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

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ABSTRACT

In a life-cycle model, a retiree faces stochastic health depreciation and chooses consumption, health expenditure, and the allocation of wealth between bonds, stocks, and housing. The model explains key facts about asset allocation and health expenditure across health status and age. The portfolio share in stocks is low overall and is positively related to health, especially for younger retirees. The portfolio share in housing is negatively related to health for younger retirees and falls significantly in age. Finally, out-of-pocket health expenditure as a share of income is negatively related to health and rises in age.

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1. Introduction

As a large cohort of baby boomers enters retirement, there is growing fiscal pressure to reduce the benefits promised by Social Security and Medicare, and the impact of such reforms on private saving and the demand for health care remains unclear. At the same time, there is growing availability of financial products like annuities, reverse mortgages, Medigap insurance, and long-term care insurance that supplement or replace public insurance. Despite enormous practical interest, there is relatively little academic work on consumption and portfolio decisions in retirement when households face health risk, compared with a large literature that studies consumption and portfolio decisions in the working phase when households face labor-income risk. This paper is an attempt to fill this gap in the life-cycle literature.

I develop a life-cycle model in which a retiree faces stochastic health depreciation, which affects her marginal utility of consumption and her life expectancy. The retiree receives income and chooses consumption, health expenditure, and the allocation of wealth between bonds, stocks, and housing to maximize expected lifetime utility. The life-cycle model takes three important inputs, which are estimated for single retirees, aged 65 or older, in the Health and Retirement Study. The first input is health transition probabilities, which are estimated from self-reported health status, mortality, and various measures of health care utilization. The second input is health insurance coverage (including Medicare), which are estimated from the ratio of out-of-pocket to total health expenditure. The third input is retirement income from Social Security and defined-benefit pension plans.

Given these inputs, the preference and health parameters are calibrated to explain the observed variation in asset allocation and health expenditure across health status and age. The portfolio share in stocks is low overall and is positively related to health, especially for younger retirees. The portfolio share in housing is negatively related to health for younger retirees and falls significantly in age. Since stocks account for a small share of financial and housing wealth, the portfolio share in bonds (net of mortgages and home equity loans) is essentially the mirror image of the portfolio share in housing. That is, the portfolio share in bonds is positively related to health for younger retirees and rises significantly in age. Finally, out-of-pocket health expenditure as a share of income is negatively related to health and rises in age.

These results are primarily driven by three economic mechanisms. The first mechanism is the horizon effect in portfolio choice, which is that younger investors should invest a higher share of their liquid wealth in risky assets (Bodie et al., 1992). The horizon effect explains why healthier retirees, who have a longer life expectancy, invest a higher share of their financial wealth in stocks instead of bonds. The horizon effect also explains why retirees substitute from risky housing to safe bonds as they age. The second mechanism is preferences that imply that non-health consumption and health are substitutes. This explains why younger retirees in worse health have a higher portfolio share in housing, which implies higher consumption of housing services. The third mechanism is decreasing returns to health investment. This explains why out-of-pocket health expenditure is higher for retirees in worse health, for whom the marginal product of health investment is higher.

Although this paper is primarily about portfolio choice, the facts about health expenditure are also important for two reasons. First, out-of-pocket health expenditure is the only measure of consumption expenditure that is available in the Health and Retirement Study. Therefore, the facts about health expenditure impose additional discipline on models of portfolio choice in retirement, just as the hump-shaped consumption profile imposes discipline on models of portfolio choice during the working phase (Cocco et al., 2005). Second, health expenditure can be thought of as an investment in "health capital", just as bonds and stocks are investments in financial wealth, and housing expenditure is an investment in housing wealth. Therefore, it is natural to think about health expenditure as part of a bigger portfolio decision between financial and housing wealth versus health capital.

The remainder of the paper proceeds as follows. Section 2 presents the life-cycle model of consumption and portfolio choice in retirement. Section 3 estimates the key inputs and outputs of the life-cycle model using the Health and Retirement Study. Section 4 calibrates and solves the life-cycle model to explain key facts about asset allocation and health expenditure across health status and age. Section 5 uses the calibrated model to examine how asset allocation would respond to a one-time reduction in Social Security benefits. Section 6 concludes with a discussion of open issues and extensions for future work.

2. Life-cycle model of consumption and portfolio choice in retirement

This section presents a life-cycle 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 financial wealth, housing wealth, and health. In each period while alive, the retiree receives income and faces stochastic health depreciation, which affects her marginal utility of consumption and her life expectancy. In response to the health shock, the retiree chooses consumption, housing expenditure, health expenditure, and the allocation of financial wealth between bonds and stocks.

The life-cycle model in this paper allows health expenditure and the allocation of wealth between bonds, stocks, and housing to all respond endogenously to health shocks. Individual features of the model have appeared in the literature. For example, several papers allow health expenditure to respond endogenously to health shocks, but they do not model housing or portfolio choice (Picone et al., 1998; Hugonnier et al., 2013). Several papers study housing and portfolio choice during the working phase when households face labor-income risk, instead of retirement when they face health risk (Cocco, 2005; Hu, 2005; Yao and Zhang, 2005). Finally, several papers study portfolio choice between bonds, stocks, and annuities (but not housing) in the context of a life-cycle model in which health expenditure and mortality are exogenous (Edwards, 2008; Horneff et al., 2009; Pang and Warshawsky, 2010; Inkmann et al., 2011; Koijen et al., 2016).

2.1. Housing expenditure

The retiree enters each period t with an initial housing stock D_{t-1}. The level of the housing stock 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 of downsizing. Whenever housing expenditure deviates from zero, the retiree pays a transaction cost of $\tau P_t D_t$ in period $t+1$, where $\tau \in [0, 1)$ and P_t is the home price. The presence of a fixed cost, which is proportional to the value of the existing housing stock, makes housing expenditure lumpy. The accumulation equation for housing is

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

Housing is a unique asset that serves a dual purpose. On the one hand, the retiree enjoys a utility flow from living in a home. On the other hand, housing is a form of savings, which the retiree can use for consumption or health expenditure while alive and bequeath upon death. For example, an individual that develops a physical disability can sell her home and use the proceeds to pay for nursing home care (Davidoff, 2010).

2.2. Health expenditure

Analogous to housing, health is modeled as an accumulation process (Grossman, 1972). The retiree enters each period t with initial health capital H_{t-1}. Health depreciates at a stochastic rate $\omega_t \leq 1$ in each period t. As discussed in Section 3.2, the distribution of ω_t depends on the state variables in period t, including previous health. 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 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 $I_t \geq 0$ if still alive. Health expenditure is an investment in the sense that its impact 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 financial assets or housing.

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 suitable for empirical analysis. First, health production is homogeneous in health capital. Second, health investment is subject to decreasing returns, captured by the parameter $\psi \in (0, 1]$ (Ehrlich and Chuma, 1990). Decreasing returns is a simple way to model the fact that treatment in poor health has a much larger impact on health than preventive care in good health.

2.3. Budget and portfolio constraints

The retiree receives income Y_t from Social Security and defined-benefit pension plans in period t if still alive. Let W_t denote cash-on-hand, which is the sum of beginning-of-period financial wealth and income in period t. The retiree uses cash-on-hand 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. As discussed in Section 3.2, the relative price of health care includes health insurance coverage.

Wealth remaining after consumption as well as housing and health expenditures can be saved in bonds and stocks. Let $A_{b,t}$ and $A_{s,t}$ denote savings in bonds and stocks in period t, respectively. Total savings is

$$\sum_{i=\{b,s\}} A_{i,t} = W_t - C_t - P_t E_t - Q_t I_t. \tag{3}$$

Let $R_{i,t+1}$ denote the gross rate of return on asset i from period t to $t+1$. Let $\mathbb{1}_{\{E_t \neq 0\}}$ denote an indicator function that is equal to one if housing expenditure deviates from zero in period

t. The intertemporal budget constraint is

$$W_{t+1} = \sum_{i=\{b,s\}} R_{i,t+1} A_{i,t} - \tau \mathbb{1}_{\{E_t \neq 0\}} P_t D_t + Y_{t+1}. \tag{4}$$

Define *total wealth* as the sum of cash-on-hand and housing wealth:

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

Define savings in housing wealth as $A_{h,t} = P_t D_t$. Combined with the accumulation equation for housing (1), total savings is

$$\sum_{i=\{b,s,h\}} A_{i,t} = w_t - C_t - Q_t I_t. \tag{6}$$

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

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

The intertemporal budget constraint is

$$w_{t+1} = \sum_{i=\{b,s\}} R_{i,t+1} A_{i,t} + (R_{h,t+1} - \tau \mathbb{1}_{\{E_t \neq 0\}}) A_{h,t} + Y_{t+1}. \tag{8}$$

2.3.1. Bonds

Bonds have a constant gross rate of return $R_{b,t+1} = \overline{R}_b$. 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% from 1958 to 2008. Therefore, the bond return is calibrated to $\overline{R}_b = 1.025$ annually.

For tractability, a mortgage or a home equity loan is modeled as a short position in bonds. Therefore, only the net bond position (i.e., bonds minus mortgage and home equity loans) is determinate in the life-cycle model. In Section 4, the simulated model is matched to the net bond position in the data. The retiree can borrow up to $A_{b,t} \geq -\lambda A_{h,t}$ in each period t.[1] The borrowing limit is calibrated to $\lambda = 0.5$ based on the evidence for older households's ability to borrow from home equity (Sinai and Souleles, 2008).

[1] This specification has a potential drawback that a retiree at the borrowing constraint must inject additional cash when the home price falls. However, the results in this paper are robust to an alternative specification $A_{b,t} \geq -\lambda P_1 D_{h,t}$, in which the borrowing limit does not depend on the current home price.

2.3.2. *Stocks*

Stocks have a stochastic gross rate of return

$$R_{s,t+1} = \overline{R}_s \epsilon_{s,t+1}, \tag{9}$$

where $\log(\epsilon_{s,t+1}) \sim \mathbb{N}(-\sigma_s^2/2, \sigma_s^2)$ is independently and identically distributed. The real return on the Center for Research in Securities Prices value-weighted stock index, deflated by the consumer price index for all items less medical care, has a mean of 7% and a standard deviation of 18% from 1958 to 2008. Based on these estimates, stock returns are calibrated with $\overline{R}_s = 1.065$ and $\sigma_s = 0.18$ annually. An equity premium of 4%, which is slightly lower than its historical estimate of 4.5%, is a common assumption in the life-cycle literature (e.g., Cocco et al., 2005). The retiree cannot short stocks, so that she faces the portfolio constraint $A_{s,t} \geq 0$ in each period t.

