Macroeconomic Dynamics, 2017, Page 1 of 38. Printed in the United States of America.
doi:10.1017/S1365100516001152

HEALTH INVESTMENT OVER THE LIFE-CYCLE

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We quantify what drives the rise in medical expenditures over the life-cycle using a stochastic dynamic overlapping generations model of health investment. Three motives for health investment are considered. First, health delivers a flow of utility each period (the consumption motive). Second, better health enables people to allocate more time to productive or pleasurable activities (the investment motive). Third, better health improves survival prospects (the survival motive). We find that, overall, the consumption motive plays a dominant role, whereas the investment motive is more important than the consumption and survival motives until the forties. The survival motive is quantitatively

We thank Carl Bonham, Michele Boldrin, Toni Braun, Kaiji Chen, Sumner La Croix, Kevin Huang, Selo Imrohoroglu, Sagiri Kitao, Nobu Kiyotaki, Dirk Krueger, Zheng Liu, Andy Mason, Makoto Nakajima, Michael Palumbo, Richard Rogerson, Richard Suen, Motohiro Yogo, Kai Zhao, seminar participants at the Chinese University of Hong Kong, the Federal Reserve Board, George Washington University, Hong Kong University of Science and Technology, Peking University, Shanghai University of Finance and Economics, University of Hawai'i at Mānoa, Utah State University, and conference participants at the 2009 Midwest Macroeconomics Meeting, 2009 QSPS Summer Workshop, 2009 Western Economic Association International (WEAI) Meeting, 15th International Conference on Computing in Economics and Finance in Sydney, 2010 Tsinghua Workshop in Macroeconomics, and 2010 SED Annual Meeting for helpful feedback. We thank Jesus Fernandez-Villaverde for providing us consumption data. Financial support from the College of Social Sciences at the University of Hawai'i at Manoa is gratefully acknowledged. Hui He thanks research support sponsored by Shanghai Pujiang Program (No. 2013140026) and the Program for Professor of Special Appointment (Eastern Scholar) at Shanghai Institutions of Higher Learning (No. 2013140034). Lei Ning thanks research support from the Fundamental Research Funds for the Central Universities (SUFE) (2017110133) and China Postdoctoral Science Foundation (Grant No. 2017M611515). Most of the work related to the paper was done when Hui He was a faculty member at Shanghai University of Finance and Economics (SHUFE). Therefore, the views expressed in this paper are those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management. Address correspondence to: Hui He, Institute for Capacity Development, International Monetary Fund, 700 19th Street NW, Washington, DC 20431, USA; e-mail: hhe@imf.org.

 1365-1005/17

less important when compared to the other two motives. We also conduct a series of counter-factual policy experiments to investigate how government policies impacting health insurance coverage, Social Security, and health care technological progress affect the behavior of medical expenditures, and social welfare.

Keywords: Quantitative Macroeconomics, Life Cycle, Medical Expenditure, Social Security

1. INTRODUCTION

In this paper, we ask what factors determine the allocation of medical expenditures over the life-cycle from a quantitative macroeconomic perspective. Although there is a growing macro-health literature that has investigated the determinants of the aggregate ratio of medical expenditures to gross domestic product (GDP) in the economy [e.g., Suen (2006), Hall and Jones (2007), Fonseca et al. (2009), Zhao (2014), He and Huang (2013)], little work has been done that investigates the driving forces behind the *life-cycle* behavior of medical expenditures, particularly, their dramatic rise after age 65 that has been documented in Meara et al. (2004) and Jung and Tran (2010). This paper fills this void.

We view health as a type of capital stock following Grossman (1972). In our model, health capital takes medical expenditures as its sole input.[1] There are three motives for health investment. First, health may be desirable in and of itself, and so people may invest because it directly adds to their well-being. Grossman refers to this as the "consumption motive" (C-Motive). Second, better health allows individuals to allocate more time to work or to enjoy leisure via reducing sick days. Grossman refers to this motive as the "investment motive" (I-Motive). Finally, better health improves the likelihood of survival. We refer to this as the "survival motive" (S-Motive). Although Grossman (1972) explains the first two of these motives qualitatively, little, if anything, is understood about how the three motives evolve over the *life-cycle* in the *quantitative* sense. In this paper, we elucidate how each of these three motives contributes to the life-cycle behavior of medical expenditures using techniques that not only allow us to quantify their relative importance, but also to better understand how health investments affect other life-cycle behaviors such as asset holdings, consumption, and labor supply. This is one of the first papers to shed light on this issue.

To accomplish this, we calibrate an overlapping generations model with endogenous health accumulation. This model, which closely follows Grossman (1972), allows health to affect utility directly (the C-Motive) and indirectly via time allocation (the I-Motive). In addition, health also affects survival (the S-Motive). To make the model close to reality, we also augment the Grossman-type framework with worker heterogeneity in productivity and model the tax deduction of health insurance premiums that is an important feature of the US economy. Parameters are calibrated so that the model can replicate key economic ratios. We then gauge the performance of the model by comparing key life-cycle profiles from the model with their counterparts in the data.

