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PORTFOLIO CHOICE IN RETIREMENT: HEALTH RISK AND THE DEMAND FOR ANNUITIES, HOUSING, AND RISKY ASSETS

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ABSTRACT

This paper develops a consumption and portfolio-choice model of a retiree who allocates wealth in four asset classes: a riskless bond, a risky asset, a real annuity, and housing. The retiree chooses health expenditure endogenously in response to stochastic depreciation of health. The model is calibrated to explain the joint dynamics of health expenditure, health, and asset allocation for retirees in the Health and Retirement Study, aged 65 and older. The calibrated model is used to assess the welfare gain from private annuitization. The welfare gain ranges from 13 percent of wealth at age 65 for those in worst health, to 18 percent for those in best health.

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1. Introduction

As a large cohort of baby boomers approach retirement, the design of products that ensure the lifetime financial security of retirees is at the forefront of the agenda in the financial industry. In public policy, there is active debate on whether the Social Security system can be reformed to improve the welfare of present and future retirees. Despite this interest, little is understood about the asset-allocation decisions of retirees. Although there is a large literature that studies life-cycle asset allocation in the working phase when households face labor-income risk, there is relatively little work on asset allocation in retirement when households face health risk. This paper attempts to fill a gap in the life-cycle literature with a positive (in contrast to normative) analysis of the joint demand for health care and financial assets in retirement.

Specifically, this paper develops a consumption and portfolio-choice model in which a retiree faces exogenous and stochastic depreciation of health, which affects the marginal utility of wealth as well as life expectancy. The retiree chooses health expenditure endogenously based on her health, wealth, and health insurance coverage. In addition, the retiree makes an asset-allocation decision between a riskless bond, a risky asset, a real annuity, and housing. I calibrate the model using data on health expenditure, health status, and asset holdings for a population of retired females in the Health and Retirement Study (HRS), aged 65 and older. The model successfully explains the cross-sectional distribution as well as the joint dynamics of health expenditure, health, and asset allocation in retirement.

This paper makes two contributions to the literature on portfolio choice in retirement. First, this paper takes a comprehensive view of portfolio choice, which reflects the reality that retirees own sophisticated portfolios allocated across four major asset classes: bonds (including cash), risky assets (including stocks and private businesses), annuities (mostly through defined-benefit pension plans and Social Security), and housing. Related models of portfolio choice in retirement focus only on a subset of these four asset classes, which is a simplification that is primarily useful for normative analysis (e.g., Turra and Mitchell, 2004;

Inkmann, Lopes, and Michaelides, 2007; Love and Perozek, 2007; Pang and Warshawsky, 2007; Edwards, 2008).

The second contribution is to build a more realistic model of health risk in which health expenditure (e.g., visiting a physical therapist) is an endogenous response to a health shock (e.g., developing a back pain). The previous literature has taken one of two extreme positions on modeling health risk. On the one hand is a complete market in which all health risk is insurable and uncertainty arises only over the time of death. In such a world, a retiree without a bequest motive should fully annuitize wealth (Yaari, 1965; Friedman and Warshawsky, 1990; Davidoff, Brown, and Diamond, 2005). On the other hand is an incomplete market in which health expenses are exogenous and stochastic, essentially modeled as negative income shocks. The inability to insure uncertainty over health expenses generates large precautionary saving in liquid assets and crowds out the demand for annuities (Hubbard, Skinner, and Zeldes, 1994; Palumbo, 1999; Sinclair and Smetters, 2004; De Nardi, French, and Jones, 2006).

This paper takes a position between these two extremes, that health risk is neither fully insurable nor entirely exogenous. A model with exogenous health expenses overstates the degree to which markets are incomplete with respect to health risk. In reality, retirees can endogenously adjust the quantity and quality of health care in response to changes in their health and wealth. More debatably, retirees may be able to change the distribution of future health (e.g., developing cancer) through endogenous investment in health (e.g., getting a mammogram). Overall, the endogeneity of health expenditure reduces the amount of background risk with respect to health, which has important implications for consumption and portfolio choice. This is analogous to the idea that the endogeneity of the labor supply (including the timing of retirement) reduces the amount of background risk with respect to labor income (Bodie, Merton, and Samuelson, 1992).

An important advantage of a model with endogenous health expenditure is the ability to conduct welfare analysis, either of new financial products or government policy. In contrast, a model with exogenous health expenses is not appropriate for welfare analysis because an alternative market structure can change the endogenous accumulation of health. In this paper, I ask whether current retirees are sufficiently annuitized through defined-benefit pension plans and Social Security. Using the calibrated model, I conduct welfare analysis of an annuity market that allows retirees to privately annuitize their wealth during retirement. I find that the welfare gain ranges from 13 percent of wealth at age 65 for those in worst health, to 18 percent for those in best health.

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 expenditure, health, and asset holdings in the HRS. Section 4 presents the main findings of the calibrated model. Section 5 presents the welfare analysis of private annuitization. Section 6 concludes.

2. A Model of Consumption and Portfolio Choice in Retirement

This section describes a model of consumption and portfolio choice in retirement. The basic structure of the model can be summarized as follows. An individual enters retirement with an initial endowment of health and tangible wealth. Tangible wealth is the sum of the asset value of bonds, stocks, annuities, and housing. In each period while alive, the retiree chooses consumption, housing expenditure, health expenditure, and the asset allocation of tangible wealth. Upon death, the retiree leaves bonds, stocks, and housing as a bequest. The asset value of annuities, and obviously health, cannot be bequeathed.

The model has two key innovations relative to previous models of consumption and portfolio choice in retirement. First, health is an outcome of the accumulation of past health shocks and the endogenous choices over health care. Picone, Uribe, and Wilson (1998) develop a related model in which the retiree can only save in a riskless bond (i.e., a model without housing or portfolio choice). Second, housing is the most important tangible asset for the typical retiree, yet it has been ignored in previous analysis of portfolio choice in retirement.[1] Housing is a unique asset in that it serves a dual purpose. On the one hand, there is consumption value from living in a home. On the other hand, housing is a store of wealth, which the retiree can leave as a bequest or use to pay health expenses in states with low realized health (e.g., nursing home expenses as emphasized by Davidoff, 2008).

2.1 Housing Expenditure

The retiree enters each period t with an initial stock of housing D_{t-1}. The stock of housing incorporates both the size and the quality of the home. Housing depreciates at a constant rate $\delta \in (0, 1]$ in each period. After depreciation, the retiree chooses housing expenditure E_t, which can be negative in the case downsizing. The accumulation equation for housing is

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

2.2 Health Expenditure

Following Grossman (1972), I also model the retiree's health as an accumulation process. The retiree enters each period t with an initial stock of health H_{t-1}. Health depreciates at a stochastic rate $\omega_t \leq 1$ in each period t. The realization of ω_t is exogenous, but its distribution can depend on state variables in period t such as H_{t-1}. For example, whether you get a heart attack today is purely chance, but the likelihood of getting a heart attack depends on whether you have a history of heart disease. 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 health depreciation is realized in period t, the retiree chooses health expenditure

[1] Cocco (2005), Hu (2005), and Yao and Zhang (2005) also develop life-cycle models with housing. However, they focus on its interaction with labor-income risk during the working phase, instead of health risk during retirement.

$I_t \geq 0$ if she is still alive. Health expenditure is an investment in the sense that its effects on health can persist for more than one period. Health investment is irreversible in the sense that the retiree cannot reduce her health through negative expenditure. Irreversibility of investment is a key economic feature that makes health fundamentally different from housing and financial assets.

The accumulation equation for health is

$$H_t = (1 - \omega_t)H_{t-1} + \psi[(1 - \omega_t)H_{t-1}]^{1-\psi} I_t^{\psi}. \tag{2}$$

This specification for health production has two key features that are well suited for empirical analysis. First, health production is homogeneous in the stock of health. Second, health expenditure has decreasing returns to scale (Ehrlich and Chuma, 1990). As the parameter $\psi \in (0, 1]$ approaches zero, health expenditure has diminishing impact on health.

2.3 Budget Constraint

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

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

The intertemporal budget constraint is

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

Define tangible wealth as the sum of financial and housing wealth,

$$\widehat{W}_t = W_t + (1 - \delta) P_t D_{t-1}. \tag{5}$$

Define the asset value of housing as $A_{D,t} = P_t D_t$. Combined with the accumulation equation for housing (1), the intraperiod budget constraint can be rewritten as

$$\sum_{n=1}^{N} A_{n,t} + A_{D,t} = \widehat{W}_t - C_t - Q_t I_t. \tag{6}$$

Define the gross rate of return on housing from period t to $t+1$ as

$$R_{D,t+1} = \frac{(1-\delta) P_{t+1}}{P_t}. \tag{7}$$

The intertemporal budget constraint can be rewritten as

$$\widehat{W}_{t+1} = \sum_{n=1}^{N} A_{n,t} R_{n,t+1} + A_{D,t} R_{D,t+1}. \tag{8}$$

2.4 Objective Function

If the retiree survives period t, she has utility flow from consumption, housing, and health. Her utility flow is a constant elasticity of substitution function over health and non-health consumption:

$$U(C_t, D_t, H_t) = [(1-\alpha)(C_t^{1-\phi} D_t^{\phi})^{1-1/\rho} + \alpha H_t^{1-1/\rho}]^{1/(1-1/\rho)}. \tag{9}$$

The parameter $\phi \in (0, 1)$ is the utility weight on housing, and $\alpha \in (0, 1)$ is the utility weight on health. The parameter $\rho \in (0, 1]$ is the elasticity of substitution between health and non-health consumption.

If the retiree dies in period t, she leaves behind tangible wealth as a bequest. Her utility flow over the bequest is

$$G(\widehat{W}_t, P_t) = \overline{u}\widehat{W}_t \left(\frac{\phi}{(1-\phi)P_t} \right)^{\phi}. \tag{10}$$

The parameter $\overline{u} > 0$ determines the strength of the bequest motive. This specification is the indirect utility function that corresponds to a Cobb-Douglas function over consumption and housing, $C_t^{1-\phi} D_t^{\phi}$. It captures the notion that housing and financial wealth are not perfectly substitutable forms of bequest (see Yao and Zhang, 2005, for a similar approach).

