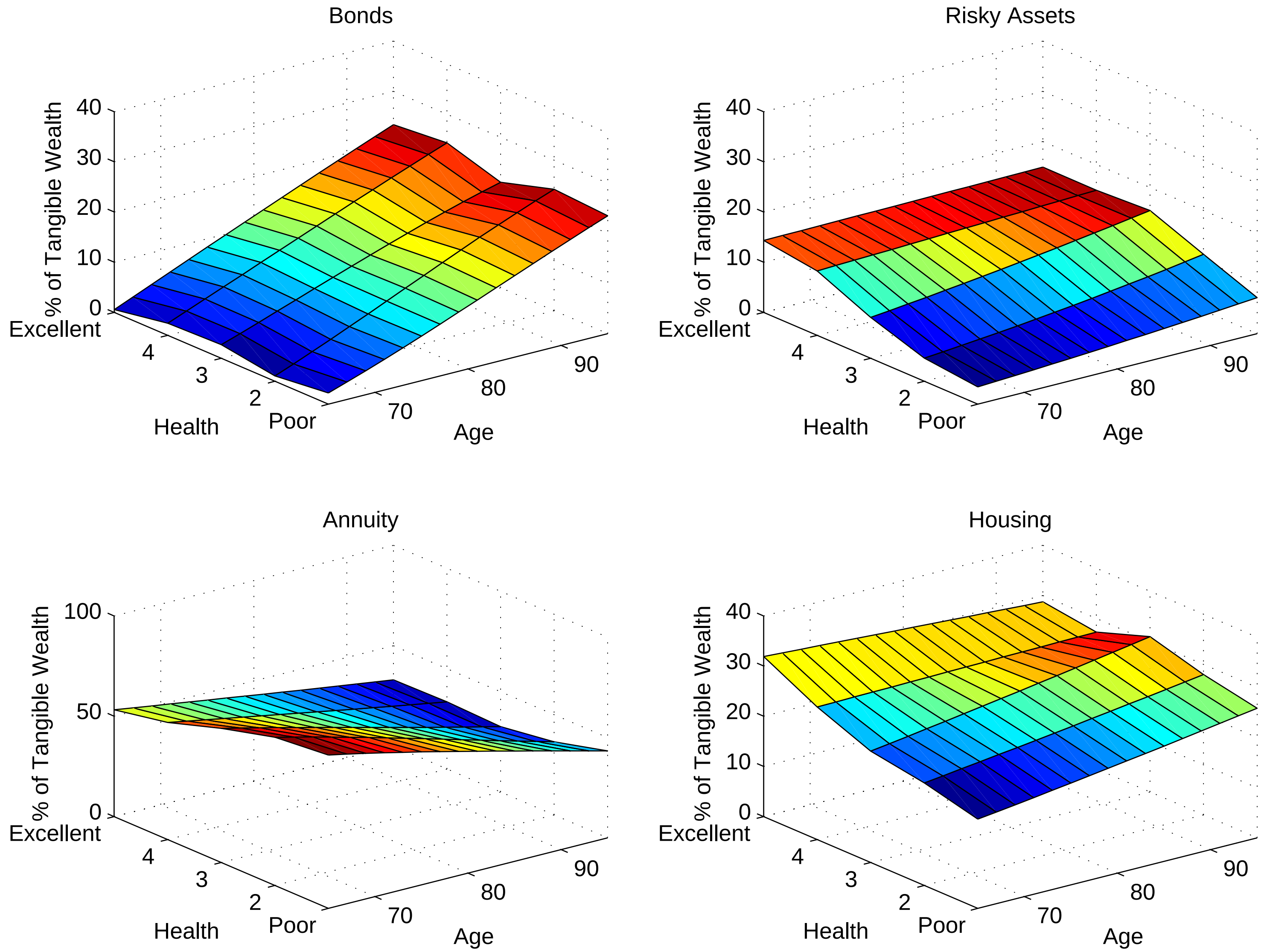

Figure 2: Asset Allocation by Age and Health Status in the HRS
The censored regression model, reported in Table 3, is used to predict the the portfolio share in each of the four tangible assets. The predicted portfolio shares are those for retired unmarried females, born in the 1931–1940 cohort.