The calibrated model matches the life-cycle profiles of consumption, working hours, health status, medical expenditure, and survival probabilities well. With the calibrated model, we carry out decomposition exercises to quantitatively isolate the effect of each motive on medical expenditures. In all counterfactual exercises, we find that the C-Motive plays a much more important role in shaping health expenditure over the life-cycle.

Focusing on different episodes of the life-cycle, we find that the I-Motive is more important than the consumption and S-Motive until the 40's. The C-Motive, however, is the dominating force behind health investment after the late 50's and early 60's. Intuitively speaking, younger people invest in their health mainly because better health allows them to enjoy more leisure and to work more, whereas older people invest in their health mainly because health improves their quality of life. The S-Motive becomes more important with age but matters less when compared to the other two motives.

By quantifying which primitive aspects of individual behavior are responsible for the run-up of medical expenditures over the life-course, we provide an important benchmark for other quantitative macroeconomists and structural labor economists who wish to analyze the economic consequences of health policy interventions.[2] In particular, our focus on the life-cycle enables us and others to make statements about how policies will affect health investment behavior over the *life-cycle* and distribute medical resources *across* generations, which is something that previous work on health investment does not do.

We conduct a series of counterfactual experiments to investigate how government policies that reduce health insurance coverage and Social Security benefits, and enhance technological progress in medicine affect the behavior of medical expenditures and social welfare. We find that all of these policies have the potential to decrease medical expenditures over the life-cycle and reduce the medical expenditure-to-GDP ratio. They also raise welfare vis-à-vis the benchmark system. Among the policies considered, reducing the insurance coverage rate and the Social Security replacement ratio have a much more significant impact on medical expenditures and social welfare than the other policies that we consider. Of course, due to the partial equilibrium nature of the benchmark model in which we assume exogenous factor prices, the model does not contain a feedback mechanism from price changes to behaviors, although it does capture equilibrium effects from endogenous government policy via the government's budget constraint.

Our work is part of a new and growing macro-health literature that incorporates endogenous health accumulation into dynamic models.[3] For example, Hall and Jones (2007), Suen (2006), Fonseca et al. (2009), and Zhao (2014) use a Grossman-type model to explain the recent increases in aggregate medical expenditures in the United States. Feng (2009) examines the macroeconomic and welfare implications of alternative reforms to the health insurance system in the United States. Jung and Tran (2009) study the general equilibrium effects of health savings accounts (HSAs). Yogo (2016) builds a model of health investment to investigate the effect of health shocks on the portfolio choices of retirees. Finally, Huang and Huffman (2014) develop a general equilibrium growth model with endogenous health accumulation and a simple search friction to evaluate the welfare effect of the current tax treatment of employer-provided medical insurance in the United States. However, none of these focuses on the life-cycle motives for health investment that is our main contribution to the literature.[4]

The balance of this paper is organized as follows. Section 2 presents the model. Section 3 describes the life-cycle profiles of income, hours worked, medical expenditures, and health status in the data. Section 4 presents the parameterization of the model. Section 5 presents the life-cycle profiles generated from our benchmark model. Section 6 decomposes the three motives for health investment and quantifies their relative importance. In Section 7, we conduct a series of counterfactual policy experiments. Section 8 concludes.

2. MODEL

This section describes an overlapping generations model with heterogeneous agents and endogenous health accumulation. Health enters the model in three ways. First, health provides direct utility as a consumption good. Second, better health increases the endowment of time. Third, better health increases the likelihood of survival.

2.1. Preferences and Demographic Structure

The economy is populated by ex ante identical individuals of measure one. Each individual lives at most J periods and derives utility from consumption, leisure, and health. The agent maximizes her expected discounted lifetime utility that is given by

$$\mathbf{E}\sum_{j=1}^{J}\beta^{j-1}\left[\prod_{k=1}^{j}\varphi_k(h_k)\right]u(c_j, l_j, h_j), \tag{1}$$

where β denotes the subjective discount factor, c is consumption, l is leisure, and h is health status. The term, $\varphi_j(h_j)$, represents the age-dependent conditional probability of surviving from age $j-1$ to j with the property $\varphi_1 = 1$ and $\varphi_{J+1} = 0$. We assume that this survival probability is a function of health status h, which is endogenously determined, and that $\varphi_j'(h_j) > 0$ so that better health improves the chances of survival.[5] In each period, there is a chance that some individuals die with unintended bequests. We assume that the government collects all accidental bequests and distributes these equally among individuals who are currently alive. There is no private annuity market.

2.2. Budget Constraints

Each period the individual is endowed with one unit of discretionary time. She splits this time between working (n), enjoying leisure (l), and being sick (s). The time constraint is then given by

$$n_j + l_j + s(h_j) = 1, \text{ for } 1 \leq j \leq J. \tag{2}$$

We assume that "sick time," s, is a decreasing function of health status so that $s'(h_j) < 0$. Notice that in contrast to recent structural work that incorporates endogenous health accumulation [e.g., Feng (2009), Jung and Tran (2009)], health does not directly affect labor productivity. Allowing health to affect the allocation of time as opposed to labor productivity is consistent with Grossman (1972), who says, "Health capital differs from other forms of human capital... a person's stock of knowledge affects his market and non-market productivity, while his stock of health determines the total amount of time he can spend producing money earnings and commodities." In that sense, our notion of the "I-Motive" for health is tied to Grossman's original notion.