Let $1_{\{\omega_t \neq 1\}}$ be an indicator function that takes the value one if the retiree dies in period t, and let $1_{\{\omega_t = 1\}} = 1 - 1_{\{\omega_t \neq 1\}}$. Following Epstein and Zin (1991), I define the retiree's objective function recursively as

$$\begin{aligned} J_t \;&=\; \{(1-\beta)U(C_t, D_t, H_t)^{1-1/\sigma} \\ &\quad +\beta \mathbf{E}_t[1_{\{\omega_{t+1} \neq 1\}} J_{t+1}^{1-\gamma} + 1_{\{\omega_{t+1} = 1\}} G(W_{t+1}, P_{t+1})^{1-\gamma}]^{(1-1/\sigma)/(1-\gamma)}\}^{1/(1-1/\sigma)}, \end{aligned} \tag{11}$$

where the terminal value is $J_{T+1} = 0$. The parameter $\beta \in (0, 1)$ is the subjective discount factor. The parameter $\sigma > 0$ is the elasticity of intertemporal substitution, and $\gamma > 1$ is the relative risk aversion.

If $\rho < \sigma$, health and non-health consumption are complements in the sense that the marginal utility of non-health consumption rises in health. For example, the marginal utility of a fine meal may be low if the retiree has diabetes. If $\rho > \sigma$, health and non-health consumption are substitutes. For example, the marginal utility of cable television may be high if the retiree has a physical disability.

2.5 Financial Assets and Housing

I now specify the retiree's trading universe and portfolio constraints. The trading universe consists of a riskless bond, a risky asset, a real annuity, and housing. These four asset classes capture the key economic features of actual assets held by retirees, and implicitly allow for a rich set of portfolio strategies. For example, a "variable annuity" can be synthesized through a portfolio strategy that is short the bond, long the risky asset, and long the annuity. A "reverse mortgage" can be synthesized through a portfolio strategy that is short the bond, long the annuity, and long housing. This synthetic portfolio differs from a true reverse mortgage in the sense that the retiree still bears housing-price risk.

2.5.1 Riskless Bond

The first asset is a riskless bond, which has a constant gross rate of return $R_{1,t} = \overline{R}_1$. For the period 1958–2008, the average real return on the one-year Treasury bond (deflated by the consumer price index for all items less medical care) is 2.5 percent. Based on this estimate, I calibrate $\overline{R}_1 = 1.025$.

To simplify the model, I have assumed away transactions costs that may arise in selling the home (see Cocco, 2005; Hu, 2005; Yao and Zhang, 2005, for a model with transactions costs). However, transactions costs should not have a significant impact on optimal consumption and portfolio choice as long as the retiree is able to borrow from home equity. I therefore allow the retiree to short the bond in order to model a mortgage or a home equity line of credit. The retiree can short the bond up to a fraction $\lambda \in [0, 1)$ of the home value, so that its portfolio constraint is $A_{1,t} \geq -\lambda A_{D,t}$. Sinai and Souleles (2007) find evidence that retirees are less able to borrow from home equity compared to younger working households. Based on their finding, I calibrate the borrowing limit to be 20 percent of the home value.

2.5.2 Risky Asset

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

$$R_{2,t} = \overline{R}_2 \nu_{2,t}, \tag{12}$$

where $\log \nu_{2,t} \sim \mathbf{N}(-\sigma_2^2/2, \sigma_2^2)$ is independently and identically distributed. For the period 1958–2008, the real return on the Center for Research in Securities Prices value-weighted index (deflated by the consumer price index for all items less medical care) has a mean of 7.3 percent and a standard deviation of 17.5 percent. Based on these estimates, I calibrate $\overline{R}_2 = 1.065$ and $\sigma_2 = 0.18$. An equity premium of 4 percent, which is slightly lower than its historical estimate, is a standard input in life-cycle models of portfolio choice (e.g., Cocco, Gomes, and Maenhout, 2005). The retiree cannot short the risky asset, so that its portfolio constraint is $A_{2,t} \geq 0$.

2.5.3 Real Annuity

The third asset is a real annuity, defined as a claim that pays off one unit of consumption in every period prior to death. Let p_t be an actuarially fair survival probability in period t, which is a deterministic function of gender, birth cohort, and age. Let $\overline{R}_3$ be the expected gross rate of return on the annuity, which is also the required rate of return that allows the insurer to break even. The price of the annuity in period t is

$$P_{3,t} = \sum_{s=1}^{T-t-1} \frac{\prod_{u=1}^{s} p_{t+u}}{\overline{R}_3^s}. \tag{13}$$

The annuity has a gross rate of return that is contingent on survival:

$$R_{3,t} = \begin{cases} \overline{R}_3/p_t & \text{if } \omega_t \neq 1 \\ 0 & \text{if } \omega_t = 1 \end{cases}. \tag{14}$$

To calibrate the annuity prices and returns, I use survival probabilities for females born in the 1940 cohort from the Social Security life tables (Bell and Miller, 2005, Table 7). The maximum possible lifetime in the life tables is age 119. Mitchell, Poterba, Warshawsky, and Brown (1999) find that the yield on annuities offered by insurance companies is about 1 to 2 percent lower than the yield on comparable Treasury bonds, due to adverse selection and transaction costs. Based on their finding, I calibrate $\overline{R}_3 = 1.015$, which is 1 percent lower than the riskless interest rate.

Almost all individuals enter retirement with implicit annuity holdings, either through a defined-benefit pension plan or Social Security. Very few retirees purchase additional annuities through private insurance markets, presumably due to various market frictions and participation costs (see Brown, 2007, for a survey). In the benchmark model, I model the present situation by not allowing retirees to trade annuities during retirement. More formally, let $B_{3,t}$ be the annuity holdings in period t, so that savings in the annuity is $A_{3,t} = P_{3,t}B_{3,t}$. The individual enters retirement with an endowment $B_{3,0}$ of the annuity. For all periods $t \geq 1$, the portfolio constraint for the annuity is $B_{3,t} = B_{3,t-1}$. In Section 5, I relax this portfolio constraint and allow the retiree to purchase additional annuities.

2.5.4 Housing

I model the gross rate of return on housing as

$$R_{D,t} = \overline{R}_D \nu_{D,t}, \tag{15}$$

where $\log \nu_{D,t} \sim \mathbf{N}(-\sigma_D^2/2, \sigma_D^2)$ is independently and identically distributed. The dynamics of the relative price of housing is then determined by equation (7), where the the initial price level is normalized to be $P_1 = 1$.

Using equation (7), I compute the real return on housing (deflated by the consumer price index for all items less medical care) based on a housing-price index and a depreciation rate of 1.14 percent for private residential fixed assets. For the period 1976–2008, the real housing return based on the Office of Federal Housing Enterprise Oversight price index has a mean of 0.4 percent and a standard deviation of 3.5 percent. Based on these estimates, I calibrate $\overline{R}_D = 1.004$ and $\sigma_D = 0.035$.

2.6 Homogeneity in Tangible Wealth

In addition to age, the state variables of the consumption and portfolio-choice problem are health, tangible wealth, annuity holdings, and the relative price of housing. However, homogeneity of the objective function implies that tangible wealth drops out as a state variable as shown in Appendix B. Therefore, the key state variable in the model is health relative to tangible wealth, defined as

$$\widehat{H}_t = \frac{(1-\omega_t)Q_t H_{t-1}}{\widehat{W}_t}. \tag{16}$$

Homogeneity is a standard assumption in life-cycle models of consumption and portfolio choice, which substantially simplifies the solution and makes the model well suited for empirical analysis.

In order to preserve homogeneity, I make two other parametric assumptions. First, the distribution of health depreciation depends on previous health only through its value relative to tangible wealth. Specifically, health depreciation depends on age and health through the distribution function

$$\omega_{t+1} \sim \omega(t, \widehat{H}_t). \tag{17}$$

In the next section, I estimate the distribution of health depreciation using the HRS.

Second, the relative price of health goods and services depends on age and health as

$$Q_t = e^{q(t-1)} Q(t, \widehat{H}_t). \tag{18}$$

The relative price of health goods and services consists of two parts. The first part is the macroeconomic growth of the relative price of health goods and services. For the period 1958–2008, the average log growth rate of the consumer price index for medical care relative to that for all items less medical care was 1.9 percent. Based on this estimate, I calibrate

$q = 0.019$. The second part accounts for the individual retiree's health insurance coverage, which varies with age and health. In Appendix A, I estimate the health insurance coverage using the HRS.

3. Health and Retirement Study

3.1 Sample of Retirees

The HRS is a panel survey designed to study the health and wealth dynamics of the elderly in the United States. I use the RAND HRS data file (Version I), which is produced by the RAND Center for the Study of Aging with funding from the National Institute on Aging and the Social Security Administration. I use the first eight waves of the HRS, which cover the years 1992 through 2006. I focus on those born 1891–1940, which includes the Study of Assets and Health Dynamics Among the Oldest Old (born before 1924), the Children of Depression (born 1924–1930), and the initial HRS cohort (born 1931–1941).

My analysis focuses on the sample of retired females, who are single (including separated, divorced, and widowed) and aged 65 and older at the time of interview. The choice of single individuals is dictated by the fact that married households maximize a more complicated objective function that depends on the health and survival of both partners. The choice of females is motivated by the fact that their life expectancy is longer than that of males, which increases the importance of annuities in the retirement portfolio. Because retirees are interviewed every two years, I code age in groups of two years from the 65–66 age group to the 117–118 age group. All empirical analysis uses the person-level analysis weight, so that the sample is representative of the United States population in the Current Population Survey.

3.2 Health Status and Health Care Utilization

Retirees in the HRS report various measures of health every two years. The primary measure of health for my study is the self-reported general health status. The respondent can report that her health is either poor, fair, good, very good, or excellent. Insofar as health enters the retiree's utility function, self-reported health status is a relevant measure of health for an empirical implementation of the model. As shown below, self-reported health status is a significant predictor of future mortality.

Panel A of Table 1 reports the percentage of retirees who have ever reported doctor-diagnosed health problems, separately by health status. The panel shows that self-reported health status is highly correlated with objective measures of physical and mental health (also see Wallace and Herzog, 1995). For example, 30 percent of those who report to be in poor health have had diabetes. The corresponding numbers are 24 percent of those in fair health, 15 percent of those in good health, 9 percent of those in very good health, and only 5 percent of those in excellent health. As another example, 56 percent of those who report to be in poor health have had heart problems. The corresponding numbers are 41 percent of those in fair health, 28 percent of those in good health, 18 percent of those in very good health, and only 12 percent of those in excellent health.

Panel B reports the percentage of retirees who report some difficulty with activities of daily living at the time of interview, separately by health status. The panel shows that self-reported health status is highly correlated with measures of functional limitation. For example, 46 percent of those who report to be in poor health have some difficulty with dressing. The corresponding numbers are 24 percent of those in fair health, 12 percent of those in good health, 6 percent of those in very good health, and only 4 percent of those in excellent health.