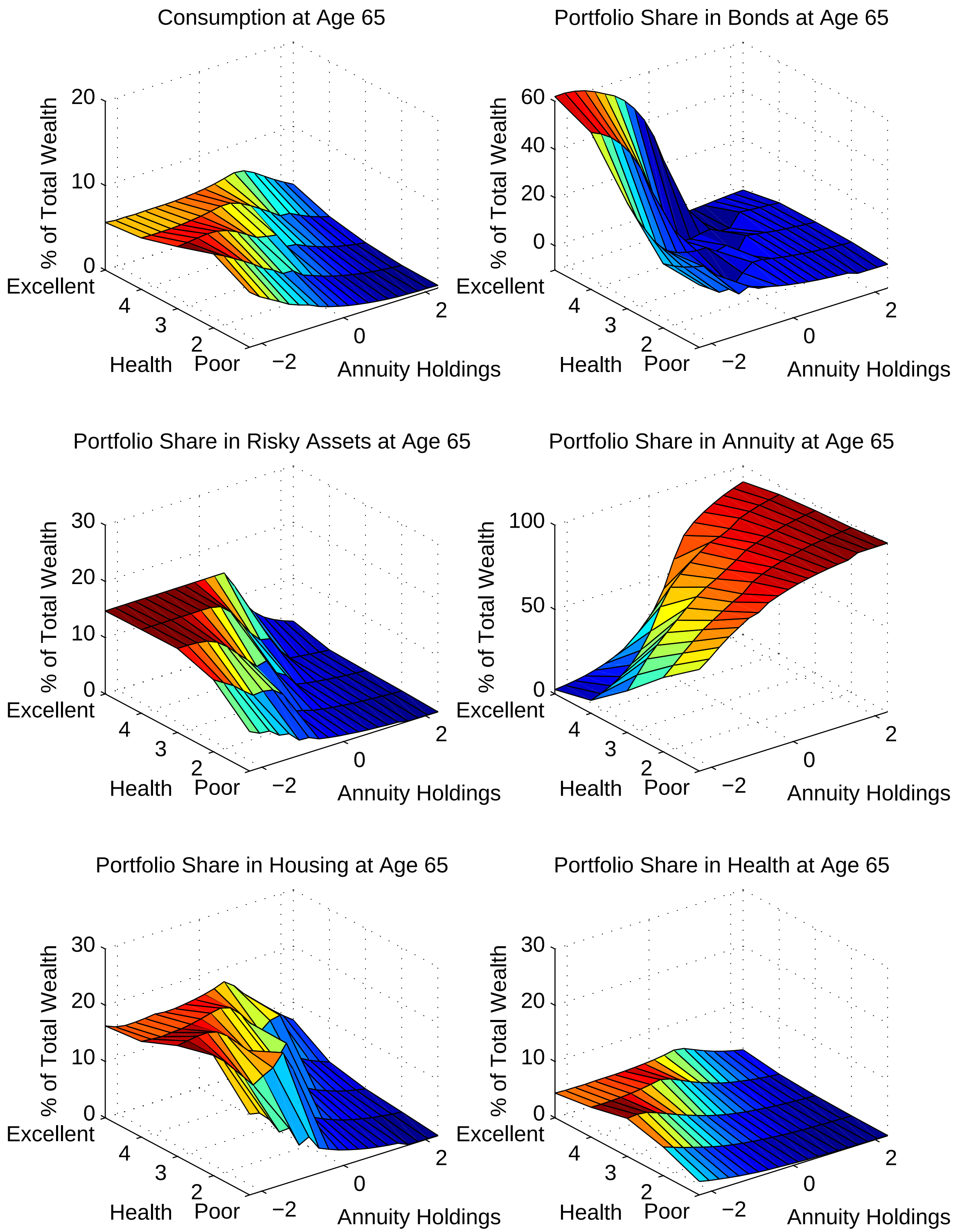

Figure 3: Consumption and Portfolio Policy Functions at Age 65–66

The consumption policy function is shown as a share of total wealth, $c_t = C_t/\widetilde{W}_t$. The portfolio policy functions are shown as a share of total savings, $a_{it} = A_{it}/(\widetilde{W}_t - C_t)$ for all assets $i = 1, \ldots, N, D, H$. All policy functions are shown as a function of health status, $H_t \in \{H_P, H_F, H_G, H_{VG}, H_E\}$, and log of initial annuity holdings, $\log B_0$. The relative price of housing is held constant at $P_1 = 1$.