The agent works until an exogenously given mandatory retirement age j_R. Labor productivity differs due to differences in age and also differs across individuals. We use ε_j to denote age-specific (deterministic) efficiency at age j. We use η to represent the idiosyncratic productivity shock an individual receives at every age. We assume that η follows a first-order autoregressive stochastic process. We let w denote the wage rate and r denote the rate of return on asset holdings. Accordingly, $w\varepsilon_j\eta n_j$ is age-j labor income.

The budget constraint for a working age individual at age j is given by

$$\begin{aligned} c_j + (1-\phi_p)m_j + (1-\tau_{\text{ss}}-\tau_{\text{med}})\pi + a_{j+1} &\leq (1-\tau_{\text{ss}}-\tau_{\text{med}})w\varepsilon_j\eta n_j \\ &\quad + (1+r)a_j + T, \forall j < j_R. \end{aligned} \tag{3}$$

A worker needs to pay a Social Security tax with rate τ_{ss} and a Medicare tax with rate τ_{med}. She also holds assets a_j and receives the lump-sum transfer from accidental bequests from the government T at the beginning of age j. The right-hand side of equation (3) thus describes her total income at age j. With her income, she needs to make decisions about consumption c_j, asset holdings in the next period a_{j+1}, labor supply n_j, and medical expenditures m_j. To capture the subsidized nature of medical spending in the United States, we assume that every working-age individual is enrolled in private health insurance. She pays the health insurance premium π, which is exempted from taxation and, in exchange, a fraction, ϕ_p, of her medical expenditures are paid by the insurance company. In other words, she only needs to pay $1-\phi_p$ percent of total medical expenditure out of her own pocket.

Once an individual is retired, she receives Social Security benefits, denoted by b. Following Imrohoroglu et al. (1995), we model the Social Security system in a simple way. Social Security benefits b are calculated to be a fraction κ of some base income, which we take as the average lifetime labor income

$$b = \kappa \frac{\sum_{j=1}^{j_R - 1} w \varepsilon_j \eta n_j}{j_R - 1},$$

where κ is the replacement ratio. She is also automatically enrolled in the Medicare system. To receive Medicare, she does not need to pay a premium. Yet, Medicare pays a fraction ϕ_m of her medical expenditures. An age-j retiree then faces the budget constraint

$$c_j + (1 - \phi_m) m_j + a_{j+1} \leq b + (1 + r) a_j + T, \forall j \geq j_R. \quad \textbf{(4)}$$

For all ages, we assume that agents are not allowed to borrow, so that

$$a_{j+1} \geq 0 \text{ for } 1 \leq j \leq J.$$

Thus, an individual has to use saving to self-insure against the idiosyncratic income shocks that she faces.

2.3. Health Investment

The individual invests in medical expenditures to produce health. Health accumulation is given by

$$h_{j+1} = (1 - \delta_{h_j}) h_j + g(m_j), \quad \textbf{(5)}$$

where δ_{h_j} is the age-dependent depreciation rate of the health stock. The term, $g(m_j)$, is the health production function that transforms medical expenditures at age j into health at age $j + 1$.

2.4. The Individual's Problem

At age j, an individual solves a dynamic programming problem. The state space at the beginning of age j is the vector (a_j, h_j, η). We let $V_j(a_j, h_j, \eta)$ denote the value function at age j given the state vector (a_j, h_j, η). The Bellman equation is then given by

$$\begin{aligned} &V_j(a_j, h_j, \eta) \\ &\quad = \max_{c_j, m_j, a_{j+1}, n_j} \left[u(c_j, l_j, h_j) + \beta \mathbf{E}_{\eta' | \eta} \varphi_{j+1}(h_{j+1}) V_{j+1}(a_{j+1}, h_{j+1}, \eta') \right], \quad \textbf{(6)} \end{aligned}$$

subject to

$$\begin{aligned} &c_j + (1 - \phi_p) m_j + (1 - \tau_{\text{ss}} - \tau_{\text{med}}) \pi + a_{j+1} \\ &\quad \leq (1 - \tau_{\text{ss}} - \tau_{\text{med}}) w \varepsilon_j \eta n_j + (1 + r) a_j + T, \forall j < j_R \end{aligned}$$

$$
\begin{aligned}
c_j + (1-\phi_m)m_j + a_{j+1} &\leq b + (1+r)a_j + T, \forall j \geq j_R \\
h_{j+1} &= (1-\delta_{h_j})h_j + g(m_j), \forall j \\
n_j + l_j + s(h_j) &= 1, \forall j \\
a_{j+1} &\geq 0, \forall j,\ a_1 = 0, h_1 \text{ is given}
\end{aligned}
$$

and the usual nonnegativity constraints.

2.5. Equilibrium Definition

Our focus in this paper is to understand the life-cycle behavior of health investment and to evaluate the impact of different policies on the life-cycle profiles of medical expenditures and health status. To serve this purpose, we take government policy on tax rates as endogenous. To simplify the analysis, we assume that factor prices are exogenous by defining a partial equilibrium with endogenous government policy. We believe this is a reasonable setting to answer our main research question.