2.3.3. *Housing*

Housing has a stochastic gross rate of return

$$R_{h,t+1} = \overline{R}_h \epsilon_{h,t+1}, \tag{10}$$

where $\log(\epsilon_{h,t+1}) \sim \mathbb{N}(-\sigma_h^2/2, \sigma_h^2)$ is independently and identically distributed. Equation (7) then determines the dynamics of the home price, where the initial level is normalized to $P_1 = 1$. Based on equation (7), the housing return is estimated using the Office of Federal Housing Enterprise Oversight price index and a depreciation rate of 1.14% for private residential fixed assets. The real housing return, deflated by the consumer price index for all items less medical care, has a mean of 0.4% and a standard deviation of 3.5% from 1976 to 2008. Therefore, housing returns are calibrated with $\overline{R}_h = 1.004$ and $\sigma_h = 0.035$ annually. The transaction cost is calibrated to $\tau = 0.08$, following Cocco (2005).

2.4. *Objective function*

If the retiree is alive in period t, she has utility flow from consumption, housing, and health. Her utility flow over consumption and housing is given by the Cobb-Douglas function. Her utility flow over non-health consumption and health is given by the constant elasticity of substitution function:

$$U(C_t, D_t, H_t) = [(1-\alpha)(C_t^{1-\phi} D_t^{\phi})^{1-1/\rho} + \alpha H_t^{1-1/\rho}]^{1/(1-1/\rho)}. \tag{11}$$

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 non-health consumption and health.

If the retiree dies in period t, she bequeathes financial and housing wealth. Her utility flow over the bequest is

$$G(w_t, P_t) = w_t \left(\frac{\phi}{(1-\phi)P_t} \right)^{\phi}. \tag{12}$$

This specification is the indirect utility function that corresponds to a Cobb-Douglas function over financial wealth and housing (i.e., $W_t^{1-\phi} D_t^{\phi}$). It captures the notion that financial wealth and housing are not perfectly substitutable forms of bequest (see Yao and Zhang (2005) for a similar approach).

Let $\mathbb{1}_{\{\omega_{t+1}=1\}}$ denote an indicator function that is equal to one if the retiree dies in period $t+1$, and let $\mathbb{1}_{\{\omega_{t+1}\neq 1\}} = 1 - \mathbb{1}_{\{\omega_{t+1}=1\}}$ denote its complement. The objective function is defined recursively as

$$\begin{aligned} J_t =& \{(1-\beta)U(C_t, D_t, H_t)^{1-1/\sigma} \\ &+ \beta \mathbb{E}_t[\mathbb{1}_{\{\omega_{t+1}\neq 1\}} J_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}} \nu^{\gamma} G(w_{t+1}, P_{t+1})^{1-\gamma}]^{(1-1/\sigma)/(1-\gamma)}\}^{1/(1-1/\sigma)}, \end{aligned} \tag{13}$$

where the terminal value is $J_{T+1}^{1-\gamma} = 0$. 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 relative risk aversion (Epstein and Zin, 1991). The parameter $\nu \geq 0$ determines the strength of the bequest motive.

If $\rho < \sigma$, non-health consumption and health 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 could be low if you have diabetes. If $\rho > \sigma$, non-health consumption and health are substitutes. For example, the marginal utility of a massage could be high if you have a physical disability. The degree of complementarity between non-health consumption and health could also capture changes in the composition of consumption with respect to health.

2.5. Homogeneity in total wealth

In addition to age, the state variables of the life-cycle model are health, the housing stock, the home price, and total wealth. However, homogeneity of the objective function allows me to eliminate total wealth as a state variable. The state variables of the life-cycle model are redefined as their values relative to total wealth:

$$h_t = \frac{(1-\omega_t)Q_t H_{t-1}}{w_t}, \tag{14}$$

$$d_t = \frac{(1-\delta)P_t D_{t-1}}{w_t}. \tag{15}$$

Homogeneity is a common assumption in the life-cycle literature, which significantly simplifies solution of the model. Three additional parametric assumptions are necessary to preserve homogeneity. First, the distribution of health depreciation ω_{t+1} depends on present health only through h_t. Second, health insurance coverage, which enters the relative price of health care, depends on present health only through h_t. Finally, the distribution of income relative to total wealth, $y_{t+1} = Y_{t+1}/w_{t+1}$, depends on present health only through h_t. In Section 3.2, health transition probabilities, health insurance coverage, and retirement income are estimated using the Health and Retirement Study.

Homogeneity implies the following transformed consumption and portfolio-choice problem. Let $\Delta w_{t+1} = w_{t+1}/w_t$. In each period t, the retiree chooses $c_t = C_t/w_t$, $i_t = Q_t I_t/w_t$, and $a_{i,t} = A_{i,t}/w_t$ for $i = \{b, s, h\}$ to maximize her objective function:

$$\begin{aligned} j_t = \frac{J_t}{w_t} =& \{(1-\beta)u_t^{1-1/\sigma} \\ &+ \beta \mathbb{E}_t[\Delta w_{t+1}^{1-\gamma}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}} j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^{\gamma} g_{t+1}^{1-\gamma})]^{(1-1/\sigma)/(1-\gamma)}\}^{1/(1-1/\sigma)}, \end{aligned} \tag{16}$$

where

$$u_t = \frac{U(C_t, D_t, H_t)}{w_t} = c_t V_t, \tag{17}$$

$$V_t = \left[(1-\alpha)\left(\frac{a_{h,t}}{P_t c_t}\right)^{\phi(1-1/\rho)} + \alpha\left(\frac{h_t[1+\psi(i_t/h_t)^{\psi}]}{Q_t c_t}\right)^{1-1/\rho}\right]^{1/(1-1/\rho)}, \tag{18}$$

$$g_t = \frac{G(w_t, P_t)}{w_t} = \left(\frac{\phi}{(1-\phi)P_t}\right)^{\phi}. \tag{19}$$

Equations (6) and (8) imply that the intertemporal budget constraint is

$$\begin{aligned} \Delta w_{t+1} =& (1-y_{t+1})^{-1}[R_{b,t+1}(1-c_t-i_t) + (R_{s,t+1}-R_{b,t+1})a_{s,t} \\ &+ (R_{h,t+1} - R_{b,t+1} - \tau\mathbb{1}_{\{a_{h,t}\neq d_t\}})a_{h,t}]. \end{aligned} \tag{20}$$

The portfolio constraints are

$$c_t + i_t + a_{s,t} + (1-\lambda)a_{h,t} \leq 1, \tag{21}$$

$$a_{i,t} \geq 0 \text{ for } i = \{s, h\}. \tag{22}$$

The law of motion for the state variables is

$$h_{t+1} = \frac{(1-\omega_{t+1})Q_{t+1}h_t}{Q_t \Delta w_{t+1}} \left[1 + \psi \left(\frac{i_t}{h_t}\right)^{\psi}\right], \tag{23}$$

$$d_{t+1} = \frac{R_{h,t+1}a_{h,t}}{\Delta w_{t+1}}, \tag{24}$$

and equation (7) for the home price.

3. Calibrating the life-cycle model with the Health and Retirement Study

The Health and Retirement Study is a panel survey designed to study the health and wealth dynamics of the elderly in the United States. The data consist of eight waves, covering every two years between 1992 and 2006. This section explains how the data are used to measure the key inputs and outputs of the life-cycle model. Appendix A contains details on the construction of the relevant variables for my analysis.

3.1. Description of the sample

My sample consists of primary respondents who were born 1891–1940, aged 65 or older, single (including widowed or divorced), and retired (including disabled or out of the labor force) at the time of interview. The sample 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 cohort of the Health and Retirement Study (born 1931–1941). Respondents must have both positive income and net worth to be included in the sample, which eliminates about 15% of the otherwise eligible.

The life-cycle model in this paper applies not only to single respondents, but also to previously married respondents once they are widowed or divorced. Therefore, previously excluded respondents may enter my sample as they are widowed or divorced. My sample consists of both females and males. The life-cycle model is calibrated separately for females and males because they have different life expectancies. To economize on the presentation, the main text focuses on the results for females, and Appendix B presents additional results for males.

The Health and Retirement Study continues to interview respondents that enter nursing homes. However, any respondent that enters a nursing home receives a zero sampling weight because these weights are based on the non-institutionalized population of the Current Population Survey. Therefore, the use of sampling weights would lead me to underestimate the cost of nursing home care, which accounts for a significant share of out-of-pocket health expenditure in old age. Therefore, I do not use sampling weights in my analysis.

The primary measure of health for my study is self-reported general health status. At each interview, the respondent's health can be either poor, fair, good, very good, or excellent. Insofar as health enters the utility function, self-reported health status is a relevant measure of health for calibrating the life-cycle model. Self-reported health status is also highly correlated with doctor-diagnosed health problems, difficulty with activities of daily living, health care utilization, and future mortality (Wallace and Herzog, 1995).

3.2. Measuring the inputs of the life-cycle model

The key inputs of the life-cycle model are health transition probabilities, the relative price of health care, and retirement income.

3.2.1. Health transition probabilities

Let h_t^* denote self-reported health status at each interview. Health status is modeled as a function of unobserved health h_t through the following response function (see Wagstaff (1986) for a similar approach):

$$h_t^* = \begin{cases} 0 & \text{Dead} & \text{if } h_t < \overline{h}_1 \\ 1 & \text{Poor} & \text{if } \overline{h}_1 \leq h_t < \overline{h}_2 \\ 2 & \text{Fair} & \text{if } \overline{h}_2 \leq h_t < \overline{h}_3 \\ 3 & \text{Good} & \text{if } \overline{h}_3 \leq h_t < \overline{h}_4 \\ 4 & \text{Very good} & \text{if } \overline{h}_4 \leq h_t < \overline{h}_5 \\ 5 & \text{Excellent} & \text{if } \overline{h}_5 \leq h_t \end{cases} . \tag{25}$$

An ordered probit model is used to estimate how future health status at two years from the present interview depends on present health status, age, financial and housing wealth, measures of health care utilization, vigorous physical activity, smoking, and birth cohort. The measures of health care utilization are interacted with health status to allow for the possibility that the marginal product of health care varies with health. I control for financial and housing wealth since the relevant measure of health for the life-cycle model is the variation in health that is independent of total wealth (i.e., h_t). Finally, all of these variables are interacted with a male dummy.

Column (1) of Table 1 reports the estimated coefficients and t-statistics for the ordered probit model. The sign of the coefficients can be interpreted as the direction of the marginal effects for the likelihood of the extreme health outcomes, namely death and excellent health. Present health status is a statistically significant predictor of future health status. The negative coefficients for poor and fair health imply that these respondents are more likely to die prior to the next interview, compared with those in good health. Conversely, the positive coefficients for very good and excellent health imply that these respondents are less likely to die. The negative coefficient on age implies that older respondents are more likely to die. The positive coefficient on financial and housing wealth implies that wealthier respondents are less likely to die, holding everything else constant.