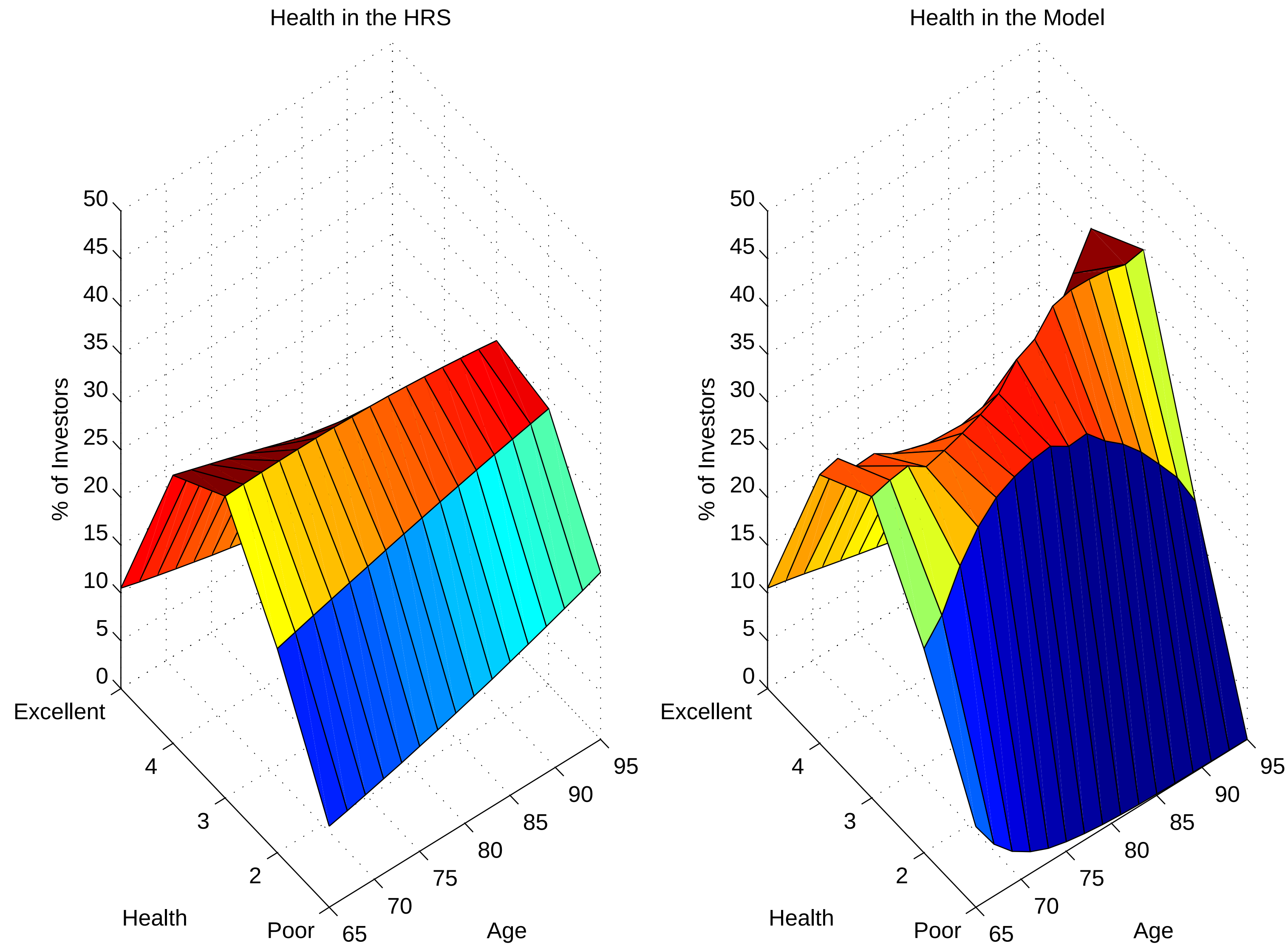

Figure 4: Distribution of Health Status by Age
An ordered probit model is used to predict the distribution of health status at each age. The latent variable depends on cohort dummies, health status, age, and the interaction of health status with age. The left panel shows the predicted distribution of health status at each age for retired unmarried females, born in the 1931–1940 cohort. The right panel shows the distribution of health status at each age for simulated retirees in the benchmark calibration.