DEFINITION 1. *Given constant prices* $\{w, r\}$, *the Social Security replacement ratio* $\{\kappa\}$, *and insurance coverage rates* $\{\phi_p, \phi_m\}$, *a partial equilibrium for the model economy is a collection of value functions* $V_j(a_j, h_j, \eta)$, *individual policy rules* $C_j(a_j, h_j, \eta)$, $M_j(a_j, h_j, \eta)$, $A_j(a_j, h_j, \eta)$, $N_j(a_j, h_j, \eta)$, *a measure of agent distribution* $\Phi_j(a_j, h_j, \eta)$ *for every age* j, *and a lump-sum transfer* T *such that the following conditions hold:*

1. *Given constant prices* $\{w, r\}$, *the policies* $\{\kappa, \tau_{\text{ss}}, \tau_{\text{med}}\}$ *and the lump-sum transfer* T, *value functions* $V_j(a_j, h_j, \eta)$ *and individual policy rules* $C_j(a_j, h_j, \eta)$, $M_j(a_j, h_j, \eta)$, $A_j(a_j, h_j, \eta)$, *and* $N_j(a_j, h_j, \eta)$ *solve the individual's dynamic programming problem (6).*
2. *The distribution of measure of age-*j *agents* $\Phi_j(a_j, h_j, \eta)$ *follows the law of motion*

$$
\Phi_{j+1}(a', h', \eta') = \sum_{a:a'=A_j(a,h,\eta)} \sum_{h:h'=H_j(a,h,\eta)} \sum_{\eta} \Gamma(\eta, \eta')\varphi_{j+1}(H_j(a,h,\eta))\Phi_j(a,h,\eta),
$$

where $\Gamma(\eta, \eta')$ *is the conditional probability for the next period* η' *given the current period* η.

3. *The share of age-*j *agents* $\mu_j, \forall j$ *is determined by*

$$
\Psi_j = \sum_a \sum_h \sum_\eta \Phi_j(a, h, \eta)
$$

$$
\mu_j = \frac{\Psi_j}{\sum_{i=1}^J \Psi_i}, \forall j
$$

where Ψ_j *is the measure of all age-*j *agents.*

4. *Social Security system is self-financing*

$$
\tau_{\text{ss}} = \frac{b \sum_{j=j_R}^J \mu_j}{wN},
$$

where N is determined by

$$N = \sum_{j=1}^{j_R-1} \sum_a \sum_h \sum_\eta \mu_j \Phi_j(a, h, \eta) \varepsilon_j N_j(a, h, \eta).$$

5. *Medicare system is self-financing*

$$\tau_{\text{med}} = \frac{\phi_m \sum_{j=j_R}^{J} \sum_a \sum_h \sum_\eta \mu_j \Phi_j(a, h, \eta) M_j(a, h, \eta)}{wN}.$$

6. *Private health insurance has a zero-profit condition*

$$\pi = \frac{\phi_p \sum_{j=1}^{j_R-1} \sum_a \sum_h \sum_\eta \mu_j \Phi_j(a, h, \eta) M_j(a, h, \eta)}{\sum_{j=1}^{j_R-1} \mu_j}.$$

7. *The lump-sum transfer of accidental bequests is determined by*

$$T = \sum_j \sum_a \sum_h \sum_\eta \mu_j \Phi_j(a, h, \eta)(1 - \varphi_{j+1}(H_j(a, h, \eta))) A_j(a, h, \eta).$$

2.6. Euler Equation for Health Investment

Before we move to the quantitative analysis of the benchmark model, we would like to understand qualitatively the three motives for health investment. For that purpose, we derive the following Euler equation for health investment at age j:

$$\frac{\partial u}{\partial c_j} = \beta \frac{g'(m_j)}{1 - \phi^j} \mathbf{E} \varphi_{j+1}(h_{j+1}) \left\{ \begin{array}{c} \dfrac{\partial u}{\partial h_{j+1}} - \dfrac{\partial u}{\partial l_{j+1}} s'(h_{j+1}) + \dfrac{\varphi'_{j+1}(h_{j+1})}{\varphi_{j+1}(h_{j+1})} u_{j+1} \\ +(1 - \phi^{j+1}) \dfrac{\partial u / \partial c_{j+1}}{g'(m_{j+1})} (1 - \delta_{h_{j+1}}) \end{array} \right\}, \tag{7}$$

where $\phi^j = \phi_p, \forall j < j_R$ and $\phi^j = \phi_m, \forall j_R \le j \le J$. The left-hand side of the equation is the marginal cost of using one additional unit of the consumption good for medical expenditures. However, one additional unit of medical expenditure will produce $g'(m_j)/(1 - \phi^j)$ units of the health stock tomorrow.