Measures of health care utilization that are positive predictors of future health status for respondents in good health are dentist visits and cholesterol tests. Doctor visits, home health care, nursing home stays, outpatient surgery, and prescription drugs predict future health status with negative coefficients, potentially due to unobserved heterogeneity in health. For doctor visits, dentist visits, nursing home stays, outpatient surgery, and prescription drugs, the coefficients on their interaction with poor health are positive, which implies that health care has a larger impact on the future health of respondents that are already in poor health. In addition to health care utilization, I examine vigorous physical activity and smoking as non-monetary measures of health investment. Vigorous physical activity is a positive and statistically significant predictor of future health status, while smoking is a negative and statistically significant predictor. A joint Wald test for measures of health care utilization, vigorous physical activity, smoking, and their interaction with health status rejects strongly. Taken together, this evidence suggests that the choices over health investment have an important impact on future health.

Respondents in poor health are more likely to use health care. Therefore, the coefficients for health care utilization are potentially downward biased, insofar as health care utilization is negatively correlated with unobserved heterogeneity in health. To investigate this possibility, column (2) of Table 1 introduces doctor-diagnosed health problems and difficulty with activities of daily living as additional measures of present health. These additional measures are statistically significant predictors of future health status, implying that present health status does not fully capture heterogeneity in health. The coefficients for health care utilization in column (2) are generally higher than those in column (1). For example, prescription drugs have a statistically insignificant coefficient of 3.83 in column (2), which is higher than the statistically significant coefficient of -12.93 in column (1).

The estimates from column (1) of Table 1 are used to predict the health transition probabilities for single females, who were born 1931–1940, have the average financial and housing wealth for her cohort and age, have not used health care in the two years prior to the interview, and does not regularly participate in vigorous physical activity and smokes at the time of interview. In other words, I estimate the counterfactual of how health status transitions from the present interview to the next in the absence of health investment. Figure 1 reports the predicted transition probabilities for females by present health status and age. The figure shows that health status is persistent and that present health is an important predictor of future mortality. Death is the most likely outcome for females in poor health at any given age, while it is the least likely outcome for those in excellent health.

Let $\Pr(h^*_{t+1} = j | h^*_t = i)$ denote the predicted transition probability from health status i in period t to health status j in period $t+1$ in the absence of health investment. Health depreciation in period $t+1$ is calibrated as

$$1 - \omega_{t+1} = \begin{cases} 0 & \text{with } \Pr(h^*_{t+1} = 0 | h^*_t = i) \\ \overline{h}_1/\overline{h}_i & \text{with } \Pr(h^*_{t+1} = 1 | h^*_t = i) \\ \overline{h}_2/\overline{h}_i & \text{with } \Pr(h^*_{t+1} = 2 | h^*_t = i) \\ \overline{h}_3/\overline{h}_i & \text{with } \Pr(h^*_{t+1} = 3 | h^*_t = i) \\ \overline{h}_4/\overline{h}_i & \text{with } \Pr(h^*_{t+1} = 4 | h^*_t = i) \\ \overline{h}_5/\overline{h}_i & \text{with } \Pr(h^*_{t+1} = 5 | h^*_t = i) \end{cases}, \tag{26}$$

conditional on health $\overline{h}_i \leq h_t < \overline{h}_{i+1}$ in period t.

3.2.2. Relative price of health care

Virtually all respondents report health insurance coverage through Medicare, Medicaid, or an employer-provided health plan. Nevertheless, some report significant out-of-pocket health expenditure, especially in old age, which can arise for a number of reasons. Medicare does not cover nursing home care, and Medicaid only covers a limited and capped amount of nursing home care for those that qualify. In addition, some may choose out-of-network or higher quality care that is not covered by their health insurance.

For each respondent at each interview, the out-of-pocket expenditure share is computed as the ratio of out-of-pocket to total health expenditure. A censored regression model is used to estimate how the out-of-pocket expenditure share depends on health status, age and its interaction with health status, financial and housing wealth and its interaction with health status, birth cohort, and the interaction of these variables with a male dummy. The out-of-pocket expenditure share is then predicted for single females, who were born 1931–1940 and have the average financial and housing wealth for her cohort and age. Let $q_t(h^*_t)$ denote the predicted out-of-pocket expenditure share for health status h_t^* in period t. The relative price of health care is modeled as

$$Q_t = e^{q(t-1)} q_t(h_t^*). \tag{27}$$

The first term accounts for secular growth in the relative price of health care, and the second term accounts for health insurance coverage. The average log growth rate of the consumer price index for medical care, relative to that for all items less medical care, is 1.9% from 1958 to 2008. Therefore, the growth rate is calibrated $q = 0.019$ annually.

Figure 2 reports the relative price of health care for females by health status and age. The relative price of health care is positively related to health, especially for younger females. For example, the relative price of health care is 0.36 for females in poor health at age 65, which is lower than 0.43 for those in excellent health. The fact that health insurance coverage is slightly better in poor health is consistent with copays and deductibles that differ between treatment and preventive care. The relative price of health care rises in age. Part of this growth is explained by an out-of-pocket expenditure share that rises in age, while the remainder is explained by the secular growth in the relative price of health care. For example, the out-of-pocket expenditure share is 0.46 for females in good health at age 65, which rises to 0.55 at age 89.

3.2.3. Retirement income

The ratio of income to total wealth is computed for each respondent at each interview. A censored regression model is used to estimate how the income-wealth ratio depends on health status, age and its interaction with health status, financial and housing wealth and its interaction with health status, birth cohort, and the interaction of these variables with a male dummy. Then the income-wealth ratio is predicted for single females, who were born 1931–1940 and have the average financial and housing wealth for her cohort and age.

3.3. Measuring the outputs of the life-cycle model

The key outputs of the life-cycle model are the allocation of financial and housing wealth and out-of-pocket health expenditure.

3.3.1. Allocation of financial and housing wealth

In Table 2, a censored regression model is used to estimate how the portfolio share in stocks depends on health status, age and its interaction with health status, financial and housing wealth and its interaction with health status, birth cohort, and the interaction of these variables with a male dummy. The portfolio share in stocks is positively related to health, even after controlling for financial and housing wealth (Rosen and Wu, 2004). The portfolio share in stocks is 2 percentage points lower for respondents in poor health at age 65, compared with those in good health. Conversely, the portfolio share in stocks is 1 percentage point higher for respondents in excellent health at age 65, compared with those in good health.

To facilitate comparison of the data with the simulated model, Panel B of Table 3 reports the predicted portfolio share in stocks for females by health status and age. The table does not extend beyond age 89 because sample attrition through death makes such extrapolation potentially unreliable. The portfolio share in stocks is low overall and is positively related to health, especially for younger females. The portfolio share in stocks is 1% for females in poor health at age 65, which is lower than 4% for those in excellent health.

Table 2 also shows how the portfolio share in housing depends on health status, age and its interaction with health status, financial and housing wealth and its interaction with health status, birth cohort, and the interaction of these variables with a male dummy. The portfolio share in housing is negatively related to health, even after controlling for financial and housing wealth. The portfolio share in housing is 16 percentage points higher for respondents in poor health at age 65, compared with those in good health. Conversely, the portfolio share in housing is 9 percentage points lower for respondents in excellent health at age 65, compared with those in good health. For respondents in good health, the portfolio share in housing falls by 14 percentage points for every ten years in age. The negative coefficient on the interaction of age with poor health implies that the portfolio share in housing falls more in age for respondents in poor health. Conversely, the positive coefficient on the interaction of age with excellent health implies that the portfolio share in housing falls less in age for respondents in excellent health.

Panel C of Table 3 reports the predicted portfolio share in housing for females by health status and age. The portfolio share in housing is high overall and is negatively related to health for younger females. The portfolio share in housing is 85% for females in poor health at age 65, which is higher than 61% for those in excellent health. The portfolio share in housing falls significantly in age. The portfolio share in housing is 70% for females in good health at age 65, which falls to 36% at age 89.

Since stocks account for a small share of financial and housing wealth, Panel A of Table 3 shows that the portfolio share in bonds is essentially the mirror image of the portfolio share in housing. That is, the portfolio share in bonds is positively related to health for younger females and rises significantly in age.

3.3.2. *Out-of-pocket health expenditure*

In Table 4, a linear regression model is used to estimate how the logarithm of out-of-pocket health expenditure as a share of income depends on health status, age and its interaction with health status, financial and housing wealth and its interaction with health status, birth cohort, and the interaction of these variables with a male dummy. Out-of-pocket health expenditure as a share of income is negatively related to health. Out-of-pocket health expenditure is 57% higher for respondents in poor health at age 65, compared with those in good health. Conversely, out-of-pocket health expenditure is 32% lower for respondents in excellent health at age 65, compared with those in good health. For respondents in good health, out-of-pocket health expenditure rises by 56% for every ten years in age.

Panel E of Table 3 reports the predicted out-of-pocket expenditure as a share of income for females by health status and age. Out-of-pocket health expenditure as a share of income is negatively related to health. Females in poor health at age 65 spend 12% of their income on health care, which is higher than 5% for those in excellent health. Similarly, females in poor health at age 89 spend 48% of their income on health care, which is higher than 17% for those in excellent health. Out-of-pocket health expenditure as a share of income rises in age. Females in good health spend 7% of their income on health care at age 65, which rises to 27% at age 89.

4. Asset allocation and health expenditure in the life-cycle model

Table 5 reports the preference and health parameters used to calibrate the life-cycle model for females. The subjective discount factor is calibrated to $\beta = 0.96$ annually, following a common practice in the life-cycle literature (e.g., Cocco et al., 2005). Relative risk aversion is calibrated to $\gamma = 5$ to explain the low portfolio share in stocks. The bequest motive is not well identified, separately from the elasticity of intertemporal substitution, based on the average life-cycle wealth profile (as discussed in De Nardi et al. (2010) and Ameriks et al. (2011)). Therefore, the benchmark case assumes no intentional bequest motive (i.e., $\nu = 0$). The remaining parameters are calibrated to explain key facts about asset allocation and health expenditure in Table 3.

4.1. *Optimal consumption and portfolio policies*

The life-cycle model is solved by numerical dynamic programming, as described in Appendix C. Figure 3 reports the optimal consumption and portfolio policies for a female aged 65 as functions of health status. My discussion will focus on the baseline policy evaluated at $d_t = 0.6$, which is the relevant region of the state space for the model simulation.

Optimal consumption decreases in health. The retiree consumes a lower share of her total wealth in better health because non-health consumption and health are substitutes at the calibrated parameters (i.e., $\sigma < \rho$). Optimal out-of-pocket health expenditure also decreases in health. The retiree spends a lower share of her total wealth on health care in better health because of decreasing returns to health investment (i.e., $\psi < 1$).

The optimal portfolio share in stocks increases in health. To understand this result, it is useful to recall the horizon effect in portfolio choice, which is that a younger investor should invest a higher share of her liquid wealth in risky assets (Bodie et al., 1992). The horizon effect comes from the fact that a young investor has a large implicit position in an illiquid bond through her claim to future income. As the value of the illiquid bond declines in age, the investor must shift her liquid wealth from stocks to bonds to keep the overall portfolio share in risky assets constant. The positive relation between the optimal portfolio share in stocks and health is analogous to the horizon effect because the retiree has a longer life expectancy in better health.