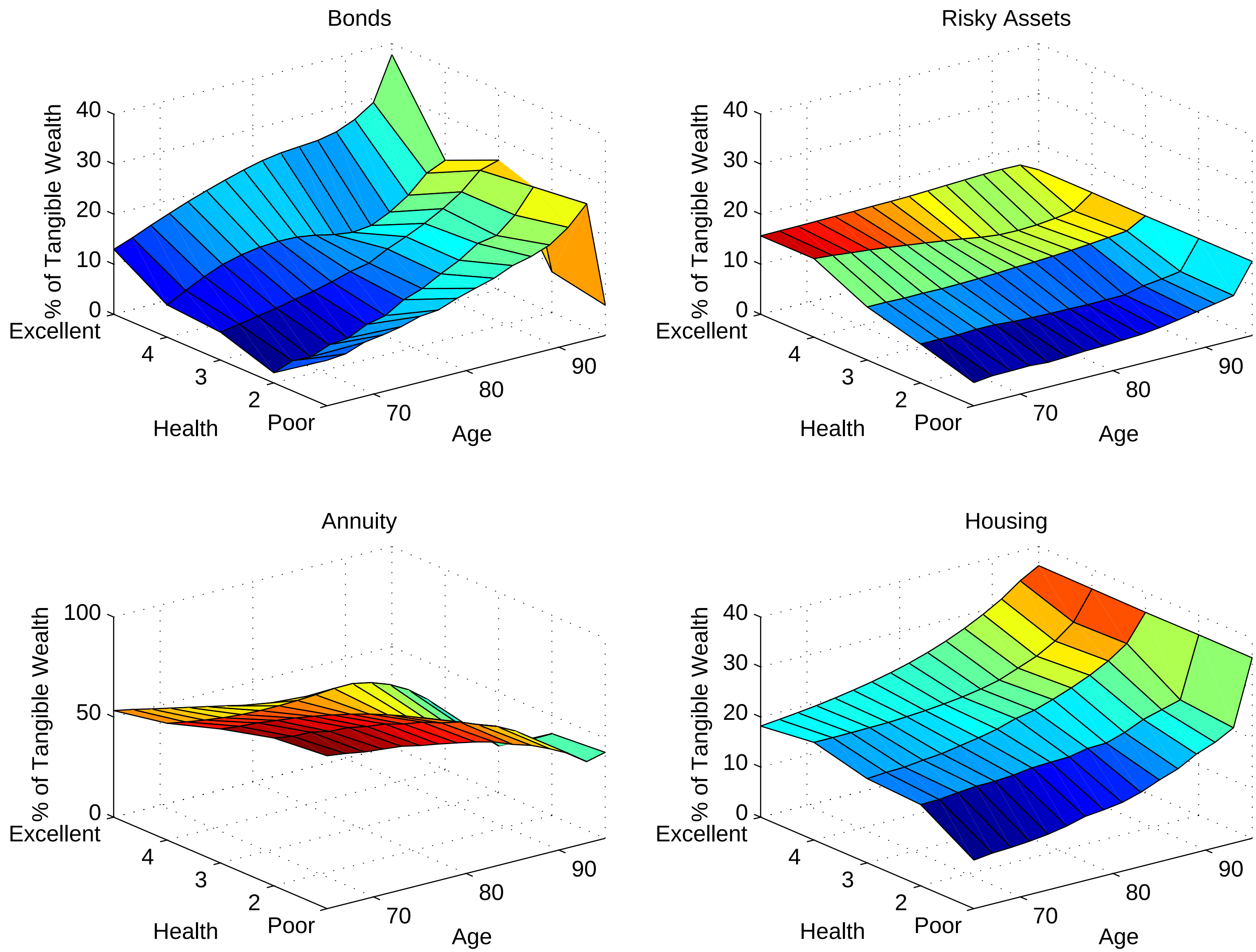

Figure 5: Asset Allocation of Simulated Retirees in the Benchmark Calibration
The figure shows the portfolio share in each of the four tangible assets as a function of age and health status. The portfolio shares are those for simulated retirees in the benchmark calibration.