The right-hand side of equation (7) shows the marginal benefit brought by this additional unit of medical expenditure. First, better health tomorrow will directly increase utility by $\partial u / \partial h_{j+1}$, which is the first term inside the bracket. This term captures the “C-Motive”. Second, better health tomorrow reduces the number of sick days [recall $s'(h) < 0$] and thus increases the available time that can be spent working or relaxing. Notice that for working ages ($j < j_R$), we have the intratemporal condition for the work-leisure choice as follows:

$$\frac{\partial u}{\partial l_j} = (1 - \tau_{\text{ss}} - \tau_{\text{med}}) w \varepsilon_j \frac{\partial u}{\partial c_j} + \frac{\kappa w \varepsilon_j}{j_R - 1} \sum_{p=j_R}^{J} \left(\beta^{p-j} \left[\prod_{k=j+1}^{p} \varphi_k(h_k) \right] \frac{\partial u}{\partial c_p} \right). \tag{8}$$

The left-hand side shows the marginal cost of shifting one additional unit of time from enjoying leisure to working. The right-hand side captures the marginal benefit of this additional unit of working time. The first term shows the direct effect in the current period. The second term represents the indirect effect on the future Social Security benefits. Substituting equation (8) into (7), for working ages $j < j_R$, the second term inside the bracket of equation (7) becomes

$$\left((1-\tau_{\text{ss}}-\tau_{\text{med}})w\varepsilon_{j+1}\frac{\partial u}{\partial c_{j+1}}+\frac{\kappa w\varepsilon_{j+1}}{j_R-1}\right.$$
$$\left.\times\sum_{p=j_R}^{J}\left(\beta^{p-j-1}\left[\prod_{k=j+2}^{p}\varphi_k(h_k)\right]\frac{\partial u}{\partial c_p}\right)\right)s'(h_{j+1}). \tag{9}$$

In words, for a working-age individual, better health tomorrow, through reducing sick time, will increase working time, and hence increase both an individual's current labor income and future Social Security benefits that will yield higher utility for workers. On the other hand, for the retirees, better health tomorrow reduces their sick time and hence increases their leisure time. The effect is captured by the term $\frac{\partial u}{\partial l_{j+1}}s'(h_{j+1})$. Thus, the second term in equation (7) is the "I-Motive" for both working and retired people. Finally, because the survival probability is a function of the health stock, better health tomorrow will also affect survival. This can be found in the third term inside the bracket of equation (7). One additional unit of health at age $j+1$ will increase the survival probability by $\varphi'_{j+1}(h_{j+1})/\varphi_{j+1}(h_{j+1})$ and, hence, an individual will have a higher chance of enjoying period utility u_{j+1} at age $j+1$. We call this term the "S-Motive". The final term in equation (7) is the continuation value for health investment.[6]

3. THE DATA

We construct the data counterparts of the model profiles from two sources. The first is the Panel Study of Income Dynamics (PSID), which we use to construct life-cycle profiles for income, hours worked, and health status. The second is the Medical Expenditure Panel Survey (MEPS), which we use to construct life-cycle profiles for medical expenditures.

3.1. Panel Study of Income Dynamics

We take all male household heads from the PSID from the years 1968 to 2005. The PSID contains an oversample of economically disadvantaged people called the Survey of Economic Opportunities (SEO). We follow Lillard and Willis (1978) and drop the SEO due to endogenous selection. Doing this also makes the data more nationally representative. Our labor income measure includes any income from farms, businesses, wages, roomers, bonuses, overtime, commissions, professional

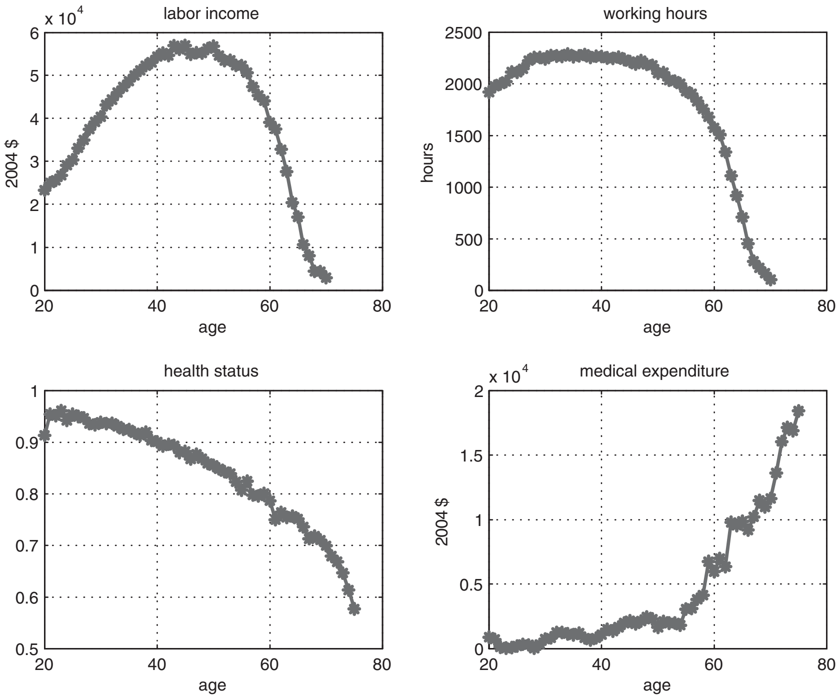

FIGURE 1. Life-cycle profile of income, working hours, health status, and medical expenditure.

practice, and market gardening. This is the same income measure used by Meghir and Pistaferri (2004). Our measure of hours worked is the total number of hours worked in the entire year. Our health status measure is a self-reported categorical variable in which the respondent reports that her health is in one of five states: excellent, very good, good, fair, or poor. Although these data can be criticized as being subjective, Smith (2007) and Baker et al. (2004) have shown that they are strongly correlated with both morbidity and mortality. In addition, Bound (1991) has shown that they hold up quite well against other health measures in analyses of retirement behavior. Finally, in a quantitative study of life-cycle behavior such as this, they have the desirable quality that they change over the life-course and that they succinctly summarize morbidity. A battery of indicators of specific medical conditions (e.g., arthritis, diabetes, heart disease, hypertension, etc.) would not do this. For the purposes of this study, we map the health variable into a binary variable in which a person is either healthy (self-rated health is either excellent, very good, or good) or unhealthy (self-rated health is either fair or poor). This is the standard way of partitioning this health variable in the literature.