The optimal portfolio share in housing decreases in health, while the optimal portfolio share in bonds increases in health. The retiree consumes less housing in better health because non-health consumption and health are substitutes at the calibrated parameters. The dashed lines represent the policy functions for a higher housing stock (i.e., $d_t = 0.7$), and the dotted lines represent the policy functions for a lower housing stock (i.e., $d_t = 0.5$). Any differences between these policies and the baseline policy can be attributed to transaction costs because the housing stock would drop out as a state variable in the absence of such costs. Consistent with the importance of transaction costs, a higher initial housing stock leads to a higher optimal portfolio share in housing, which is offset nearly one-to-one with a lower optimal portfolio share in bonds.

The policy functions are used to simulate a population of 100,000 retirees, who make optimal consumption and portfolio decisions every two years from age 65 until death. Initial health is drawn from a lognormal distribution (i.e., $\log h_1 \sim \mathbb{N}(\mu_h, \sigma_h)$) to match the observed health distribution at age 65. The initial housing stock is calibrated conditional on health to match the observed portfolio share in housing by health status at age 65. As discussed in Section 3.2, The path of income by health status and age is estimated under the assumption of homogeneity in wealth. By construction, the simulated model matches the observed ratio of total wealth to income by health status and age.

4.2. Allocation of financial and housing wealth

Panel B of Table 6 reports the portfolio share in stocks by health status and age for the simulated model. Consistent with the evidence in Panel B of Table 3, the portfolio share in stocks is low overall and is positively related to health, especially for younger retirees. The portfolio share in stocks is 6% for retirees in poor health at age 65, which is lower than 10% for those in excellent health. As discussed above, the horizon effect in portfolio choice explains the positive relation between the portfolio share in stocks and health because retirees in better health have a longer life expectancy.

Panel C of Table 6 reports the portfolio share in housing by health status and age for the simulated model. Consistent with the evidence in Panel C of Table 3, the portfolio share in housing is high overall and is negatively related to health for younger retirees. The portfolio share in housing is 83% for retirees in poor health at age 65, which is higher than 61% for those in excellent health. Housing consumption and health are substitutes at the calibrated parameters, which explains the negative relation between the portfolio share in housing (i.e., consumption of housing services) and health.

Also consistent with the evidence, Panel C of Table 6 shows that the portfolio share in housing falls significantly in age. The portfolio share in housing is 68% for retirees in good health at age 65, which falls to 36% at age 89. Since stocks account for a small share of financial and housing wealth, Panel A shows that the portfolio share in bonds is essentially the mirror image of the portfolio share in housing. Because housing is risky and bonds are safe, the horizon effect in portfolio choice explains the negative relation between the portfolio share in housing and age.

4.3. Out-of-pocket health expenditure

Panel E of Table 6 reports out-of-pocket health expenditure as a share of income by health status and age for the simulated model. Consistent with the evidence in Panel E of Table 3, out-of-pocket health expenditure as a share of income is negatively related to health. Retirees in poor health at age 65 spend 37% of their income on health care, which is higher than 2% for those in excellent health. Similarly, retirees in poor health at age 89 spend 31% of their income on health care, which is higher than 3% for those in excellent health. Retirees in better health spend a lower share of their total wealth on health care because of decreasing returns to health investment. Also consistent the evidence, out-of-pocket health expenditure as a share of income rises in age. Retirees in good health spend 9% of their income on health care at age 65, which rises to 12% at age 89.

Panel F of Table 6 reports the health distribution by age as an additional check of the simulated model. If health expenditure were not sufficiently productive, the simulated model would produce bunching of retirees in poor health. Conversely, if health expenditure were too productive, the simulated model would produce bunching of retirees in excellent health. The health distribution in the simulated model is non-degenerate throughout the life cycle, consistent with the evidence in Panel F of Table 3. At age 89, 10% of retirees are in poor health, 27% are in fair health, 37% are in good health, 23% are in very good health, and 3% are in excellent health.

4.4. Summary of the results for males

Appendix B reports asset allocation and health expenditure for males in the Health and Retirement Study and in the simulated model. The results are similar to those for females, so the main differences are briefly summarized. The life-cycle model explains asset allocation and health expenditure for males with small differences in the preference and health parameters. First, males have lower life expectancy and higher average depreciation of health. Therefore, health expenditure must be more productive for males to match the observed out-of-pocket health expenditure and the health distribution. Accordingly, the returns to health investment is calibrated to $\psi = 0.20$, compared with $\psi = 0.19$ for females. Second, older males have a higher portfolio share in housing. For example, the portfolio share in housing for males in good health at age 89 is 47%, compared with 36% for females. Therefore, the utility weight on housing is calibrated to $\phi = 0.9$, compared with $\phi = 0.6$ for females.

5. Predicted response to a reduction in Social Security benefits

In contrast to a reduced-form approach, the structural approach in this paper allows us to understand the economic mechanisms (i.e., preferences, technology, and constraints) that explain the key facts about asset allocation and health expenditure across health status and age. Another advantage is that the calibrated model could be used to understand how asset allocation and health expenditure would respond to policy changes. In this section, I consider a one-time reduction in Social Security benefits as an example of such a policy experiment. In Table 7, the life-cycle model is simulated with retirees receiving only 50% of the estimated income.

Under the maintained assumption of homogeneity in wealth, the reduction in the level of wealth from the policy experiment has no effect. However, the change in the composition of wealth matters through the horizon effect in portfolio choice, as discussed in Section 4.1. The reduction in income implies that retirees now have a smaller implicit position in an illiquid bond. Therefore, retirees must shift their liquid wealth from stocks and housing to bonds to keep the overall portfolio share in risky assets constant. For example, Panel A of Table 7 shows that the portfolio share in bonds is 58% for retirees in good health at age 71, compared with 50% for the corresponding number in Panel A of Table 6.

I have assumed homogeneity in wealth for tractability in this paper. However, this assumption limits the potential responses to policy experiments that have wealth effects, such as a reduction in Social Security or Medicare benefits. In future work, it would be interesting to reconsider the impact of these policy experiments in a life-cycle model that relaxes the assumption of homogeneity in wealth.

6. Conclusion

This paper has shown that a life-cycle model, in which consumption and portfolio decisions respond endogenously to health shocks, explains key facts about asset allocation and health expenditure across health status and age. An open issue is whether the life-cycle model (with appropriate modifications) could explain a larger set of moments related to heterogeneity across retirees and dynamics in response to health shocks. For example, an earlier version of this paper (Yogo, 2009) attempted to explain how financial and housing wealth responds to health shocks at a higher frequency (from one interview to the next in the Health and Retirement Study). In future work, it would be interesting to explore what assumptions about preferences and constraints are necessary to explain how asset allocation and health expenditure respond to health shocks at different horizons.

In addition, there are various extensions of the life-cycle model that are promising for future work. First, an extension to married households makes consumption and portfolio decisions depend on the health and survival of both partners (Lillard and Weiss, 1997; Jacobson, 2000; Love, 2010). Second, an extension to the working phase prior to retirement introduces an endogenous response of labor supply to health shocks as well as public and employer-provided health insurance (Blau and Gilleskie, 2008; French and Jones, 2011). Finally, the portfolio-choice problem could be extended to insurance products such as annuities, life insurance, Medigap insurance, and long-term care insurance (Koijen et al., 2016).

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Table 1

Future health in relation to present health and health investment.