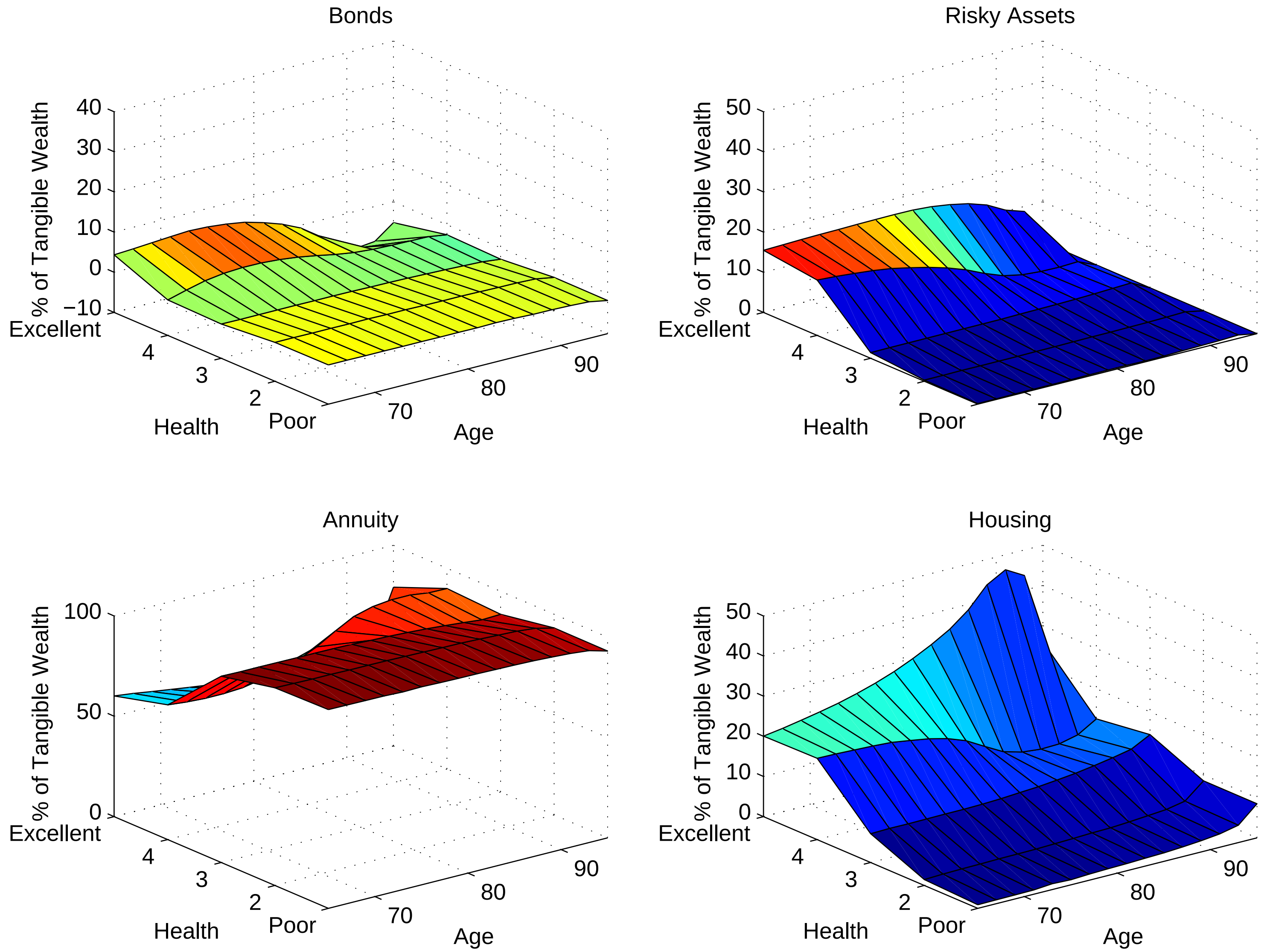

Figure 6: Asset Allocation of Simulated Retirees with No Bequest Motive

The figure shows the portfolio share in each of the four tangible assets as a function of age and health status. The portfolio shares are those for simulated retirees with no bequest motive.