Figures 1(a)–(c) show the life-cycle profile of the mean of labor income, working hours, and health.[7] These calculations were made by estimating linear fixed effects regressions of the outcomes on a set of age dummies on the subsample of men between ages 20 and 75. Because we estimated the individual fixed effects, our estimates are not tainted by heterogeneity across individuals (and, by implication, cohorts). Each figure plots the estimated coefficients on the age dummy variables, which can be viewed as a life-cycle profile of a representative agent. Figure 1(a) shows the labor income profile (in 2004 dollars). The figure shows a hump shape with a peak at about 60 K in the early 50's. A major source of the decline is early retirements. This can be seen in Panel (b) in the same figure, which plots yearly hours worked. Hours worked are fairly constant at just over 40 per week until about the mid 50's, when they start to decline quite rapidly. Figure 1(c) shows the profile of health status. The figure shows a steady decline in health. Approximately 95% of the population reports being healthy at age 25, and this declines to just under 60% at age 75.[8]

3.2. Medical Expenditure Survey

Our MEPS sample spans the years 2003–2007.[9] As discussed in Kashihara and Carper (2008), the MEPS measure of medical expenditures that we employ includes "direct payments from all sources to hospitals, physicians, other health care providers (including dental care), and pharmacies for services reported by respondents in the MEPS-HC." Note that these expenditures include both out-of-pocket expenditures and expenditures from the insurance company. It, thus, corresponds to the *total* medical expenditures that a representative agent would pay in the model (i.e., out-of-pocket plus what the insurer pays).

Figure 1(d) shows the life-cycle profile of mean medical expenditures (in 2004 dollars). The profile was calculated in the same way as the profiles in the three previous figures, i.e., we estimated linear fixed effects regressions with a full set of age dummies on the subsample of males ages 20 to 75. The profile shows an increasing and convex relationship with age. Consistent with findings in the literature, we see that medical expenditures increase significantly after age 55. In fact, medical expenditures at age 75 are six times higher than at age 55.

4. CALIBRATION

We now outline the calibration of the model's parameters. We calibrate the model to match the US economy in the early 2000s. For the parameters that are commonly used, we borrow from the literature. For those that are model-specific, we choose parameter values to solve the partial equilibrium and simultaneously match all relevant moment conditions as closely as possible. Table 1 summarizes the parameter values used for the benchmark model. Table 2 shows the targeted moment conditions in the data and the model.

TABLE 1. Parameters of the model

Parameter	Description	Value	Source
	Demographics		
J	Maximum life span	16	Age 95–99
j_R	Mandatory retirement age	10	Age 65–69
ϖ_0	Survival prob.	-5.81	Calibrated
ϖ_1	Survival prob.	0.285	Calibrated
ϖ_2	Survival prob.	0.0082	Calibrated
ϖ_3	Survival prob.	-0.17	Calibrated
	Preferences		
β	Subjective discount rate	$(0.975)^5$	Calibrated
σ	Intertem. ela. sub. coefficient	2	Common value
ψ	Elasticity b/w cons. and health	-9.7	Calibrated
ρ	Share of c in c–leisure combination	0.342	Calibrated
λ	Share of cons–leisure com. in utility	0.97	Calibrated
$\underline{c}$	Sonstant term in utility	2.3	Calibrated
	Health accumulation		
d_0	Dep. rate of health	-4.3	Calibrated
d_1	Dep. rate of health	0.31	Calibrated
d_2	Dep. rate of health	0.004	Calibrated
B	Productivity of health technology	0.98	Calibrated
ξ	Return to scale for health investment	0.8	Calibrated
	Sick time		
Q	Scale factor of sick time	0.005	Calibrated
γ	Elasticity of sick time to health	1.4	Calibrated
	Labor productivity		
$\{\varepsilon_j\}_{j=1}^{j_R-1}$	Age-efficiency profile		Conesa et al. (2009)
ρ_η	Persistence of productivity shock	0.96	Heathcote et al. (2010)
σ_η	Variance of productivity shock	0.018	Heathcote et al. (2010)
	Health insurance		
ϕ_p	Coverage rate, private insurance	0.8	MEPS data
ϕ_m	Coverage rate, Medicare	0.8	MEPS data
	Social Security		
κ	Social Security replacement ratio	40%	Kotlikoff et al. (1999)
	Factor prices		
w	Wage rate	\$12.03	PSID
r	Interest rate	0.2167	Fernandez-Villaverde et al. (2011)