	(1)				(2)			
Explanatory variable	Coefficient for females		Interaction effect for males		Coefficient for females		Interaction effect for males	
Health status:								
Poor	-141.42	(-5.87)	24.48	(0.65)	-101.42	(-3.99)	7.69	(0.20)
Fair	-81.01	(-5.72)	23.65	(0.96)	-68.82	(-4.61)	14.30	(0.56)
Very good	56.10	(4.42)	18.40	(0.67)	57.22	(4.43)	14.95	(0.54)
Excellent	114.38	(5.76)	23.86	(0.61)	111.61	(5.59)	18.78	(0.48)
(Age − 65)/10	-17.40	(-5.96)	6.10	(0.92)	-11.23	(-3.77)	3.95	(0.59)
× Poor	11.59	(3.13)	-13.78	(-1.63)	7.57	(2.00)	-10.46	(-1.22)
× Fair	13.06	(4.23)	-14.23	(-2.07)	11.19	(3.60)	-13.71	(-1.98)
× Very good	-5.17	(-1.50)	-8.33	(-1.06)	-4.99	(-1.43)	-9.40	(-1.19)
× Excellent	-7.23	(-1.12)	-2.64	(-0.20)	-5.78	(-0.89)	-2.59	(-0.19)
Financial and housing wealth	2.64	(3.69)	0.77	(0.46)	1.76	(2.44)	1.18	(0.68)
× Poor	-2.65	(-2.38)	1.03	(0.41)	-2.61	(-2.30)	-0.90	(-0.35)
× Fair	-2.03	(-2.11)	-1.04	(-0.46)	-2.06	(-2.13)	-1.76	(-0.76)
× Very good	1.67	(1.33)	2.16	(0.78)	1.77	(1.41)	1.74	(0.63)
× Excellent	4.07	(1.66)	-10.05	(-2.02)	4.50	(1.86)	-10.99	(-2.22)
Doctor visits	-2.18	(-0.24)	8.78	(0.49)	0.71	(0.08)	9.32	(0.52)
× Poor	10.44	(0.49)	-6.79	(-0.20)	-1.68	(-0.08)	-5.43	(-0.15)
× Fair	12.37	(0.87)	-21.53	(-0.84)	12.07	(0.82)	-20.21	(-0.77)
× Very good	-5.83	(-0.46)	-20.51	(-0.77)	-7.55	(-0.59)	-18.68	(-0.69)
× Excellent	8.38	(0.44)	-26.47	(-0.71)	8.99	(0.47)	-29.99	(-0.80)
Dentist visits	7.24	(2.34)	11.12	(1.55)	6.18	(1.98)	12.36	(1.71)
× Poor	3.59	(0.64)	-13.82	(-1.11)	1.60	(0.28)	-14.25	(-1.13)
× Fair	1.94	(0.43)	-19.05	(-1.89)	1.71	(0.38)	-19.80	(-1.94)
× Very good	15.74	(3.12)	-5.45	(-0.47)	15.41	(3.04)	-6.38	(-0.55)
× Excellent	19.77	(1.94)	-14.72	(-0.70)	17.34	(1.70)	-11.78	(-0.56)
Home health care	-21.54	(-3.93)	-21.14	(-1.63)	-12.64	(-2.27)	-20.63	(-1.60)
× Poor	-4.87	(-0.67)	22.62	(1.35)	1.36	(0.18)	24.85	(1.45)
× Fair	-4.17	(-0.60)	18.13	(1.09)	-0.59	(-0.08)	16.14	(0.98)
× Very good	-14.79	(-1.39)	12.72	(0.48)	-14.69	(-1.37)	18.29	(0.69)
× Excellent	-60.66	(-2.20)	10.06	(0.20)	-60.07	(-2.18)	32.77	(0.62)
Nursing home stays	-19.41	(-2.32)	-21.09	(-0.98)	-16.14	(-1.92)	-7.31	(-0.34)
× Poor	0.88	(0.08)	-13.57	(-0.51)	9.04	(0.79)	-19.24	(-0.72)
× Fair	-9.84	(-0.87)	15.38	(0.59)	2.00	(0.18)	3.12	(0.12)
× Very good	-13.68	(-0.87)	-26.61	(-0.68)	-11.28	(-0.72)	-33.90	(-0.89)
× Excellent	-87.60	(-2.17)	119.79	(1.86)	-83.99	(-2.04)	117.17	(1.76)
Outpatient surgery	-0.44	(-0.12)	9.30	(1.19)	1.60	(0.44)	8.41	(1.07)
× Poor	3.22	(0.51)	-21.30	(-1.49)	-0.12	(-0.02)	-19.27	(-1.31)
× Fair	0.93	(0.18)	-6.60	(-0.59)	0.18	(0.04)	-5.34	(-0.47)
× Very good	2.58	(0.43)	-10.58	(-0.84)	2.90	(0.49)	-10.22	(-0.81)
× Excellent	0.36	(0.03)	20.18	(0.84)	1.15	(0.09)	23.32	(0.96)
Prescription drugs	-12.93	(-2.74)	-4.44	(-0.42)	3.83	(0.79)	-7.93	(-0.73)
× Poor	7.09	(0.52)	18.06	(0.71)	6.44	(0.47)	21.25	(0.81)
× Fair	-11.87	(-1.39)	9.97	(0.60)	-12.23	(-1.44)	13.74	(0.83)
× Very good	-3.92	(-0.57)	-5.58	(-0.37)	-8.45	(-1.22)	-4.69	(-0.31)
× Excellent	-16.48	(-1.45)	1.07	(0.04)	-25.03	(-2.20)	5.76	(0.24)
Cholesterol tests	3.55	(0.92)	-18.55	(-1.96)	7.30	(1.88)	-22.00	(-2.29)
× Poor	-3.59	(-0.52)	-5.43	(-0.36)	-4.39	(-0.62)	1.28	(0.08)
× Fair	3.55	(0.62)	28.44	(2.19)	2.08	(0.36)	34.33	(2.62)
× Very good	11.95	(1.86)	8.62	(0.57)	9.70	(1.50)	13.37	(0.87)
× Excellent	2.51	(0.21)	9.77	(0.41)	1.40	(0.12)	11.88	(0.49)
Vigorous physical activity	17.66	(5.55)	5.71	(0.80)	14.12	(4.41)	3.74	(0.52)
× Poor	-0.50	(-0.06)	4.48	(0.28)	-4.64	(-0.57)	-4.39	(-0.27)
× Fair	5.30	(1.01)	-20.79	(-1.96)	4.67	(0.89)	-20.54	(-1.91)
× Very good	-2.25	(-0.46)	0.93	(0.08)	-0.08	(-0.02)	2.99	(0.27)
× Excellent	19.65	(2.10)	-6.96	(-0.34)	21.48	(2.29)	-3.10	(-0.15)
Smoking	-15.13	(-3.23)	-12.15	(-1.12)	-15.76	(-3.34)	-14.92	(-1.37)
× Poor	4.23	(0.54)	-1.18	(-0.07)	-0.15	(-0.02)	18.06	(1.04)
× Fair	9.49	(1.39)	-6.79	(-0.47)	7.47	(1.10)	-4.24	(-0.29)
× Very good	2.17	(0.28)	3.83	(0.21)	2.27	(0.29)	5.82	(0.32)
× Excellent	-26.53	(-1.55)	27.88	(0.89)	-29.06	(-1.71)	35.48	(1.13)

Table 1 (continued)

Explanatory variable	(1) Coefficient for females		(1) Interaction effect for males		(2) Coefficient for females		(2) Interaction effect for males	
Doctor-diagnosed health problems:								
High blood pressure					-10.60	(-5.50)	7.17	(1.69)
Diabetes					-18.26	(-7.93)	-4.63	(-0.94)
Cancer					-14.88	(-6.09)	-0.10	(-0.02)
Lung disease					-22.55	(-7.90)	-12.99	(-2.24)
Heart problems					-17.35	(-8.68)	3.21	(0.75)
Stroke					-9.26	(-3.26)	1.19	(0.20)
Psychiatric problems					-8.44	(-3.50)	-2.32	(-0.38)
Arthritis					-12.40	(-6.12)	7.04	(1.70)
Some difficulty with activities of daily living:								
Bathing					-17.73	(-5.68)	-19.87	(-2.48)
Dressing					-9.42	(-3.27)	0.54	(0.08)
Eating					-29.47	(-6.47)	14.22	(1.38)
Birth cohort:								
1891–1900	-67.14	(-3.33)	80.21	(1.44)	-67.14	(-3.33)	115.47	(2.02)
1901–1910	-22.98	(-3.39)	-5.01	(-0.33)	-22.98	(-3.39)	-5.16	(-0.33)
1911–1920	-4.00	(-1.01)	-4.44	(-0.49)	-4.00	(-1.01)	-0.52	(-0.06)
1921–1930	1.44	(0.54)	-2.28	(-0.39)	1.44	(0.54)	0.20	(0.03)
Constant			-14.20	(-0.83)			-14.31	(-0.82)
Wald test for health investment	439.57	(0.00)			259.46	(0.00)		
Wald test for male interaction effects			131.86	(0.00)			140.98	(0.00)
Observations	19,404				19,223			

Note: An ordered probit model is used to explain future health status at two years from the present interview. The table reports the estimated coefficients in percentage points and heteroskedasticity-robust t-statistics in parentheses. The Wald test for the dependence of future health status on health investment includes measures of health care utilization (i.e., doctor visits, dentist visits, home health care, nursing home stays, outpatient surgery, prescription drugs, and cholesterol tests), vigorous physical activity, smoking, and the interaction of these variables with present health status. The p-value for the Wald test is reported in parentheses. The sample consists of single retirees in the Health and Retirement Study, who were born 1891–1940, aged 65 or older, and interviewed between 1992 and 2006.

Table 2

Portfolio shares in stocks and housing in relation to health.

	Stocks				Housing			
Explanatory variable	Elasticity for females		Interaction effect for males		Elasticity for females		Interaction effect for males	
Health status:								
Poor	-2.11	(-4.24)	3.02	(1.41)	16.19	(5.74)	-3.06	(-0.54)
Fair	-1.66	(-3.54)	0.91	(0.72)	9.68	(4.61)	-6.27	(-1.67)
Very good	0.95	(1.64)	0.61	(0.58)	-5.55	(-2.81)	-1.14	(-0.29)
Excellent	0.99	(1.11)	-1.28	(-1.28)	-8.80	(-3.55)	4.69	(0.90)
(Age – 65)/10	0.89	(3.84)	0.45	(1.00)	-14.17	(-14.32)	6.74	(3.40)
× Poor	1.01	(2.53)	-1.41	(-1.75)	-5.77	(-3.45)	6.16	(1.71)
× Fair	0.90	(2.99)	-0.97	(-1.69)	-3.37	(-2.65)	2.83	(1.18)
× Very good	-0.33	(-1.22)	0.19	(0.36)	1.81	(1.49)	0.90	(0.38)
× Excellent	-0.23	(-0.58)	0.90	(1.25)	5.37	(3.37)	-4.85	(-1.55)
Financial and housing wealth	3.84	(25.98)	-0.59	(-2.14)	8.68	(28.89)	-1.55	(-2.24)
× Poor	0.02	(0.06)	-0.47	(-0.79)	3.23	(5.65)	-1.12	(-0.87)
× Fair	-0.13	(-0.54)	0.56	(1.18)	1.93	(4.38)	-0.51	(-0.55)
× Very good	0.06	(0.28)	-0.13	(-0.34)	-1.06	(-2.14)	0.09	(0.08)
× Excellent	-0.19	(-0.60)	-0.12	(-0.23)	-2.44	(-2.92)	0.99	(0.69)
Birth cohort:								
1891–1900	-1.70	(-1.96)	-2.10	(-1.51)	-8.73	(-1.69)	2.96	(0.30)
1901–1910	-0.78	(-1.88)	-0.43	(-0.49)	-0.82	(-0.43)	-9.40	(-2.51)
1911–1920	0.50	(1.54)	-0.48	(-0.82)	-0.30	(-0.24)	-6.57	(-2.51)
1921–1930	1.28	(4.85)	0.59	(1.11)	1.90	(1.79)	-6.39	(-3.05)
Constant			1.66	(2.06)			-5.02	(-1.82)
Wald test for male interaction effects			147.15	(0.00)			143.28	(0.00)
Observations	28,522				28,522			

Note: A censored regression model is used to explain the portfolio shares in stocks and housing. The table reports the estimated elasticities at the mean of the explanatory variables in percentage points and heteroskedasticity-robust t-statistics in parentheses. The sample consists of single retirees in the Health and Retirement Study, who were born 1891–1940, aged 65 or older, and interviewed between 1992 and 2006.

Table 3

Asset allocation and health expenditure for females in the Health and Retirement Study.

	Age				
Health status	65	71	77	83	89
Panel A: Bonds (% of financial and housing wealth)					
Poor	13	24	36	47	57
Fair	19	29	39	49	57
Good	27	36	44	52	59
Very good	32	40	47	54	60
Excellent	36	41	46	51	55
Panel B: Stocks (% of financial and housing wealth)					
Poor	1	2	3	3	5
Fair	2	2	3	4	5
Good	3	3	4	4	5
Very good	4	4	4	4	5
Excellent	4	4	4	5	5
Panel C: Housing (% of financial and housing wealth)					
Poor	85	74	62	49	38
Fair	80	69	58	47	37
Good	70	61	52	44	36
Very good	64	57	49	42	35
Excellent	61	55	50	45	40
Panel D: Ratio of total wealth to income					
Poor	2.9	2.8	2.7	2.6	2.5
Fair	2.8	2.7	2.7	2.6	2.6
Good	2.6	2.6	2.6	2.6	2.5
Very good	2.5	2.5	2.5	2.5	2.6
Excellent	2.5	2.5	2.5	2.5	2.6
Panel E: Out-of-pocket health expenditure (% of income)					
Poor	12	17	24	34	48
Fair	9	13	17	24	33
Good	7	10	14	19	27
Very good	6	8	11	16	22
Excellent	5	7	9	13	17
Panel F: Health distribution (% at given age)					
Poor	10	11	13	14	16
Fair	23	25	26	27	28
Good	33	33	33	32	32
Very good	25	24	22	21	19
Excellent	8	7	6	5	5

Note: Panels B and C report the predicted values from the censored regression model in Table 2. Panel D reports the predicted values from the censored regression model for the income-wealth ratio in Section 3.2. Panel E reports the predicted values from the regression model in Table 4. Panel F reports the predicted values from an ordered probit model that explains health status as a function of age, financial and housing wealth, birth cohort, and the interaction of these variables with a male dummy. All predicted values are for single females, who were born 1931–1940 and have the average financial and housing wealth for her cohort and age.