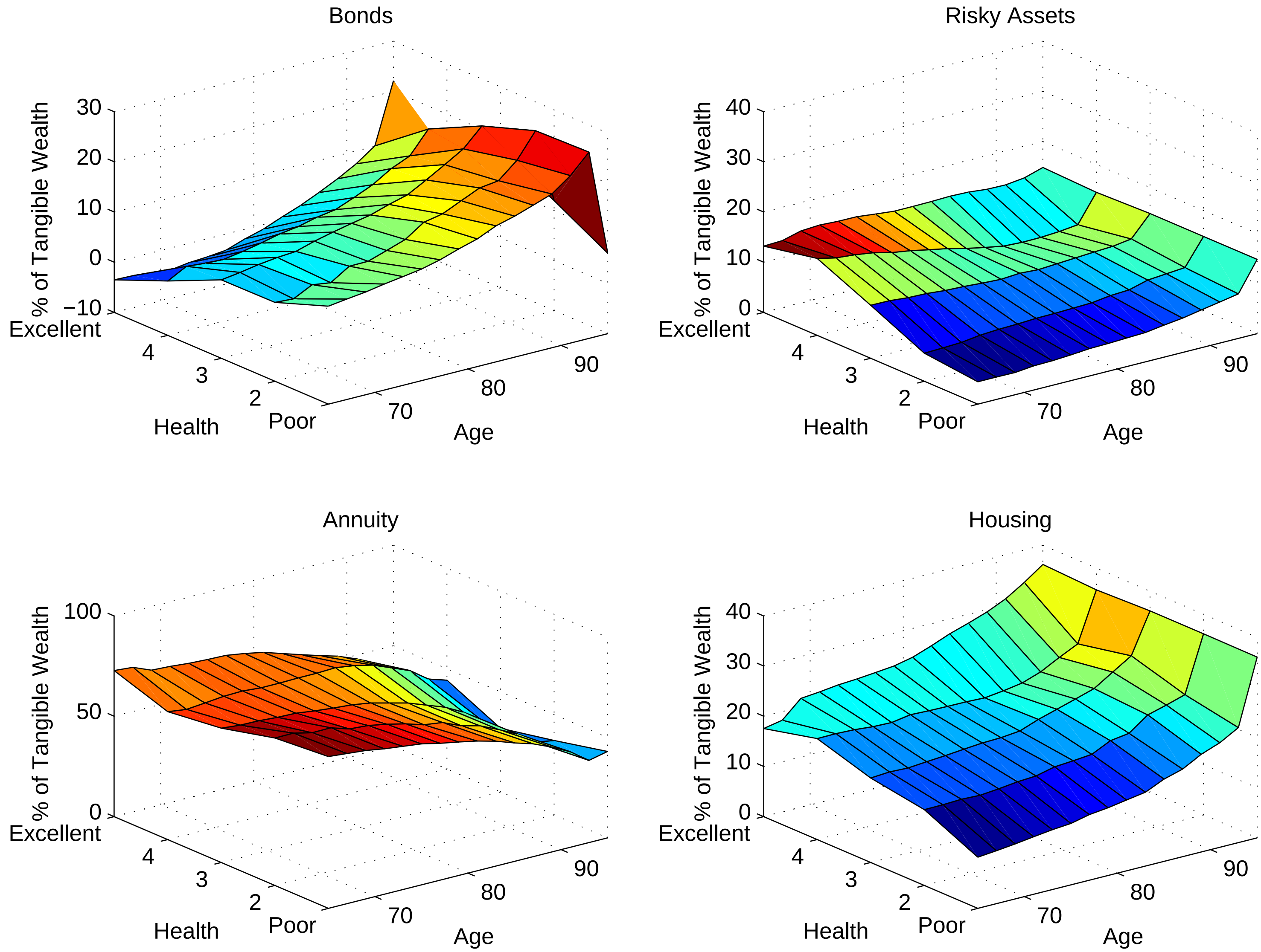

Figure 7: Asset Allocation of Simulated Retirees with an Actuarially Fair Annuity Market
The figure shows the portfolio share in each of the four tangible assets as a function of age and health status. The portfolio shares are those for simulated retirees in an economy with an actuarially fair annuity market.