Panel C reports the percentage of retirees who report utilizing health care in the two years prior to the interview, separately by health status. The panel shows that self-reported health status is negatively correlated with measures of health care utilization. For example, 97 percent of those who report to be in poor health have visited a doctor in the two years prior to the interview. The corresponding numbers are 97 percent of those in fair health, 95 percent of those in good health, 93 percent of those in very good health, and only 88 percent of those in excellent health.

In addition to health care, Panel C reports two other measures of health investment broadly defined, vigorous physical activity and smoking. Only 7 percent of those who report to be in poor health participate in vigorous physical activity at least three times a week. The corresponding numbers are 14 percent of those in fair health, 25 percent of those in good health, 34 percent of those in very good health, and only 46 percent of those in excellent health.

3.3 Health Transition Probabilities

The health accumulation equation (2) determines the transition dynamics of health and is therefore a key input in the model. In this section, I estimate its empirical analog using data on self-reported status and an ordered probit model (see Wagstaff, 1986; Khwaja, 2002, for a similar approach).

In each period t, the retiree reports her health status H_t^*. The health status depends on a latent variable H_t, which captures unobservable health, through the response function

$$H_t^* = \begin{cases} 0 & \text{Dead} & \text{if} & & & H_t & < & H_P \\ 1 & \text{Poor} & \text{if} & H_P & \leq & H_t & < & H_F \\ 2 & \text{Fair} & \text{if} & H_F & \leq & H_t & < & H_G \\ 3 & \text{Good} & \text{if} & H_G & \leq & H_t & < & H_{VG} \\ 4 & \text{Very Good} & \text{if} & H_{VG} & \leq & H_t & < & H_E \\ 5 & \text{Excellent} & \text{if} & H_E & \leq & H_t & & \end{cases} . \tag{19}$$

I model future health H_{t+1} as a function of explanatory variables in period t, which include cohort dummies, present health status, age, tangible wealth, and their interaction with present health status. Additional explanatory variables are measures of health care utilization, which include dummies for a doctor visit, a dentist visit, home health care, nursing home, outpatient surgery, prescription drugs, a cholesterol test, a mammogram, vigorous physical activity, and smoking. I interact these measures of health care utilization with health status to allow for the possibility that the marginal product of health care varies across health.

Column (1) of Table 2 reports the estimated coefficients for the benchmark specification. The sign of the coefficients can be interpreted as the direction of the marginal effects for the extreme health outcomes, death and excellent health (Wooldridge, 2002, p. 506). The coefficients for health status show that present health is a significant predictor of future health. The coefficients are negative for poor and fair health, and positive for very good and excellent health. This means that relative to those in good health, which is the omitted category, those who are presently in poor or fair health are more likely to die in the next period. The coefficient for age is negative, which implies that health deteriorates as retirees age. The coefficient for tangible wealth is positive, which implies that wealthier retirees are less likely to die holding everything else constant.

Of the explanatory variables that measure health care utilization, those that are significant predictors of future health are a dentist visit, vigorous physical activity, and smoking. Those that are insignificant predictors of future health are a doctor visit, nursing home, outpatient surgery, a cholesterol test, and a mammogram. Home health care and prescription drugs predict future health with a negative sign, so the null hypothesis that these goods and services improve future health is rejected. A joint Wald test on these measures of health care utilization rejects with a p-value of 0 percent, suggesting that taken together, health care utilization is a significant predictor of future health.

A potential problem with this benchmark specification is unobservable heterogeneity in health that is not fully captured by present health status. Insofar as health care utilization is negatively correlated with unobserved heterogeneity in health (i.e., those that are already sick are more likely to utilize health care), the coefficients for health care utilization are likely to be downward biased. In order to explore this possibility, column (2) of Table 2 estimates an alternative specification that includes dummies for doctor-diagnosed health problems and measures of some difficulty with activities of daily living. These additional measures of health enter significantly, capturing heterogeneity in health that is not fully captured by self-reported health status. Controlling for these additional measures of health, the coefficients for health care utilization become more positive, confirming the hypothesis that they were downward biased in the benchmark specification.

I use the estimated ordered probit model to predict the health transition probabilities in the absence of health expenditure (i.e., shutting off all dummies related to health care utilization). Figure 1 shows the predicted transition probabilities by health and age for retired females, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The figure clearly illustrates that present health is a significant predictor of future mortality. Conditional on being in poor health at any given age, death is the most likely outcome in the next period. Conditional on being in excellent health at any given age, death is the least likely outcome in the next period. These predicted health transition probabilities correspond to the distribution of health depreciation in equation (17), which I use to calibrate the model in Section 4.

3.4 Asset Allocation

Retirees in the HRS report holdings of four major asset classes: bonds, risky assets, annuities, and housing (see Appendix A for definitions). For each asset class, I compute its portfolio share as a ratio to tangible wealth, which is the sum of the value of all four asset classes. I use a censored regression model to estimate how the portfolio share in each asset class depends on cohort dummies, health status, age, tangible wealth, and their interaction with health status. Table 3 reports the estimated regression models for annuities, risky assets, and housing. (I omit bonds because the portfolio shares must add up to one.) Hurd (2002) and Coile and Milligan (2006) also document asset allocation in the HRS. However, they ignore the asset value of annuities in their analysis, which is important from the perspective of the life-cycle model.

The portfolio share in risky assets rises in health, holding constant tangible wealth (also see Rosen and Wu, 2004). Relative to those in good health, which is the omitted category, those in poor health have 1.40 percentage points less in risky assets. Relative to those in good health, those in excellent health have 0.67 percentage points more in risky assets. The portfolio share in risky assets also rises in age, which partly arises from the fact that the portfolio share in annuities falls in age. For those in good health, the portfolio share falls by 1.32 percentage points for each ten years of age. The portfolio share in risky assets also rises in the logarithm of tangible wealth. For those in good health, the portfolio share rises by 6.32 percentage points when tangible wealth rises by 100 percent.

The portfolio share in annuities falls in health, holding constant tangible wealth. Relative to those in good health, those in poor health have 1.66 percentage points more in annuities. Relative to those in good health, those in excellent health have 5.68 percentage points less in annuities. The portfolio share in annuities also falls in age, which is a direct consequence of the fact that the present value of future annuity income falls in age. For those in good health, the portfolio share falls by 11.70 percentage points for each ten years of age. The portfolio share in annuities also falls in the logarithm of tangible wealth. For those in good health, the portfolio share falls by 23.36 percentage points when tangible wealth rises by 100 percent.

In addition to being part of wealth, housing is the only measure of non-health consumption that is available in the HRS. The portfolio share in housing does not vary in health, holding constant tangible wealth. This suggests that housing and health are neither strong complements nor substitutes in the utility function, leading to the parameterization $\rho = \sigma$ for the model. The portfolio share in housing falls in age, which partly arises from the fact that the portfolio share in annuities falls in age. For those in good health, the portfolio share rises by 1.70 percentage points for each ten years of age. The portfolio share in housing rises in the logarithm of tangible wealth. For those in good health, the portfolio share rises by 12.00 percentage points when tangible wealth rises by 100 percent.

4. Health Expenditure and Asset Allocation in the Benchmark Model

As described in Appendix B, I solve the consumption and portfolio-choice model by dynamic programming. Using the optimal consumption and portfolio policies, I simulate a population of 100,000 retirees every two years (to coincide with the frequency of interviews in the HRS) from age 65–66 until death. The initial distribution of health is drawn from a lognormal distribution (i.e., $\log \widehat{H}_1 \sim \mathbf{N}(\mu_H, \sigma_H)$) to match the distribution of health for retirees in the HRS at age 65–66. In addition, the initial value of annuities is chosen to match the portfolio share in annuities, conditional on health status, for retirees in the HRS at age 65–66.

Table 4 summarizes the parameters used to calibrate the benchmark model. Following a standard practice for life-cycle models, I calibrate the subjective discount factor to be $\beta = 0.96$. As discussed below, I calibrate the remaining preference parameters to match the targeted moments in the HRS. Overall, the model does a remarkable job of explaining the cross-sectional distribution as well as the joint dynamics of health and wealth in the HRS.

4.1 Health Expenditure

To facilitate the comparison of the data and the model, Panel A of Table 5 reports out-of-pocket health expenditure as a percentage of income by health and age for retirees in the HRS. The table reports the five categories of health status and six age groups: 65–66, 71–72, 77–78, 83–84, and 89–90. The table does not extend beyond age 90 because attrition through death in both the data and the model makes the comparison potentially unreliable. Health expenditure falls in health and rises in age. At age 65–66, those in poor health spend 16 percent of their income on health care, compared to 5 percent for those in excellent health. Retirees in good health spend 8 percent of their income on health care at age 65–66, compared to 25 percent at age 89–90.

Panel B reports health expenditure as a percentage of income by health and age for simulated retirees in the benchmark model. I use the parameter α, which is the utility weight on health, to match the level of health expenditure. I use the parameter σ, which is the elasticity of intertemporal substitution, to match the variation in health expenditure with age. Finally, I use the parameter ψ, which is the returns to scale on health investment, to match the cross-sectional variation in health expenditure across health. The model successfully matches the overall pattern in the data, that health expenditure falls in health and rises in age. At age 65–66, those in poor health spend 21 percent of their income on health care, compared to 6 percent for those in excellent health. Retirees in good health spend 12 percent of their income on health care at age 65–66, compared to 19 percent at age 89–90.

4.2 Distribution of Health

Panel A of Table 6 reports the cross-sectional distribution of health by age for retirees in the HRS. The distribution of health at age 65–66 is 10 percent in poor, 24 percent in fair, 33 percent in good, 25 percent in very good, and 8 percent in excellent. Health subsequently deteriorates over retirement. The distribution of health at age 89–90 is 14 percent in poor, 27 percent in fair, 33 percent in good, 21 percent in very good, and 5 percent in excellent.

Panel B reports the cross-sectional distribution of health by age for simulated retirees in the benchmark model. I calibrate the initial endowment of health to match the distribution of health at age 65–66. I use the parameters μ_H and σ_H, the mean and the standard deviation of health, to control the dynamics of health over retirement. The model predicts high accumulation of health early in retirement, implying that health investment is initially too productive. However, health subsequently deteriorates over retirement, and the model matches the distribution of health by age 89–90. The distribution of health at age 89–90 is

11 percent in poor, 23 percent in fair, 36 percent in good, 26 percent in very good, and 5 percent in excellent.