TABLE 2. Target moments: Data vs. model

Target (Data source)	Data	Model
Capital-to-output ratio (NIPA)	2.6	2.5
Nonmed. consumption-to-labor income ratio (CEX and PSID)	78.5%	71.2%
Med. expenditure (ages 55–74)/(ages 20–54) (MEPS)	7.96	7.93
Fraction of average working hours (PSID)	0.349	0.347
Med. expenditure-to-output ratio (NHA)	15.1%	16.0%
Med. expenditure-to-labor income ratio (MEPS and PSID)	5.8%	4.9%
Fraction of average sick time (ages 20–64) (Lovell 2004)	2%	1%
Sick time (ages 45–64)/Sick time (ages 20–44) (Lovell 2004)	1.36	1.19
Average health status (ages 20–74) (PSID)	0.845	0.863
Health (ages 20–29)/health (ages 30–39) (PSID)	1.02	1.02
Health (ages 30–39)/health (ages 40–49) (PSID)	1.05	1.04
Dependency ratio (US Life Table)	39.7%	39.0%
Average death rate (ages 20–100) (US Life Table)	8.24%	8.30%
Sur. prob. (ages 65–69)/sur. prob. (ages 20–24) (Life Table)	0.915	0.910
$\triangle$sur (65–69 to 75–79)/$\triangle$sur (55–59 to 65–69) (Life Table)	2.27	2.23
$\triangle$sur (55–59 to 65–69)/$\triangle$med. exp. (55–59 to 65–69) (MEPS and Life Table)	−0.06	−0.08

4.1. Demographics

The model period is 5 years. An individual is assumed to be born at the real-time age of 20. Therefore, the model period $j = 1$ corresponds to ages 20–24, $j = 2$ corresponds to ages 25–29, and so on. Death is certain after age $J = 16$, which corresponds to ages 95–99. Retirement is mandatory and occurs at age 65 ($j_R = 10$ in the model).

Similar to Fonseca et al. (2009), we assume that the survival probability is a logistic function that depends on health status

$$\varphi_j(h_j) = \frac{1}{1 + \exp(\varpi_0 + \varpi_1 j + \varpi_2 j^2 + \varpi_3 h_j)}, \tag{10}$$

where we impose a condition that requires $\varpi_3 < 0$ so that the survival probability is a positive function of an individual's health. Note that the survival probability is also age-dependent.[10] Given suitable values for ϖ_1 and ϖ_2, it is decreasing with age at an increasing rate.

We calibrate the four parameters in the survival probability function to match four moment conditions involving survival probabilities in the data that we take from the US Life Table 2002. The four moment conditions are as follows:

1. Dependency ratio ($\frac{\text{number of people aged 65 and over}}{\text{number of people aged 20–64}}$), which is 39.7%.
2. Age-share weighted average death rate from age 20 to 100, which is 8.24%.
3. The ratio of survival probabilities for ages 65–69 to ages 20–24, which is 0.915.

4. The ratio of the change in survival probabilities from ages 65–69 to 75–79 to the change in survival probabilities from ages 55–59 to 65–69 ($\frac{\varphi_{12}-\varphi_{10}}{\varphi_{10}-\varphi_{8}}$ in the model), which is 2.27.

Our calibration obtains $\varpi_0 = -5.81,\ \varpi_1 = 0.285,\ \varpi_2 = 0.0082$, and $\varpi_3 = -0.17$.

4.2. Preferences

The period utility function takes the form

$$u(c_j, l_j, h_j) = \frac{[\lambda(c_j^{\rho} l_j^{1-\rho})^{\psi} + (1-\lambda)h_j^{\psi}]^{\frac{1-\sigma}{\psi}}}{1-\sigma} + \underline{c}. \tag{11}$$

We assume that consumption and leisure are nonseparable and we take a Cobb–Douglas specification as the benchmark. The parameter λ measures the relative importance of the consumption–leisure combination in the utility function. The parameter ρ determines the weight of consumption in the consumption–leisure combination. Since we know less about the elasticity of substitution among consumption, leisure, and health, we allow for a more flexible CES specification between the consumption–leisure combination and health. The elasticity of substitution between the consumption–leisure combination and health is $\frac{1}{1-\psi}$. The parameter σ determines the intertemporal elasticity of substitution.

For the standard CRRA utility function, σ is usually chosen to be bigger than one that implies that the period utility function is negative. This is not a problem in many environments since it is the rank and not the level of utility that matters. However, for a model with endogenous survival, negative utility makes an individual prefer shorter lives over longer lives. To avoid this, we have to ensure that the level of utility is positive. Following Hall and Jones (2007), we add a constant term $\underline{c} > 0$ in the period utility function to avoid negative utility.[11]