Table 4
Out-of-pocket health expenditure in relation to health.

Explanatory variable	Coefficient for females		Interaction effect for males	
Health status:				
Poor	57.25	(7.09)	1.22	(0.07)
Fair	29.49	(4.93)	3.24	(0.28)
Very good	-17.88	(-3.13)	-12.07	(-1.04)
Excellent	-31.82	(-3.52)	5.62	(0.32)
(Age − 65)/10	56.44	(17.58)	-5.68	(-0.83)
× Poor	0.47	(0.09)	0.64	(0.06)
× Fair	-3.92	(-0.99)	0.14	(0.02)
× Very good	-1.24	(-0.32)	12.79	(1.56)
× Excellent	-4.83	(-0.78)	-5.60	(-0.45)
Financial and housing wealth	4.57	(5.03)	0.01	(0.01)
× Poor	5.34	(3.31)	1.34	(0.36)
× Fair	4.43	(3.31)	-4.63	(-1.60)
× Very good	3.10	(2.11)	-3.60	(-1.17)
× Excellent	-1.79	(-0.71)	4.52	(0.93)
Birth cohort:				
1891–1900	-64.51	(-3.89)	12.96	(0.27)
1901–1910	-40.31	(-6.18)	-1.10	(-0.08)
1911–1920	-39.22	(-8.94)	1.78	(0.20)
1921–1930	-22.10	(-6.60)	-12.23	(-1.80)
Constant	-267.90	(-67.47)	-15.15	(-1.88)
Wald test for male interaction effects			7.53	(0.00)
Observations	25,891			

Note: A linear regression model is used to explain the logarithm of out-of-pocket health expenditure as a share of income. The table reports the estimated coefficients in percentage points and heteroskedasticity-robust t-statistics in parentheses. The sample consists of single retirees in the Health and Retirement Study, who were born 1891–1940, aged 65 or older, and interviewed between 1992 and 2006.

Table 5

Calibration parameters for females.

Parameter	Symbol	Value
Preferences:		
Subjective discount factor	β	0.96
Elasticity of intertemporal substitution	σ	0.5
Relative risk aversion	γ	5
Utility weight on housing	ϕ	0.6
Utility weight on health	α	0.1
Elasticity of substitution between non-health consumption and health	ρ	0.7
Strength of the bequest motive	ν	0
Financial assets:		
Bond return	$\overline{R}_b - 1$	2.5%
Average stock return	$\overline{R}_s - 1$	6.5%
Standard deviation of stock returns	σ_s	18%
Housing:		
Depreciation rate	δ	1.14%
Average housing return	$\overline{R}_h - 1$	0.4%
Standard deviation of housing returns	σ_h	3.5%
Borrowing limit	λ	50%
Transaction cost	τ	8%
Health:		
Average of log health	μ_H	-11
Standard deviation of log health	σ_H	1.2
Returns to health investment	ψ	0.19

Note: The life-cycle model is solved and simulated at a two-year frequency to match the frequency of interviews in the Health and Retirement Study. The subjective discount factor, the average and the standard deviation of asset returns, and the depreciation rate are annualized.

Table 6

Asset allocation and health expenditure for females in the simulated model.

	Age				
Health status	65	71	77	83	89
Panel A: Bonds (% of financial and housing wealth)					
Poor	11	42	46	47	48
Fair	18	50	52	52	51
Good	26	50	59	60	60
Very good	28	56	64	66	67
Excellent	29	66	65	64	65
Panel B: Stocks (% of financial and housing wealth)					
Poor	6	8	7	6	5
Fair	5	5	4	4	4
Good	6	7	5	4	4
Very good	9	11	7	6	5
Excellent	10	8	8	8	8
Panel C: Housing (% of financial and housing wealth)					
Poor	83	49	48	47	47
Fair	77	45	44	45	45
Good	68	43	36	36	36
Very good	63	33	29	28	28
Excellent	61	26	27	27	26
Panel D: Ratio of total wealth to income					
Poor	2.9	2.8	2.7	2.6	2.5
Fair	2.8	2.7	2.7	2.6	2.6
Good	2.6	2.6	2.6	2.6	2.5
Very good	2.5	2.5	2.5	2.5	2.6
Excellent	2.5	2.5	2.5	2.5	2.6
Panel E: Out-of-pocket health expenditure (% of income)					
Poor	37	26	29	30	31
Fair	18	15	17	18	19
Good	9	7	9	10	12
Very good	4	3	4	5	6
Excellent	2	2	3	3	3
Panel F: Health distribution (% at given age)					
Poor	10	8	9	10	11
Fair	23	21	23	25	27
Good	33	34	36	37	37
Very good	25	31	27	25	23
Excellent	8	6	5	4	3

Note: The solution to the life-cycle model is used to simulate a population of 100,000 females starting at age 65. The table reports the mean of the given variable in the cross section of retirees that remain alive at the given age. Table 5 reports the parameters of the life-cycle model.

Table 7

Asset allocation and health expenditure for females with lower retirement income.

	Age				
Health status	65	71	77	83	89
Panel A: Bonds (% of financial and housing wealth)					
Poor	9	48	46	47	48
Fair	21	57	56	58	60
Good	27	58	62	64	65
Very good	28	57	68	68	70
Excellent	29	56	68	69	73
Panel B: Stocks (% of financial and housing wealth)					
Poor	14	9	8	8	8
Fair	5	5	4	4	4
Good	7	6	5	5	4
Very good	9	8	7	6	5
Excellent	11	10	10	9	5
Panel C: Housing (% of financial and housing wealth)					
Poor	77	42	46	45	45
Fair	74	38	39	37	36
Good	67	36	33	32	30
Very good	62	35	25	25	25
Excellent	60	35	23	22	22
Panel D: Ratio of total wealth to income					
Poor	5.8	5.6	5.4	5.2	5.0
Fair	5.5	5.4	5.3	5.2	5.1
Good	5.2	5.2	5.2	5.1	5.1
Very good	5.0	5.1	5.1	5.1	5.1
Excellent	5.0	5.0	5.0	5.1	5.1
Panel E: Out-of-pocket health expenditure (% of income)					
Poor	42	32	32	33	33
Fair	19	18	18	19	20
Good	9	9	10	11	11
Very good	3	4	4	5	6
Excellent	2	2	2	2	3
Panel F: Health distribution (% at given age)					
Poor	10	5	6	7	7
Fair	23	16	18	20	23
Good	33	32	34	35	36
Very good	25	35	33	30	28
Excellent	8	12	10	8	6

Note: The solution to the life-cycle model, in which the retiree receives only 50% of the estimated income, is used to simulate a population of 100,000 females starting at age 65. The table reports the mean of the given variable in the cross section of retirees that remain alive at the given age. Table 5 reports the parameters of the life-cycle model.

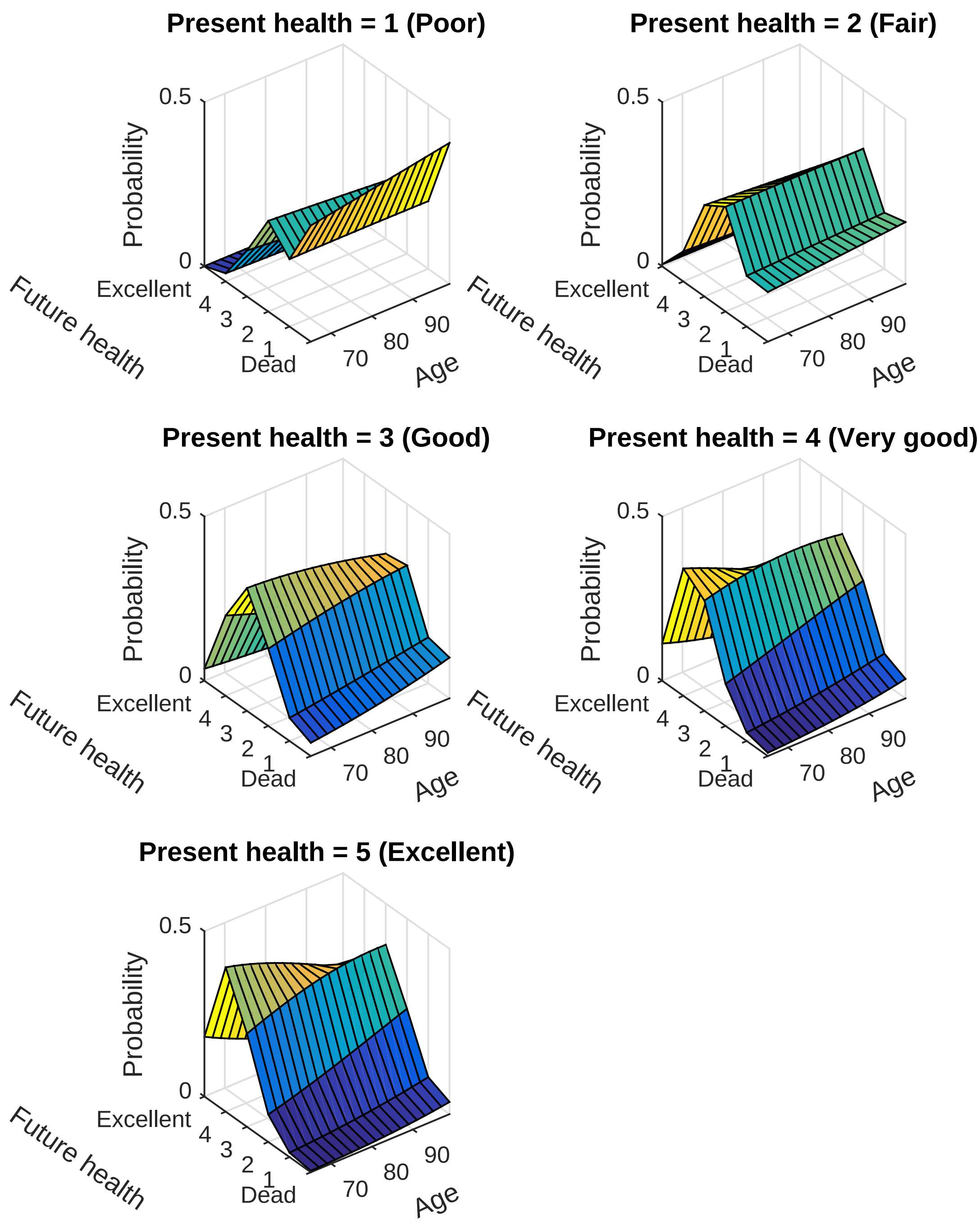

Figure 1. Health transition probabilities in the absence of health investment. *Note*: The predicted probabilities from the ordered probit model in column (1) of Table 1 are reported. The predicted probabilities are for single females, who were born 1931–1940, have the average financial and housing wealth for her cohort and age, have not used health care in the two years prior to the interview, and does not regularly participate in vigorous physical activity and smokes at the time of interview.