4.3 Asset Allocation

4.3.1 Portfolio Share in Bonds

Panel A of Table 7 reports the portfolio share in bonds by health and age for retirees in the HRS. The tabulation uses predicted values from the regression model in Table 3. The portfolio share in bonds is mostly level in health but rises in age. Retirees in good health have 3 percent of their tangible wealth in bonds at age 65–66, compared to 22 percent at age 89–90. Retirees allocate a surprisingly large share of their wealth to liquid assets late in retirement.

Panel B reports the portfolio share in bonds by health and age for simulated retirees in the benchmark model. I use the parameter $\overline{u}$, which is the strength of the bequest motive, to match the level of the portfolio share in bonds at age 91–92. That a bequest motive is necessary to explain liquid asset holdings, even in a model with uninsurable health risk, is consistent with previous findings (Ameriks, Caplin, Laufer, and Van Nieuwerburgh, 2007; Love, Palumbo, and Smith, 2009). The model successfully matches how the portfolio share in bonds rises in age. Retirees in good health have 4 percent of their tangible wealth in bonds at age 65–66, compared to 20 percent at age 89–90.

4.3.2 Portfolio Share in Risky Assets

Panel A of Table 8 reports the portfolio share in risky assets by health and age for retirees in the HRS. The portfolio share in risky assets rises slightly in both health and age. At age 65–66, those in poor health have 3 percent of their tangible wealth in risky assets, compared to 5 percent for those in excellent health. Retirees in good health have 4 percent of their tangible wealth in risky assets at age 65–66, compared to 9 percent at age 89–90.

Panel B of Table 8 reports the portfolio share in risky assets by health and age for simulated retirees in the benchmark model. I use the parameter γ, which is the relative risk aversion, to match the level of the portfolio share in risky assets. The model successfully matches how the portfolio share in risky assets rises slightly in both health and age. At age 65–66, those in poor health have 3 percent of their tangible wealth in risky assets, compared to 7 percent for those in excellent health. Retirees in good health have 6 percent of their tangible wealth in risky assets at age 65–66, compared to 10 percent at age 89–90.

4.3.3 Portfolio Share in Annuities

Panel A of Table 9 reports the portfolio share in annuities by health and age for retirees in the HRS. The portfolio share in annuities falls slightly in health and falls significantly in age. At age 65–66, those in poor health have 73 percent of their tangible wealth in annuities, compared to 66 percent for those in excellent health. Retirees in good health have 71 percent of their tangible wealth in annuities at age 65–66, compared to 43 percent at age 89–90.

Panel B reports the portfolio share in annuities by health and age for simulated retirees in the benchmark model. I calibrate the initial endowment of annuities to match the portfolio share in annuities at age 65–66. The model successfully matches how the portfolio share in annuities falls in age. Retirees in good health have 71 percent of their tangible wealth in annuities at age 65–66, compared to 42 percent at age 89–90.

4.3.4 Portfolio Share in Housing

Panel A of Table 10 reports the portfolio share in housing by health and age for retirees in the HRS. The portfolio share in housing is mostly level in health but rises in age. Retirees in good health have 22 percent of their tangible wealth in housing at age 65–66, compared to 26 percent at age 89–90. Housing remains a significant share of the portfolio, even late in retirement. Venti and Wise (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.

Panel B reports the portfolio share in housing by health and age for simulated retirees in the benchmark model. I use the parameter ϕ, which is the utility weight on housing, to match the level of the portfolio share in housing. I use the parameter ρ, which is the elasticity of substitution between health and non-health consumption, to match the cross-sectional variation in the portfolio share in housing across health. The model successfully matches how the portfolio share in housing rises in age. Retirees in good health have 20 percent of their tangible wealth in housing at age 65–66, compared to 28 percent at age 89–90.

5. Welfare Analysis of Private Annuitization

In the benchmark model, the retiree holds a constant endowment of the annuity throughout retirement, as part of a defined-benefit pension plan or Social Security. I now relax this constraint and allow the retiree to purchase additional annuities in any period during retirement. In modeling an annuity market, I adopt two important institutional features of the private annuity market in the United States. First, the pricing of annuities is contingent on age but not on health, calibrated to private insurance rates (Mitchell, Poterba, Warshawsky, and Brown, 1999). Second, annuities are illiquid in the sense that the retiree cannot sell them back to the insurer (due to the potential for adverse selection). In the model, this amounts to a portfolio constraint $B_{3,t} \geq B_{3,t-1}$ for the annuity in each period t.

Table 11 shows the health expenditure and the asset allocation of simulated retirees in the model with an annuity market. Health expenditure is expressed as a percentage of income coming from the initial endowment of annuities at age 65, so that the units are comparable to those in the benchmark model. The presence of an annuity market causes a large reallocation from bonds and stocks to annuities. In addition, the retiree reduces her health expenditure on average, which has an intuitive interpretation as a reduction of saving in health. These results suggest that much of the liquid asset holdings in the benchmark model are a consequence of longevity risk, rather than precautionary saving arising from uncertainty over health expenses.

I calculate the welfare gain from private annuitization by comparing the value function in the model with an annuity market with that in the benchmark model (Brown, 2001). The welfare gain, as a percentage of tangible wealth at age 65, is 13.4 percent for those in poor health, 13.8 percent for those in fair health, 14.8 percent for those in good health, 15.8 percent for those in very good health, and 18.0 percent for those in excellent health. The fact that the welfare gain rises in health is consistent with survey evidence that healthier retirees prefer the annuity income of Social Security to an actuarially equivalent lump-sum payment (Brown, Casey, and Mitchell, 2008). To put these numbers into perspective, Mitchell, Poterba, Warshawsky, and Brown (1999) find a welfare gain of about 40 percent in a model without health expenses or a bequest motive. In other words, health expenses and a bequest motive can partly, but not entirely, explain the so-called annuity puzzle.

6. Conclusion

The study of consumption and portfolio choice in retirement is ultimately about the degree to which markets are incomplete with respect to health risk. This paper investigates the possibility that markets may be more complete than previous studies may have assumed because health expenditure responds endogenously to changes in health and wealth. Indeed, evidence from the HRS reveals that health expenditure as a percentage of income falls significantly in health, controlling for wealth. Moreover, measures of health care utilization are significant predictors of future health and mortality. To quantify the importance of these effects, I calibrate a consumption and portfolio-choice model in which health expenditure is an endogenous response to stochastic depreciation of health. I use the model to explain the cross-sectional distribution and the joint dynamics of health expenditure, health, and asset allocation for retired females in the HRS, aged 65 and older.

In a policy experiment, I use the calibrated model to assess the welfare gain from private annuitization, beyond the forced annuitization through defined-benefit pension plans and Social Security. The welfare gain ranges from 13 percent of wealth at age 65 for those in worst health, to 18 percent for those in best health. Put differently, the market frictions and participation costs that would prevent private annuitization must be as large as these welfare gains. Importantly, the presence of an annuity market not only reduces saving in liquid assets, but also reduces saving in one's own health through health expenditure. In other words, the same frictions that prevent private annuitization appear to be linked to the high demand for health care.

There are several issues that I have not examined, which are worth addressing in future work. First, the model can be used to assess the welfare implications of other financial products, such as variable annuities and reverse mortgages (e.g., Horneff, Maurer, Mitchell, and Stamos, 2007). Second, the model can be extended to married households, in which consumption and portfolio choice depend on the health and survival of both partners (e.g., Lillard and Weiss, 1997; Jacobson, 2000; Love, 2008). Finally, the horizon can be extended to include the working phase prior to retirement. A number of interesting issues then arise such as the correlation between health and labor-income risk (e.g., Grossman, 1972; Hugonnier, Pelgrin, and St-Amour, 2009) and the optimal timing of retirement (e.g., Farhi and Panageas, 2007; Chai, Horneff, Maurer, and Mitchell, 2009). Both health and access to health insurance can affect the timing of retirement, and consequently, consumption and portfolio decisions (e.g., French and Jones, 2007; Blau and Gilleskie, 2008).

Appendix A. Health and Retirement Study

A.1 Relative Price of Health Goods and Services

The RAND HRS data file contains a measure of total health expenditure on hospitals, nursing homes, doctor visits, dentist visits, outpatient surgery, prescription drugs, home health care, and special facilities. It also contains a measure of the out-of-pocket health expenditure, that is, the part of total health expenditure paid by the retiree. Almost all retirees (over 99 percent) report health insurance coverage through Medicare, Medicaid, or insurance from a previous employer. For each retiree, I compute the out-of-pocket expenditure share as the ratio of out-of-pocket health expenditure to total health expenditure.

I use a censored regression model to estimate how the out-of-pocket expenditure share depends on cohort dummies, health status, age, tangible wealth, and their interaction with health status. Table 12 reports the estimated elasticities of the censored regression model. The out-of-pocket expenditure share rises in health, holding constant tangible wealth. Relative to those in good health, which is the omitted category, those in poor health pay 10.59 percentage points less out-of-pocket. Relative to those in good health, those in fair health pay 3.71 percentage points less out-of-pocket. This relation suggests that insurance subsidizes more heavily those health goods and services that treat the unhealthy, relative to those that maintain the health of the already healthy. The out-of-pocket expenditure share also rises in age. For those in good health, the out-of-pocket expenditure share rises by 6.10 percentage points for each ten years of age.

I use the estimated censored regression model to predict the out-of-pocket expenditure share by age and health status. The predicted out-of-pocket expenditure shares correspond to $Q(t, \widehat{H}_t)$ in equation (18), which I use to calibrate the model in Section 4.

A.2 Definition of Asset Classes

Bonds consist 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. Following Hurd (2002), I assume that half of the value of IRA and Keogh accounts is safe and that the other half is risky. I subtract the value of liabilities from the value of bonds. Liabilities consist all mortgages for primary and secondary residence; other home loans for primary residence; and other debt. Risky assets consist of businesses; stocks, mutual funds, and investment trusts; and the risky part of IRA and Keogh accounts. Housing consists of primary and secondary residence.

Annuities consist of an employer pension or annuity; Social Security disability and supplemental security income; and Social Security retirement income. The asset value of annuity income is calculated as total annuity income times the price of a real annuity, given by equation (13). This calculation uses survival probabilities for females in the Social Security life tables (Bell and Miller, 2005, Table 7), matched to individuals in the HRS by birth cohort, and a real interest rate of 1.5 percent. For simplicity, this calculation assumes away any inflation and counterparty risk of annuity income (see Gustman, Mitchell, Samwick, and Steinmeier, 1997, for a similar calculation).

Appendix B. Solution of the Consumption and Portfolio-Choice Model

B.1 Normalizing the Model by Tangible Wealth

Because the consumption and portfolio-choice model is homogeneous, I can normalize all variables by tangible wealth to eliminate a state variable. I normalize the policy variables as $\widehat{C}_t = C_t/\widehat{W}_t$, $\widehat{I}_t = Q_t I_t/\widehat{W}_t$, and $\widehat{A}_{n,t} = A_{n,t}/\widehat{W}_t$ for each asset $n = 1, \ldots, N, D$.

The intraperiod budget constraint (6) can be normalized as

$$\sum_{n=1}^{N} \widehat{A}_{n,t} + \widehat{A}_{D,t} = 1 - \widehat{C}_t - \widehat{I}_t. \tag{B1}$$

The intertemporal budget constraint (8) can be normalized as

$$R_{t+1} = \frac{\widehat{W}_{t+1}}{\widehat{W}_t} = \sum_{n=1}^{N} \widehat{A}_{n,t} R_{n,t+1} + \widehat{A}_{D,t} R_{D,t+1}. \tag{B2}$$

Combining these two budget constraints, I eliminate $\widehat{A}_{1,t}$ as a policy variable:

$$R_{t+1} = (1 - \widehat{C}_t - \widehat{I}_t) R_{1,t+1} + \sum_{n=2}^{N} \widehat{A}_{n,t}(R_{n,t+1} - R_{1,t+1}) + \widehat{A}_{D,t}(R_{D,t+1} - R_{1,t+1}). \tag{B3}$$

In addition to age, there are three state variables in the consumption and portfolio-choice problem. The first state variable is health relative to tangible wealth, defined in equation (16). The law of motion for health is

$$\widehat{H}_{t+1} = \frac{(1 - \omega_{t+1}) Q_{t+1} \widehat{H}_t}{Q_t R_{t+1}} \left[1 + \psi \left(\frac{\widehat{I}_t}{\widehat{H}_t} \right)^{\psi} \right]. \tag{B4}$$

The second state variable is the value of annuities relative to tangible wealth, defined as

$$\widehat{B}_{3,t} = \frac{P_{3,t} B_{3,t-1}}{\widehat{W}_t}. \tag{B5}$$

The law of motion for the value of annuities is

$$\widehat{B}_{3,t+1} = \frac{P_{3,t+1} \widehat{A}_{3,t}}{P_{3,t} R_{t+1}}. \tag{B6}$$

The third state variable is the relative price of housing, whose law of motion is given by equation (7).

The intraperiod utility flow (9) can be normalized as

$$\widehat{U}_t = \frac{U(C_t, D_t, H_t)}{\widehat{W}_t} = \widehat{C}_t V_t, \tag{B7}$$

where

$$V_t = \left[(1-\alpha)\left(\frac{\widehat{A}_{D,t}}{P_t\widehat{C}_t}\right)^{\phi(1-1/\rho)} + \alpha\left(\frac{\widehat{H}_t[1+\psi(\widehat{I}_t/\widehat{H}_t)^{\psi}]}{Q_t\widehat{C}_t}\right)^{1-1/\rho}\right]^{1/(1-1/\rho)}. \tag{B8}$$

The bequest function can be normalized as

$$\widehat{G}_t = \frac{G(W_t, P_t)}{\widehat{W}_t} = \overline{u}\left(\frac{\phi}{(1-\phi)P_t}\right)^{\phi}. \tag{B9}$$

The marginal utility of consumption is

$$\frac{\partial \widehat{U}_t}{\partial \widehat{C}_t} = (1-\alpha)(1-\phi)V_t^{1/\rho}\left(\frac{\widehat{A}_{D,t}}{P_t\widehat{C}_t}\right)^{\phi(1-1/\rho)}. \tag{B10}$$

The marginal utility of health expenditure is

$$\frac{\partial \widehat{U}_t}{\partial \widehat{I}_t} = \frac{\alpha\psi^2\widehat{C}_t V_t^{1/\rho}}{\widehat{H}_t^{\psi}\widehat{I}_t^{1-\psi} + \psi\widehat{I}_t}\left(\frac{\widehat{H}_t[1+\psi(\widehat{I}_t/\widehat{H}_t)^{\psi}]}{Q_t\widehat{C}_t}\right)^{1-1/\rho}. \tag{B11}$$

The marginal utility of the portfolio share in housing is

$$\frac{\partial \widehat{U}_t}{\partial \widehat{A}_{D,t}} = \frac{(1-\alpha)\phi\widehat{C}_t V_t^{1/\rho}}{\widehat{A}_{D,t}}\left(\frac{\widehat{A}_{D,t}}{P_t\widehat{C}_t}\right)^{\phi(1-1/\rho)}. \tag{B12}$$

B.2 Dynamic Programming Problem

The Bellman equation is

$$\begin{aligned}
\widehat{J}_t &= \frac{J_t}{\widehat{W}_t} \\
&= \max_{\widehat{C}_t,\widehat{I}_t,\widehat{A}_{2,t},\ldots,\widehat{A}_{N,t},\widehat{A}_{D,t}} \{(1-\beta)\widehat{U}_t^{1-1/\sigma} \\
&\quad +\beta \mathbf{E}_t[R_{t+1}^{1-\gamma}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1}^{1-\gamma} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]^{(1-1/\sigma)/(1-\gamma)}\}^{1/(1-1/\sigma)}. \qquad \text{(B13)}
\end{aligned}$$

The consumption and portfolio-choice problem is subject to the following constraints:

$$\widehat{C}_t + \widehat{I}_t + \widehat{A}_{2,t} + \widehat{A}_{3,t} + (1-\lambda)\widehat{A}_{D,t} \leq 1, \qquad \text{(B14)}$$

$$\widehat{A}_{3,t} \geq \widehat{B}_{3,t}. \qquad \text{(B15)}$$

In the benchmark model without private annuitization, constraint (B15) holds as an equality.

The partial derivative of the value function with respect to consumption is

$$\begin{aligned}
\frac{\partial \widehat{J}_t}{\partial \widehat{C}_t} &= \widehat{J}_t^{1/\sigma}\Bigg\{(1-\beta)\widehat{U}_t^{-1/\sigma}\frac{\partial \widehat{U}_t}{\partial \widehat{C}_t} \\
&\quad -\beta \mathbf{E}_t[R_{t+1}^{1-\gamma}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1}^{1-\gamma} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)} \\
&\quad \times \mathbf{E}_t[R_{t+1}^{-\gamma}R_{1,t+1}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]\}. \qquad \text{(B16)}
\end{aligned}$$

The partial derivative of the value function with respect to health expenditure is

$$\begin{aligned}
\frac{\partial \widehat{J}_t}{\partial \widehat{I}_t} &= \widehat{J}_t^{1/\sigma}\Bigg\{(1-\beta)\widehat{U}_t^{-1/\sigma}\frac{\partial \widehat{U}_t}{\partial \widehat{I}_t} \\
&\quad -\beta \mathbf{E}_t[R_{t+1}^{1-\gamma}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1}^{1-\gamma} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)} \\
&\quad \times \mathbf{E}_t[R_{t+1}^{-\gamma}R_{1,t+1}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]\}. \qquad \text{(B17)}
\end{aligned}$$

The partial derivative of the value function with respect to the portfolio share in each financial asset is

$$\begin{aligned}\frac{\partial \widehat{J}_t}{\partial \widehat{A}_{n,t}} &= \widehat{J}_t^{1/\sigma}\beta \mathbf{E}_t[R_{t+1}^{1-\gamma}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1}^{1-\gamma} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)} \\ &\quad \times \mathbf{E}_t[R_{t+1}^{-\gamma}(R_{n,t+1} - R_{1,t+1})(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})], \qquad \text{(B18)}\end{aligned}$$

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

$$\begin{aligned}\frac{\partial \widehat{J}_t}{\partial \widehat{A}_{D,t}} &= \widehat{J}_t^{1/\sigma}\Bigg\{(1-\beta)\widehat{U}_t^{-1/\sigma}\frac{\partial \widehat{U}_t}{\partial \widehat{A}_{D,t}} \\ &\quad + \beta \mathbf{E}_t[R_{t+1}^{1-\gamma}(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1}^{1-\gamma} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)} \\ &\quad \times \mathbf{E}_t[R_{t+1}^{-\gamma}(R_{D,t+1} - R_{1,t+1})(1_{\{\omega_{t+1}\neq 1\}}\widehat{J}_{t+1} + 1_{\{\omega_{t+1}=1\}}\widehat{G}_{t+1}^{1-\gamma})]\Bigg\}. \qquad \text{(B19)}\end{aligned}$$

B.3 Numerical Algorithm

Retirees are assumed to die with certainty at age 119–120. I use value iteration to solve the dynamic programming problem recursively from age 117–118 back to age 65–66. I discretize health $\widehat{H}_t$ into five grid points, where the grid values are based on the initial distribution of health at age 65–66. I discretize the value of annuities $\widehat{B}_{3,t}$ into five grid points, equally spaced from 0.1 to 0.9. I discretize the relative price of housing P_t into five grid points, equally spaced on a logarithmic scale from 1 to 1.5. I compute the transition probabilities between these five grid points based on the moments for housing return (15). Finally, I discretize the lognormal shock to risky assets $\nu_{2,t}$ into five grid points, spaced so that each grid value realizes with equal probability.

References

Ameriks, John, Andrew Caplin, Steven Laufer, and Stijn Van Nieuwerburgh. 2007. "The Joy of Giving or Assisted Living? Using Strategic Surveys to Separate Bequest and Precautionary Motives." Working Paper No. 13105, National Bureau of Economic Research.

Bell, Felicitie C. and Michael L. Miller. 2005. "Life Tables for the United States Social Security Area 1900–2100." Actuarial Study No. 120, Social Security Administration.

Blau, David M. and Donna B. Gilleskie. 2008. "The Role of Retiree Health Insurance in the Employment Behavior of Older Men." *International Economic Review* 49 (2):475–514.

Bodie, Zvi, Robert C. Merton, and William F. Samuelson. 1992. "Labor Supply Flexibility and Portfolio Choice in a Life Cycle Model." *Journal of Economic Dynamics and Control* 16 (3-4):427–449.

Brown, Jeffrey R. 2001. "Private Pensions, Mortality Risk, and the Decision to Annuitize." *Journal of Public Economics* 82 (1):29–62.