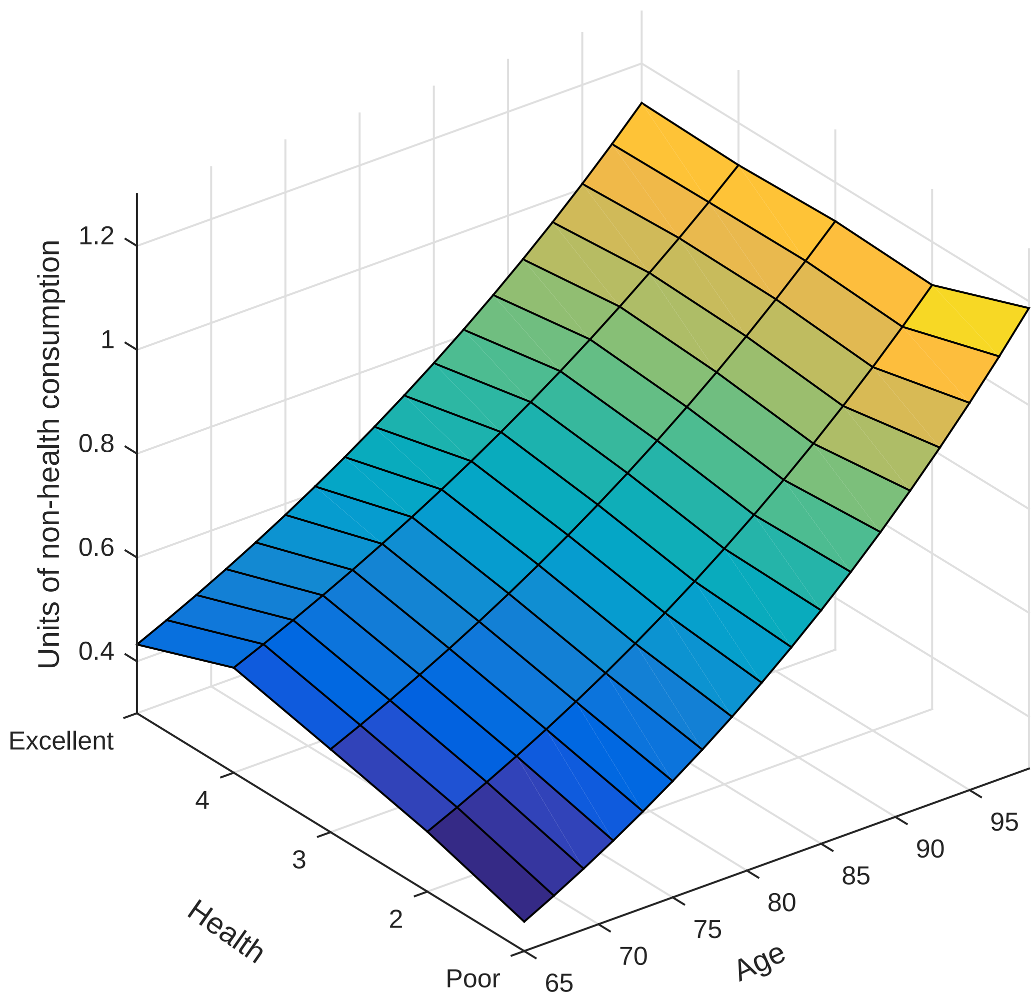

Figure 2. Relative price of health care. *Note*: The relative price of health care including health insurance coverage is reported, based on equation (27) with $q = 0.019$. A censored regression model is used to estimate how the out-of-pocket expenditure share depends on health status, age and its interaction with health status, financial and housing wealth and its interaction with health status, birth cohort, and the interaction of these variables with a male dummy. The predicted values for single females, who were born 1931–1940 and have the average financial and housing wealth for her cohort and age, are used to construct $q_t(h_t^*)$.

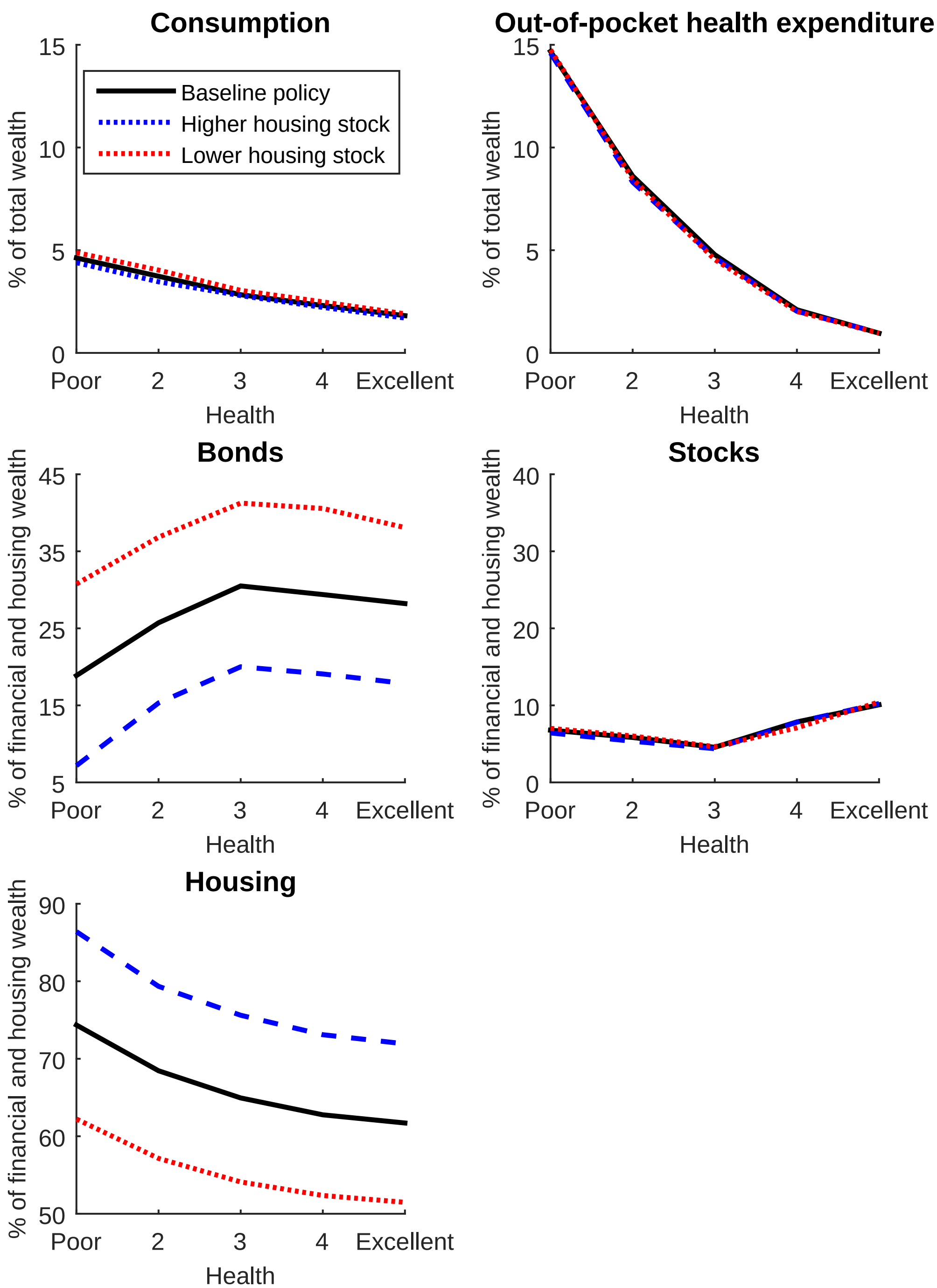

Figure 3. Optimal consumption and portfolio policies in the life-cycle model. *Note*: The optimal consumption and portfolio policies for females at age 65 are reported as functions of health status. The baseline policy corresponds to $d_t = 0.6$, and higher (lower) housing stock corresponds to $d_1 = 0.7$ ($d_1 = 0.5$). The home price is fixed at $P_1 = 1$.

Appendix A. Definition of variables based on the Health and Retirement Study

Most of the variables are based on the RAND HRS (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.

Out-of-pocket health expenditure is the sum of out-of-pocket health expenditure from the RAND HRS, payments of health insurance premiums, and end-of-life health expenditure from the exit interviews (since wave 3 when the data are available). Out-of-pocket health expenditure from the RAND HRS is the total amount paid for hospitals, nursing homes, doctor visits, dentist visits, outpatient surgery, prescription drugs, home health care, and special facilities. Payments of health insurance premiums are the sum of premiums paid for Medicare/Medicaid HMO, private health insurance, long-term care insurance, and prescription drug coverage (i.e., Medicare Part D). The premium reported at monthly, quarterly, semi-annual, or annual frequency is converted to the total implied payment over two years. End-of-life health expenditure from the exit interviews is the total amount paid for hospitals, nursing homes, doctor visits, prescription drugs, home health care, other health services, other medical expenses, and other non-medical expenses.

Income is the sum of labor income, employer pension and annuity income, Social Security disability and supplemental security income, Social Security retirement income, and unemployment or workers compensation. The after-tax income is calculated by subtracting federal income tax liabilities, estimated through the NBER TAXSIM program (Version 9).

Bonds consist of checking, savings, and money market accounts; CD, government savings bonds, and T-bills; bonds and bond funds; and the imputed value of bonds in IRA and Keogh accounts. Because the asset allocation in IRA and Keogh accounts is not available, the portfolio share in bonds for each respondent is imputed to be the same as that in non-retirement accounts. The value of liabilities is subtracted from the value of bonds. Liabilities consist of all mortgages for primary and secondary residence, other home loans for primary residence, and other debt. Stocks consist of businesses; stocks, mutual funds, and investment trusts; and the imputed value of stocks in IRA and Keogh accounts. Housing consists of primary and secondary residence.

Appendix B. Asset allocation and health expenditure for males

This appendix reports asset allocation and health expenditure for males in the Health and Retirement Study and in the simulated model. That is, it reports the analogs of Tables 3, 5, and 6 for males.

Table B1

Asset allocation and health expenditure for males in the Health and Retirement Study.

	Age				
Health status	65	71	77	83	89
Panel A: Bonds (% of financial and housing wealth)					
Poor	18	22	26	29	33
Fair	29	33	37	41	45
Good	31	35	39	42	45
Very good	36	38	40	42	43
Excellent	36	39	42	44	46
Panel B: Stocks (% of financial and housing wealth)					
Poor	4	5	5	6	7
Fair	3	4	5	6	7
Good	4	5	6	7	8
Very good	6	7	8	9	11
Excellent	4	5	6	8	10
Panel C: Housing (% of financial and housing wealth)					
Poor	78	73	69	65	60
Fair	68	63	58	53	48
Good	65	60	56	51	47
Very good	58	55	52	49	46
Excellent	60	56	52	48	44
Panel D: Ratio of total wealth to income					
Poor	2.4	2.5	2.7	2.9	3.1
Fair	2.5	2.7	2.8	3.0	3.1
Good	2.4	2.5	2.7	2.9	3.2
Very good	2.3	2.5	2.7	2.9	3.2
Excellent	2.3	2.5	2.6	2.8	3.0
Panel E: Out-of-pocket health expenditure (% of income)					
Poor	11	14	20	27	37
Fair	8	11	14	19	25
Good	6	8	11	15	20
Very good	4	6	9	13	19
Excellent	5	6	7	9	12
Panel F: Health distribution (% at given age)					
Poor	10	12	13	15	18
Fair	24	25	27	28	29
Good	33	33	33	32	31
Very good	25	23	21	20	18
Excellent	8	7	6	5	4

Note: Panels B and C report the predicted values from the censored regression model in Table 2. Panel D reports the predicted values from the censored regression model for the income-wealth ratio in Section 3.2. Panel E reports the predicted values from the regression model in Table 4. Panel F reports the predicted values from an ordered probit model that explains health status as a function of age, financial and housing wealth, birth cohort, and the interaction of these variables with a male dummy. All predicted values are for single males, who were born 1931–1940 and have the average financial and housing wealth for his cohort and age.

Table B2
Calibration parameters for males.

Parameter	Symbol	Value
Preferences:		
Subjective discount factor	β	0.96
Elasticity of intertemporal substitution	σ	0.5
Relative risk aversion	γ	5
Utility weight on housing	ϕ	0.9
Utility weight on health	α	0.1
Elasticity of substitution between non-health consumption and health	ρ	0.7
Strength of the bequest motive	ν	0
Financial assets:		
Bond return	$\overline{R}_b - 1$	2.5%
Average stock return	$\overline{R}_s - 1$	6.5%
Standard deviation of stock returns	σ_s	18%
Housing:		
Depreciation rate	δ	1.14%
Average housing return	$\overline{R}_h - 1$	0.4%
Standard deviation of housing returns	σ_h	3.5%
Borrowing limit	λ	50%
Transaction cost	τ	8%
Health:		
Average of log health	μ_H	-11
Standard deviation of log health	σ_H	1.2
Returns to health investment	ψ	0.20

Note: The life-cycle model is solved and simulated at a two-year frequency to match the frequency of interviews in the Health and Retirement Study. The subjective discount factor, the average and the standard deviation of asset returns, and the depreciation rate are annualized.

Table B3

Asset allocation and health expenditure for males in the simulated model.

	Age				
Health status	65	71	77	83	89
Panel A: Bonds (% of financial and housing wealth)					
Poor	19	27	30	37	38
Fair	29	41	48	47	47
Good	31	42	50	51	55
Very good	34	48	53	57	61
Excellent	29	49	57	62	62
Panel B: Stocks (% of financial and housing wealth)					
Poor	6	9	8	5	5
Fair	5	6	3	3	3
Good	5	11	5	5	4
Very good	9	13	9	8	6
Excellent	11	14	12	10	10
Panel C: Housing (% of financial and housing wealth)					
Poor	75	64	62	58	57
Fair	66	53	49	49	49
Good	64	47	45	44	42
Very good	57	39	38	35	33
Excellent	60	36	31	28	28
Panel D: Ratio of total wealth to income					
Poor	2.4	2.5	2.7	2.9	3.1
Fair	2.5	2.7	2.8	3.0	3.1
Good	2.4	2.5	2.7	2.9	3.2
Very good	2.3	2.5	2.7	2.9	3.2
Excellent	2.3	2.5	2.6	2.8	3.0
Panel E: Out-of-pocket health expenditure (% of income)					
Poor	33	26	27	30	33
Fair	17	13	16	18	19
Good	8	7	9	10	12
Very good	4	3	4	5	6
Excellent	3	2	3	3	4
Panel F: Health distribution (% at given age)					
Poor	10	10	11	11	10
Fair	24	21	23	25	26
Good	33	37	37	37	36
Very good	25	26	25	23	23
Excellent	8	6	5	4	4

Note: The solution to the life-cycle model is used to simulate a population of 100,000 males starting at age 65. The table reports the mean of the given variable in the cross section of retirees that remain alive at the given age. Table B2 reports the parameters of the life-cycle model.

Appendix C. Numerical solution of the life-cycle model

Health h_t is discretized into 5 grid points, spaced to match the lognormal distribution for health at age 65. The housing stock d_t is discretized into 9 grid points, equally spaced between 0.1 and 0.9. The home price P_t is discretized into 5 grid points, equally spaced on a logarithmic scale between 1 and 1.5. The transition probabilities between these 5 grid points are calculated to match the moments for housing returns. Finally, the lognormal shock for stock returns $\epsilon_{s,t}$ is discretized into 5 grid points by Gauss-Hermite quadrature. The fineness of the state space is chosen after some experimentation to minimize computation time without sacrificing accuracy.

Because the retiree dies with certainty in period 28 (i.e., age 119), her value function in that period is given by equation (19). For each period $t < 28$ and at each grid point in the state space, the problem is solved recursively through the following algorithm.

1. Suppose that paying the transaction cost to change the housing stock is optimal (i.e., $a_{h,t} \neq d_t$). Find the policies c_t, i_t, and $a_{i,t}$ for $i = \{s, h\}$ that maximizes the objective function, using numerical interpolation to evaluate the value function in period $t + 1$.

2. If $(1 - \lambda)d_t \geq 1$, the policies from step 1 must be optimal because the retiree must reduce the housing stock to satisfy the budget constraint. Otherwise, proceed to step 3.

3. Suppose that avoiding the transaction cost by keeping the present housing stock is optimal (i.e., $a_{h,t} = d_t$). Find the policies c_t, i_t, and $a_{s,t}$ that maximizes the objective function, using numerical interpolation to evaluate the value function in period $t + 1$.

4. Compare the value of the objective function achieved in steps 1 and 3. The policy that achieves the higher value is the optimal policy.

The use of analytical partial derivatives of the objective function makes the numerical optimization routine faster and more accurate than it would otherwise be. The partial derivative of the objective function with respect to consumption is

$$\begin{aligned}\frac{\partial j_t}{\partial c_t} =& j_t^{1/\sigma} \Bigg\{ (1-\beta) u_t^{-1/\sigma} \frac{\partial u_t}{\partial c_t} \\ & - \beta \mathbb{E}_t [\Delta w_{t+1}^{1-\gamma} (\mathbb{1}_{\{\omega_{t+1} \neq 1\}} j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}} \nu^\gamma g_{t+1}^{1-\gamma})]^{(\gamma - 1/\sigma)/(1-\gamma)} \\ & \times \mathbb{E}_t \left[\frac{R_{b,t+1}}{\Delta w_{t+1}^\gamma (1 - y_{t+1})} (\mathbb{1}_{\{\omega_{t+1} \neq 1\}} j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}} \nu^\gamma g_{t+1}^{1-\gamma}) \right] \Bigg\},\end{aligned} \tag{C1}$$

where

$$\frac{\partial u_t}{\partial c_t} = (1-\alpha)(1-\phi)V_t^{1/\rho}\left(\frac{a_{h,t}}{P_t c_t}\right)^{\phi(1-1/\rho)}. \tag{C2}$$

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

$$\begin{aligned}\frac{\partial j_t}{\partial i_t} =& j_t^{1/\sigma}\left\{(1-\beta)u_t^{-1/\sigma}\frac{\partial u_t}{\partial i_t}\right.\\ &- \beta\mathbb{E}_t[\Delta w_{t+1}^{1-\gamma}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}}j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^\gamma g_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)}\\ &\left.\times\mathbb{E}_t\left[\frac{R_{b,t+1}}{\Delta w_{t+1}^{\gamma}(1-y_{t+1})}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}}j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^\gamma g_{t+1}^{1-\gamma})\right]\right\},\end{aligned} \tag{C3}$$

where

$$\frac{\partial u_t}{\partial i_t} = \frac{\alpha\psi^2 c_t V_t^{1/\rho}}{h_t^{\psi} i_t^{1-\psi} + \psi i_t}\left(\frac{h_t[1+\psi(i_t/h_t)^{\psi}]}{Q_t c_t}\right)^{1-1/\rho}. \tag{C4}$$

The partial derivative of the objective function with respect to savings in stocks is

$$\begin{aligned}\frac{\partial j_t}{\partial a_{s,t}} =& j_t^{1/\sigma}\beta\mathbb{E}_t[\Delta w_{t+1}^{1-\gamma}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}}j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^\gamma g_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)}\\ &\times\mathbb{E}_t\left[\frac{(R_{s,t+1}-R_{b,t+1})}{\Delta w_{t+1}^{\gamma}(1-y_{t+1})}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}}j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^\gamma g_{t+1}^{1-\gamma})\right].\end{aligned} \tag{C5}$$

Finally, the partial derivative of the objective function with respect to savings in housing wealth is

$$\begin{aligned}\frac{\partial j_t}{\partial a_{h,t}} =& j_t^{1/\sigma}\left\{(1-\beta)u_t^{-1/\sigma}\frac{\partial u_t}{\partial a_{h,t}}\right.\\ &+ \beta\mathbb{E}_t[\Delta w_{t+1}^{1-\gamma}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}}j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^\gamma g_{t+1}^{1-\gamma})]^{(\gamma-1/\sigma)/(1-\gamma)}\\ &\left.\times\mathbb{E}_t\left[\frac{(R_{h,t+1}-R_{b,t+1}-\tau)}{\Delta w_{t+1}^{\gamma}(1-y_{t+1})}(\mathbb{1}_{\{\omega_{t+1}\neq 1\}}j_{t+1}^{1-\gamma} + \mathbb{1}_{\{\omega_{t+1}=1\}}\nu^\gamma g_{t+1}^{1-\gamma})\right]\right\},\end{aligned} \tag{C6}$$

where

$$\frac{\partial u_t}{\partial a_{h,t}} = \frac{(1-\alpha)\phi c_t V_t^{1/\rho}}{a_{h,t}}\left(\frac{a_{h,t}}{P_t c_t}\right)^{\phi(1-1/\rho)}. \tag{C7}$$