———. 2007. "Rational and Behavioral Perspectives on the Role of Annuities in Retirement Planning." Working Paper No. 13537, National Bureau of Economic Research.

Brown, Jeffrey R., Marcus D. Casey, and Olivia S. Mitchell. 2008. "Who Values the Social Security Annuity? New Evidence on the Annuity Puzzle." Working Paper No. 13800, National Bureau of Economic Research.

Chai, Jingjing, Wolfram Horneff, Raimond Maurer, and Olivia S. Mitchell. 2009. "Extending Life Cycle Models of Optimal Portfolio Choice Integrating Flexible Work, Endogenous Retirement, and Investment Decisions with Lifetime Payouts." Working Paper No. 15079, National Bureau of Economic Research.

Cocco, João F. 2005. "Portfolio Choice in the Presence of Housing." *Review of Financial Studies* 18 (2):535–567.

Cocco, João F., Francisco J. Gomes, and Pascal J. Maenhout. 2005. "Consumption and Portfolio Choice over the Life Cycle." *Review of Financial Studies* 18 (2):491–533.

Coile, Courtney C. and Kevin S. Milligan. 2006. "How Household Portfolios Evolve After Retirement: The Effect of Aging and Health Shocks." Working Paper No. 12391, National Bureau of Economic Research.

Davidoff, Thomas. 2008. "Illiquid Housing as Self-Insurance: The Case of Long-Term Care." Working paper, University of California at Berkeley.

Davidoff, Thomas, Jeffrey R. Brown, and Peter A. Diamond. 2005. "Annuities and Individual Welfare." *American Economic Review* 95 (5):1573–1590.

De Nardi, Mariacristina, Eric French, and John Bailey Jones. 2006. "Differential Mortality, Uncertain Medical Expenditures, and the Savings of Elderly Singles." Working Paper No. 12554, National Bureau of Economic Research.

Edwards, Ryan D. 2008. "Health Risk and Portfolio Choice." *Journal of Business and Economic Statistics* 26 (4):472–485.

Ehrlich, Isaac and Hiroyuki Chuma. 1990. "A Model of the Demand for Longevity and the Value of Life Extension." *Journal of Political Economy* 98 (4):761–782.

Epstein, Larry G. and Stanley E. Zin. 1991. "Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: An Empirical Analysis." *Journal of Political Economy* 99 (2):263–286.

Farhi, Emmanuel and Stavros Panageas. 2007. "Saving and Investing for Early Retirement: A Theoretical Analysis." *Journal of Financial Economics* 83 (1):87–121.

French, Eric and John Bailey Jones. 2007. "The Effects of Health Insurance and Self-Insurance on Retirement Behavior." Working Paper No. 2001-19, Federal Reserve Bank of Chicago.

Friedman, Benjamin M. and Mark J. Warshawsky. 1990. "The Cost of Annuities: Implications for Saving Behavior and Bequests." *Quarterly Journal of Economics* 105 (1):135–154.

Grossman, Michael. 1972. "On the Concept of Health Capital and the Demand for Health." *Journal of Political Economy* 80 (2):223–255.

Gustman, Alan L., Olivia S. Mitchell, Andrew A. Samwick, and Thomas L. Steinmeier. 1997. "Pension and Social Security Wealth in the Health and Retirement Study." Working Paper No. 5912, National Bureau of Economic Research.

Horneff, Wolfram J., Raimond H. Maurer, Olivia S. Mitchell, and Michael Z. Stamos. 2007. "Money in Motion: Dynamic Portfolio Choice in Retirement." Working Paper No. 12942, National Bureau of Economic Research.

Hu, Xiaoqing. 2005. "Portfolio Choices for Homeowners." *Journal of Urban Economics* 58 (1):114–136.

Hubbard, R. Glenn, Jonathan Skinner, and Stephen P. Zeldes. 1994. "The Importance of Precautionary Motives in Explaining Individual and Aggregate Saving." *Carnegie-Rochester Conference Series on Public Policy* 40:59–125.

Hugonnier, Julien, Florian Pelgrin, and Pascal St-Amour. 2009. "Health and (Other) Asset Holdings." Working paper, University of Lausanne.

Hurd, Michael D. 2002. "Portfolio Holdings of the Elderly." In *Household Portfolios*, edited by Luigi Guiso, Michael Haliassos, and Tullio Jappelli, chap. 11. Cambridge, MA: MIT Press, 431–472.

Inkmann, Joachim, Paula Lopes, and Alexander Michaelides. 2007. "How Deep is the Annuity Market Participation Puzzle?" Discussion Paper No. 2007-011, Network for Studies on Pensions, Aging and Retirement.

Jacobson, Lena. 2000. "The Family as Producer of Health — An Extended Grossman Model." *Journal of Health Economics* 19 (5):611–637.

Khwaja, Ahmed W. 2002. "Health Insurance, Habits and Health Outcomes: Moral Hazard in a Dynamic Stochastic Model of Investment in Health." Working paper, Duke University.

Lillard, Lee A. and Yoram Weiss. 1997. "Uncertain Health and Survival: Effects on End-of-Life Consumption." *Journal of Business and Economic Statistics* 15 (2):254–268.

Love, David A. 2008. "Marital Status and Portfolio Choice." Working paper, Williams College.

Love, David A., Michael G. Palumbo, and Paul A. Smith. 2009. "The Trajectory of Wealth in Retirement." *Journal of Public Economics* 93 (1-2):191–208.

Love, David A. and Maria G. Perozek. 2007. "Should the Old Play It Safe? Portfolio Choice with Uncertain Medical Expenses." Working paper, Williams College.

Mitchell, Olivia S., James M. Poterba, Mark J. Warshawsky, and Jeffrey R. Brown. 1999. "New Evidence on the Money's Worth of Individual Annuities." *American Economic Review* 89 (5):1299–1318.

Palumbo, Michael G. 1999. "Uncertain Medical Expenses and Precautionary Saving Near the End of the Life Cycle." *Review of Economic Studies* 66 (2):395–421.

Pang, Gaobo and Mark Warshawsky. 2007. "Optimizing the Equity-Bond-Annuity Portfolio in Retirement: The Impact of Uncertain Health Expenses." Technical Paper No. 07/14, Watson Wyatt Worldwide.

Picone, Gabriel, Martin Uribe, and R. Mark Wilson. 1998. "The Effect of Uncertainty on the Demand for Medical Care, Health Capital and Wealth." *Journal of Health Economics* 17 (2):171–185.

Rosen, Harvey S. and Stephen Wu. 2004. "Portfolio Choice and Health Status." *Journal of Financial Economics* 72 (3):457–484.

Sinai, Todd and Nicholas S. Souleles. 2007. "Net Worth and Housing Equity in Retirement." Working Paper No. 13693, National Bureau of Economic Research.

Sinclair, Sven H. and Kent A. Smetters. 2004. "Health Shocks and the Demand for Annuities." Technical Paper No. 2004-9, Congressional Budget Office.

Turra, Cassio M. and Olivia S. Mitchell. 2004. "The Impact of Health Status and Out-of-Pocket Medical Expenditures on Annuity Valuation." Working Paper No. 2004-086, Michigan Retirement Research Center.

Venti, Steven F. and David A. Wise. 2004. "Aging and Housing Equity: Another Look." In *Perspectives on the Economics of Aging*, edited by David A. Wise, chap. 3. Chicago: The University of Chicago Press, 127–175.

Wagstaff, Adam. 1986. "The Demand for Health: Some New Empirical Evidence." *Journal of Health Economics* 5 (3):195–233.

Wallace, Robert B. and A. Regula Herzog. 1995. "Overview of the Health Measures in the Health and Retirement Study." *Journal of Human Resources* 30 (0):84–107.

Wooldridge, Jeffrey M. 2002. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: MIT Press.

Yaari, Menahem E. 1965. "Uncertain Lifetime, Life Insurance, and the Theory of the Consumer." *Review of Economic Studies* 32 (2):137–150.

Yao, Rui and Harold H. Zhang. 2005. "Optimal Consumption and Portfolio Choices with Risky Housing and Borrowing Constraints." *Review of Financial Studies* 18 (1):197–239.

Table 1: Descriptive Statistics for Health Status and Health Care Utilization

Panel A reports the percentage of retirees who have ever reported doctor-diagnosed health problems, separately by health status. Panel B reports the percentage of retirees who report some difficulty with activities of daily living at the time of interview, separately by health status. Panel C reports the percentage of retirees who report utilizing health care in the two years prior to the interview, separately by health status. The sample consists of retired females in the HRS, born 1891–1940 and aged 65 and older.

	Health Status				
	Poor	Fair	Good	Very Good	Excellent
Panel A: Doctor-Diagnosed Health Problems (% of Retirees)					
High blood pressure	72	67	61	50	34
Diabetes	30	24	15	9	5
Cancer	19	16	14	13	9
Lung disease	21	14	8	5	3
Heart problems	56	41	28	18	12
Stroke	29	17	11	7	4
Psychiatric problems	31	21	13	9	5
Arthritis	81	74	65	55	38
Panel B: Some Difficulty with Activities of Daily Living (% of Retirees)					
Bathing	48	24	12	7	5
Dressing	46	24	12	6	4
Eating	24	10	4	3	2
Panel C: Health Care Utilization (% of Retirees)					
Doctor visit	97	97	95	93	88
Dentist visit	33	41	50	57	59
Home health care	35	20	12	7	5
Nursing home	23	12	8	6	5
Outpatient surgery	19	19	18	17	16
Prescription drugs	95	93	87	80	65
Cholesterol test	78	77	77	78	70
Mammogram	53	59	62	63	60
Vigorous physical activity	7	14	25	34	46
Smoking	10	11	10	9	8

Table 2: Estimation of the Health Transition Probabilities

The table reports estimates of an ordered probit model for predicting future health status (at two years from the present interview). The latent variable, which captures unobservable health, depends on cohort dummies, present health status, age, tangible wealth, and their interaction with health status. Additional explanatory variables include dummies for measures of health care utilization (a doctor visit, a dentist visit, home health care, nursing home, outpatient surgery, prescription drugs, a cholesterol test, a mammogram, vigorous physical activity, and smoking), dummies for doctor-diagnosed health problems, and dummies for measures of some difficulty with activities of daily living. The table reports the estimated coefficients with heteroskedasticity-robust *t*-statistics in parentheses. The sample consists of retired females in the HRS, born 1891–1940 and aged 65 and older.

Explanatory Variable	(1)		(2)	
Birth cohort:				
1891–1900	-67.44	(-3.36)	-80.35	(-3.99)
1901–1910	-26.26	(-3.24)	-36.18	(-4.38)
1911–1920	-4.98	(-1.02)	-13.41	(-2.68)
1921–1930	0.20	(0.06)	-4.81	(-1.48)
Health status:				
Poor	-150.39	(-5.40)	-120.26	(-4.31)
Fair	-87.35	(-5.34)	-77.28	(-4.58)
Very good	40.09	(2.74)	36.16	(2.42)
Excellent	118.38	(5.30)	110.93	(4.94)
$(\text{Age} - 65)/10$	-18.11	(-5.04)	-13.42	(-3.68)
× Poor	14.42	(3.42)	11.19	(2.62)
× Fair	15.03	(4.11)	13.75	(3.71)
× Very good	0.36	(0.09)	1.79	(0.43)
× Excellent	2.19	(0.29)	4.77	(0.63)
Tangible wealth	7.00	(3.24)	5.77	(2.63)
× Poor	-10.73	(-3.03)	-9.74	(-2.72)
× Fair	-7.35	(-2.42)	-6.97	(-2.27)
× Very good	5.44	(1.52)	5.53	(1.54)
× Excellent	5.63	(0.97)	5.42	(0.93)
Doctor visit	-1.63	(-0.15)	-0.88	(-0.08)
× Poor	-2.73	(-0.12)	-10.78	(-0.48)
× Fair	2.06	(0.13)	2.75	(0.16)
× Very good	3.14	(0.21)	2.76	(0.19)
× Excellent	-14.95	(-0.68)	-12.44	(-0.56)
Dentist visit	9.15	(2.55)	6.57	(1.82)
× Poor	2.47	(0.38)	2.38	(0.36)
× Fair	1.27	(0.24)	2.05	(0.39)
× Very good	11.24	(1.90)	11.48	(1.94)
× Excellent	13.31	(1.11)	12.73	(1.06)
Home health care	-29.92	(-4.88)	-19.44	(-3.13)
× Poor	3.97	(0.49)	7.88	(0.95)
× Fair	1.48	(0.19)	5.12	(0.65)
× Very good	-13.60	(-1.09)	-15.33	(-1.22)
× Excellent	-92.41	(-3.21)	-86.65	(-3.10)
Nursing home	1.54	(0.15)	0.69	(0.07)
× Poor	-16.11	(-1.18)	-9.03	(-0.66)
× Fair	-30.40	(-2.16)	-21.95	(-1.55)
× Very good	-24.87	(-1.25)	-17.43	(-0.87)
× Excellent	-86.20	(-1.60)	-84.47	(-1.54)

Explanatory Variable	(1)		(2)	
Outpatient surgery	0.00	(0.00)	1.52	(0.35)
× Poor	2.74	(0.38)	1.58	(0.21)
× Fair	0.18	(0.03)	-0.35	(-0.06)
× Very good	-1.83	(-0.26)	-1.78	(-0.25)
× Excellent	-0.84	(-0.06)	-0.13	(-0.01)
Prescription drugs	-20.77	(-3.92)	-3.70	(-0.68)
× Poor	20.06	(1.36)	26.10	(1.74)
× Fair	-3.17	(-0.32)	-2.61	(-0.27)
× Very good	-1.53	(-0.19)	-5.11	(-0.64)
× Excellent	-12.65	(-0.99)	-22.64	(-1.78)
Cholesterol test	4.25	(0.96)	8.25	(1.86)
× Poor	-3.71	(-0.48)	-6.12	(-0.80)
× Fair	5.69	(0.87)	4.25	(0.65)
× Very good	15.00	(2.01)	13.09	(1.74)
× Excellent	-13.19	(-0.95)	-14.09	(-1.02)
Mammogram	2.61	(0.66)	3.21	(0.81)
× Poor	0.57	(0.09)	-0.79	(-0.12)
× Fair	0.14	(0.02)	-0.85	(-0.15)
× Very good	-1.92	(-0.30)	-1.37	(-0.22)
× Excellent	32.52	(2.58)	31.95	(2.53)
Vigorous physical activity	15.10	(4.22)	10.49	(2.91)
× Poor	6.14	(0.68)	2.00	(0.22)
× Fair	10.06	(1.68)	9.50	(1.57)
× Very good	4.85	(0.85)	7.68	(1.35)
× Excellent	19.54	(1.82)	22.83	(2.13)
Smoking	-17.95	(-3.15)	-18.38	(-3.16)
× Poor	4.88	(0.54)	3.37	(0.36)
× Fair	6.45	(0.80)	2.90	(0.36)
× Very good	6.96	(0.77)	6.88	(0.76)
× Excellent	-29.06	(-1.50)	-28.96	(-1.52)
Doctor-diagnosed health problems:				
High blood pressure			-11.51	(-5.27)
Diabetes			-19.24	(-7.04)
Cancer			-15.66	(-5.40)
Lung disease			-26.41	(-7.93)
Heart problems			-16.49	(-7.14)
Stroke			-8.73	(-2.63)
Psychiatric problems			-11.99	(-4.28)
Arthritis			-12.10	(-5.17)
Some difficulty with activities of daily living:				
Bathing			-14.93	(-4.24)
Dressing			-12.25	(-3.79)
Eating			-28.51	(-5.68)
Cut points:				
Poor	-2.06	(-19.49)	-2.26	(-20.45)
Fair	-1.45	(-13.92)	-1.63	(-15.00)
Good	-0.62	(-5.94)	-0.77	(-7.13)
Very good	0.39	(3.79)	0.26	(2.41)
Excellent	1.63	(15.15)	1.51	(13.53)
Wald test on health care utilization	403.99	(0.00)	244.16	(0.00)
Observations	13,540		13,423	

Table 3: Estimation of the Portfolio Share in Risky Assets, Annuities, and Housing
The table reports estimates of a censored regression model for the percentage of tangible wealth in each of three asset classes. Tangible wealth is the sum of the asset value of bonds, risky assets, annuities, and housing. Explanatory variables include cohort dummies, health status, age, tangible wealth, and their interaction with health status. The table reports the estimated elasticities at the mean of the explanatory variables with heteroskedasticity-robust t-statistics in parentheses. The sample consists of retired females in the HRS, born 1891–1940 and aged 65 and older.

Explanatory Variable	Risky Assets		Annuities		Housing	
Birth cohort:						
1891–1900	-3.46	(-18.13)	21.73	(10.56)	-15.41	(-8.42)
1901–1910	-3.27	(-15.95)	8.93	(8.31)	-4.62	(-3.86)
1911–1920	-2.37	(-8.43)	5.37	(6.93)	-1.33	(-1.61)
1921–1930	-0.34	(-1.49)	2.31	(3.81)	1.37	(2.19)
Health status:						
Poor	-1.40	(-2.43)	1.66	(1.37)	0.55	(0.37)
Fair	-1.66	(-4.77)	2.17	(2.20)	-0.38	(-0.38)
Very good	0.62	(1.66)	-1.53	(-1.55)	1.11	(1.11)
Excellent	0.67	(1.22)	-5.68	(-2.72)	5.08	(2.52)
$(\text{Age} - 65)/10$	1.32	(5.51)	-11.70	(-20.73)	1.70	(2.62)
$\times$ Poor	-0.13	(-0.28)	0.66	(0.83)	-0.19	(-0.18)
$\times$ Fair	0.74	(2.44)	-0.78	(-1.20)	0.42	(0.56)
$\times$ Very good	-0.11	(-0.43)	0.70	(1.04)	-0.81	(-1.08)
$\times$ Excellent	-0.17	(-0.47)	2.20	(1.93)	-1.31	(-1.10)
Tangible wealth	6.32	(33.42)	-23.36	(-35.26)	12.00	(26.29)
$\times$ Poor	0.88	(2.22)	-1.26	(-1.07)	3.83	(3.43)
$\times$ Fair	0.61	(2.14)	-0.95	(-0.92)	1.40	(1.71)
$\times$ Very good	-0.45	(-1.81)	1.01	(1.20)	-2.58	(-3.73)
$\times$ Excellent	-0.85	(-2.37)	4.50	(2.25)	-5.46	(-4.20)
Observations	20,635		20,635		20,635	

Table 4: Parameters in the Benchmark Model

The table summarizes the parameters used to calibrate the benchmark model. 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.

Parameter	Symbol	Value
Preferences:		
Subjective discount factor	β	0.96
Elasticity of intertemporal substitution	σ	0.7
Relative risk aversion	γ	8
Utility weight on housing	ϕ	0.4
Utility weight on health	α	0.3
Elasticity of substitution between health and non-health consumption	ρ	0.7
Strength of the bequest motive	$\overline{u}$	0.2
Asset returns:		
Bond return	$\overline{R}_1 - 1$	2.5%
Average risky-asset return	$\overline{R}_2 - 1$	6.5%
Standard deviation of risky-asset return	σ_2	18%
Average annuity return	$\overline{R}_3 - 1$	1.5%
Housing:		
Depreciation rate	δ	1.14%
Average housing return	$\overline{R}_D - 1$	0.4%
Standard deviation of housing return	σ_D	3.5%
Borrowing limit	λ	20%
Health:		
Growth rate of the relative price of health goods and services	q	1.9%
Average of log health	μ_H	-12
Standard deviation of log health	σ_H	1
Returns to scale on health investment	ψ	0.12

Table 5: Health Expenditure by Age and Health Status

Panel A reports the out-of-pocket health expenditure as a percentage of annuity income for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The tabulation uses predicted values from a regression model in which the explanatory variables are cohort dummies, health status, age, tangible wealth, and their interaction with health status. Panel B reports the out-of-pocket health expenditure averaged over simulated retirees in the benchmark model. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: HRS Data (% of Annuity Income)					
Poor	16	20	25	31	39
Fair	12	16	20	25	31
Good	8	11	14	19	25
Very good	6	8	11	14	19
Excellent	5	6	8	10	13
Panel B: Benchmark Model (% of Annuity Income)					
Poor	21	22	26	31	35
Fair	16	18	21	25	27
Good	12	14	16	19	19
Very good	7	9	9	11	11
Excellent	6	6	5	7	7

Table 6: Distribution of Health by Age

Panel A reports the distribution of health for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The tabulation uses predicted values from an ordered probit model in which the explanatory variables are cohort dummies, age, and tangible wealth. Panel B reports the distribution of health for simulated retirees in the benchmark model. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: HRS Data (% of Retirees)					
Poor	10	11	12	13	14
Fair	24	25	26	26	27
Good	33	33	33	33	33
Very good	25	24	23	22	21
Excellent	8	7	7	6	5
Panel B: Benchmark Model (% of Retirees)					
Poor	10	8	8	9	11
Fair	24	15	17	20	23
Good	33	32	33	35	36
Very good	25	33	31	29	26
Excellent	8	13	10	7	5

Table 7: Portfolio Share in Bonds by Age and Health Status

Panel A reports the percentage of tangible wealth in bonds for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The tabulation uses predicted values from the censored regression model in Table 3. Panel B reports the percentage of tangible wealth in bonds averaged over simulated retirees in the benchmark model. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: HRS Data (% of Tangible Wealth)					
Poor	3	7	12	17	22
Fair	3	8	13	17	21
Good	3	8	13	18	22
Very good	3	8	13	18	22
Excellent	3	7	12	16	20
Panel B: Benchmark Model (% of Tangible Wealth)					
Poor	8	9	13	18	21
Fair	5	8	12	17	21
Good	4	7	11	16	20
Very good	2	6	11	16	20
Excellent	3	5	11	17	20

Table 8: Portfolio Share in Risky Assets by Age and Health Status

Panel A reports the percentage of tangible wealth in risky assets for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The tabulation uses predicted values from the censored regression model in Table 3. Panel B reports the percentage of tangible wealth in risky assets averaged over simulated retirees in the benchmark model. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: HRS Data (% of Tangible Wealth)					
Poor	3	3	4	5	6
Fair	3	4	5	7	9
Good	4	5	6	8	9
Very good	5	6	7	8	10
Excellent	5	6	7	8	10
Panel B: Benchmark Model (% of Tangible Wealth)					
Poor	3	7	8	9	9
Fair	5	7	8	9	9
Good	6	7	8	9	10
Very good	7	7	8	9	10
Excellent	7	8	8	9	9

Table 9: Portfolio Share in Annuities by Age and Health Status

Panel A reports the percentage of tangible wealth in annuities for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The tabulation uses predicted values from the censored regression model in Table 3. Panel B reports the percentage of tangible wealth in annuities averaged over simulated retirees in the benchmark model. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: HRS Data (% of Tangible Wealth)					
Poor	73	66	60	53	46
Fair	73	66	58	51	43
Good	71	64	57	50	43
Very good	70	63	57	50	43
Excellent	66	60	54	48	43
Panel B: Benchmark Model (% of Tangible Wealth)					
Poor	73	62	54	47	43
Fair	73	62	54	47	42
Good	71	62	54	46	42
Very good	70	62	54	46	42
Excellent	66	62	54	47	42

Table 10: Portfolio Share in Housing by Age and Health Status

Panel A reports the percentage of tangible wealth in housing for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The tabulation uses predicted values from the censored regression model in Table 3. Panel B reports the percentage of tangible wealth in housing averaged over simulated retirees in the benchmark model. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: HRS Data (% of Tangible Wealth)					
Poor	22	23	24	25	26
Fair	21	22	24	25	26
Good	22	23	24	25	26
Very good	23	23	24	24	25
Excellent	27	27	27	27	28
Panel B: Benchmark Model (% of Tangible Wealth)					
Poor	16	22	25	27	26
Fair	18	23	26	27	27
Good	20	24	27	28	28
Very good	22	25	27	29	29
Excellent	25	25	27	28	28

Table 11: Health Expenditure and Asset Allocation in the Model with an Annuity Market
Panel A reports the out-of-pocket health expenditure as a percentage of annuity income averaged over simulated retirees in the model with an annuity market. Panels B through E report the percentage of tangible wealth in bonds, risky assets, annuities, and housing. The parameters of the model are those reported in Table 4.

Health Status	Age				
	65–66	71–72	77-78	83–84	89–90
Panel A: Health Expenditure (% of Annuity Income)					
Poor	16	17	19	22	21
Fair	10	12	14	16	15
Good	6	8	9	12	12
Very good	4	5	6	7	9
Excellent	3	4	5	5	9
Panel B: Bonds (% of Tangible Wealth)					
Poor	0	0	0	-1	-1
Fair	0	0	0	-1	-1
Good	0	0	0	-1	-1
Very good	0	0	0	-1	-1
Excellent	0	0	-1	-1	-1
Panel C: Risky Assets (% of Tangible Wealth)					
Poor	0	0	0	0	0
Fair	0	0	0	0	0
Good	0	0	0	0	0
Very good	0	0	0	0	0
Excellent	0	0	0	0	0
Panel D: Annuities (% of Tangible Wealth)					
Poor	96	97	97	97	97
Fair	97	97	97	97	97
Good	97	97	97	97	97
Very good	96	97	97	97	97
Excellent	96	96	96	96	96
Panel E: Housing (% of Tangible Wealth)					
Poor	4	4	4	3	3
Fair	4	4	4	4	4
Good	4	3	3	3	3
Very good	4	4	4	4	4
Excellent	4	5	5	5	5

Table 12: Estimation of the Out-of-Pocket Expenditure Share

The table reports estimates of a censored regression model for the percentage of total health expenditure that is paid out-of-pocket. Health expenditure includes the cost of hospitals, nursing homes, doctor visits, dentist visits, outpatient surgery, prescription drugs, home health care, and special facilities. Explanatory variables include cohort dummies, health status, age, tangible wealth, and their interaction with health status. The table reports the estimated elasticities at the mean of the explanatory variables with heteroskedasticity-robust *t*-statistics in parentheses. The sample consists of retired females in the HRS, born 1891–1940 and aged 65 and older.

Explanatory Variable	Elasticity	
Birth cohort:		
1891–1900	-27.69	(-10.10)
1901–1910	-17.73	(-8.09)
1911–1920	-12.60	(-7.27)
1921–1930	-5.37	(-4.08)
Health status:		
Poor	-10.59	(-4.88)
Fair	-3.71	(-1.96)
Very good	3.92	(1.98)
Excellent	-3.34	(-1.23)
(Age – 65)/10	6.10	(4.90)
× Poor	4.09	(2.74)
× Fair	1.49	(1.17)
× Very good	-1.66	(-1.25)
× Excellent	-0.21	(-0.11)
Tangible wealth	5.59	(7.15)
× Poor	0.66	(0.50)
× Fair	3.70	(3.24)
× Very good	0.87	(0.74)
× Excellent	0.28	(0.18)
Observations	14,088	

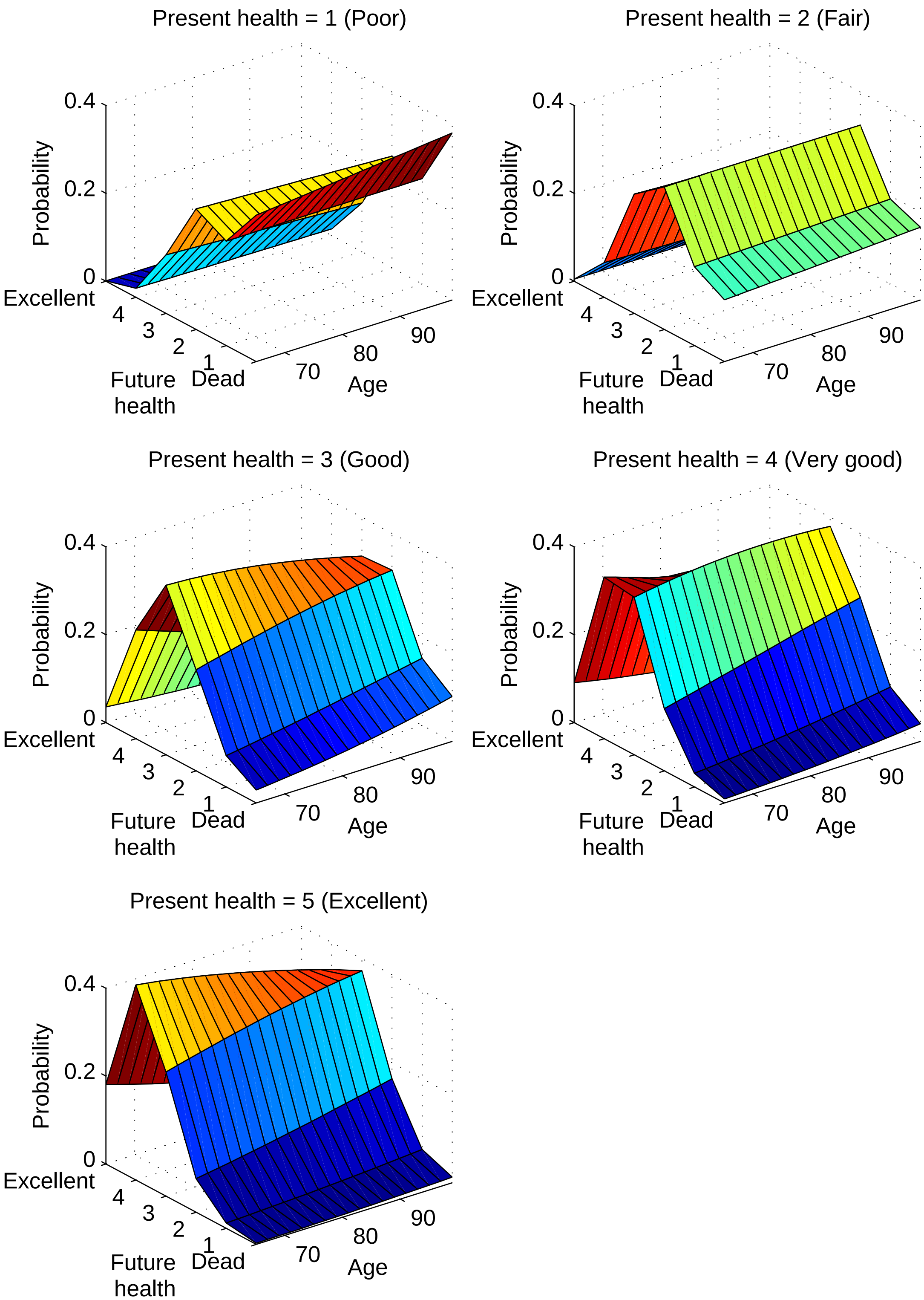

Figure 1: Health Transition Probabilities in the Absence of Health Expenditure
The figure shows the health transition probabilities in the absence of health expenditure for retired females in the HRS, born 1931–1940 and at the average tangible wealth conditional on cohort and age. The predicted probabilities are based on the ordered probit model in column (1) of Table 2.