We calibrate the annual subjective time discount factor to be 0.975 to match the capital-to-output ratio in 2002, which is 2.6 so that $\beta = (0.975)^5$. We choose $\sigma = 2$ to obtain an intertemporal elasticity of substitution of 0.5, which is a value widely used in the literature [e.g., Imrohoroglu et al. (1995), Fernandez-Villaverde and Krueger (2011)]. We calibrate the share of the consumption–leisure combination in the utility function, λ, to be 0.97 to match the average consumption-to-labor income ratio for working age adults, which is 78.5%.[12] We calibrate the share of consumption ρ to be 0.342 to match the fraction of working hours in discretionary time for workers, which is 0.349 from the PSID. We calibrate the parameter of the elasticity of substitution between the consumption–leisure combination and health ψ to be -9.7, which implies an elasticity of $\frac{1}{1-\psi} = 0.093$. This value is chosen to match the ratio of average medical expenditures for ages 55–74 to ages 20–54, which is 7.96 from the MEPS.[13] Since the elasticity of substitution between consumption and leisure is one, health and the consumption–leisure combination are complements. This implies that the marginal utility of consumption increases as the health stock improves, which is confirmed by several empirical studies [Viscusi and Evans (1990), Finkelstein et al. (2013)]. Finally, as shown in equation (7), the level of period utility u affects the "S-Motive." This means that the constant term $\underline{c}$ in the period utility function affects health investment through the survival probability. Moreover, this effect should be more relevant to older ages. We therefore calibrate $\underline{c}$ to match the ratio of the change in survival to the change in medical expenditures from ages 65–69 to 55–59, which is −0.68 in the data. The resulting $\underline{c}$ is 2.3. As Hall and Jones (2007) point out, $\underline{c}$ also determines the value of a statistical life (VSL). Our benchmark model generates an average VSL of 8.5 million dollars, which is in the range of the estimates of empirical literature.[14]

4.3. Endowments

An individual's labor productivity depends on two parts: a deterministic age-dependent efficiency component and a stochastic idiosyncratic productivity shock. We take the age-efficiency profile $\{\varepsilon_j\}_{j=1}^{j_R-1}$ from Conesa et al. (2009), who constructed it following Hansen (1993). For the idiosyncratic component η, we follow Heathcote et al. (2010) and Huggett (1996) and assume that the log of η follows a first-order autoregressive process with a persistence parameter $\rho_\eta = 0.96$ and the variance of the white noise $\sigma_\eta^2 = 0.018$. We then approximate this continuous process with a two-state, first-order discrete Markov process. The two realizations of shock are $\eta_1 = 0.67$ and $\eta_2 = 1.45$. And the corresponding 2×2 transition matrix is $\left[\begin{smallmatrix} 0.9978 & 0.0022 \\ 0.0022 & 0.9978 \end{smallmatrix}\right]$. The invariant distribution of two states is $[\,0.5\;0.5\,]$.

4.4. Health Investment

We assume that the depreciation rate of health in equation (5) is age-dependent and it takes the form

$$\delta_{h_j} = \frac{\exp(d_0 + d_1 j + d_2 j^2)}{1 + \exp(d_0 + d_1 j + d_2 j^2)}. \tag{12}$$

This functional form guarantees that the depreciation rate is bounded between zero and one and (given suitable values for d_1 and d_2) increases with age.

The production function for health at age j in equation (5) is specified as

$$g(m_j) = B m_j^{\xi},$$

where B measures the productivity of medical care and ξ represents the return to scale for health investment. Accordingly, we have five model-specific parameters governing the health accumulation process: d_0, d_1, d_2, B, ξ. We choose values of d_0, d_1, and d_2 to match three moment conditions regarding health status: average health status from age 20 to 74, the ratio of health status for ages 20–29 to ages 30–39, and the ratio of health status for ages 30–39 to ages 40–49.[15] This results in $d_0 = -4.3$, $d_1 = 0.31$, and $d_2 = 0.004$. We calibrate $B = 0.98$ and $\xi = 0.8$ to match two moment conditions regarding medical expenditure. B determines the scale of medical expenditures. We thus calibrate it to match the medical expenditure-to-GDP ratio, which was 15.1% in 2002.[16] ξ determines the curvature of health production technology. We calibrate it to match the average medical expenditure-to-labor income ratio from age 20 to 64, which is 5.8%.[17]

4.5. Health Insurance

The MEPS data show that American retirees have about 80% of their medical expenditures paid by health insurance. Medicare pays the majority of this [see Attanasio et al. (2010), De Nardi et al. (2015)]. For the working age population, employer-based health insurance (EHI) pays the majority of medical expenditures. The coverage rate of EHI is roughly 70–80%. Therefore, we set both coverage rates for private insurance and Medicare at 80%.

4.6. Sick Time

Following Grossman (1972), we assume that sick time takes the form

$$s(h_j) = Qh_j^{-\gamma}, \tag{13}$$

where Q is the scale factor and γ measures the sensitivity of sick time to health. We calibrate these two parameters to match two moment conditions in the data. Based on data from the National Health Interview Survey, Lovell (2004) reports that employed adults in the United States on average miss 4.6 days of work per year due to illness or other health-related factors. This translates into 2.1% of total available working days.[18] We use this ratio as an approximation to the share of sick time in total discretionary time over working ages. We choose $Q = 0.005$ to match this ratio. Lovell (2004) also shows that the absence rate increases with age. For workers between ages 45 and 64 years, it is 5.7 days per year that is 1.5 days higher than the rate for younger workers between ages 18 and 44 years. We choose $\gamma = 1.4$ to match the ratio of sick time for ages 45–64 to ages 20–44, which is 1.36.

4.7. Social Security

The Social Security replacement ratio κ is set to 40%. This replacement ratio is commonly used in the literature [see, for example, Kotlikoff et al. (1999), Cagetti and De Nardi (2009)].

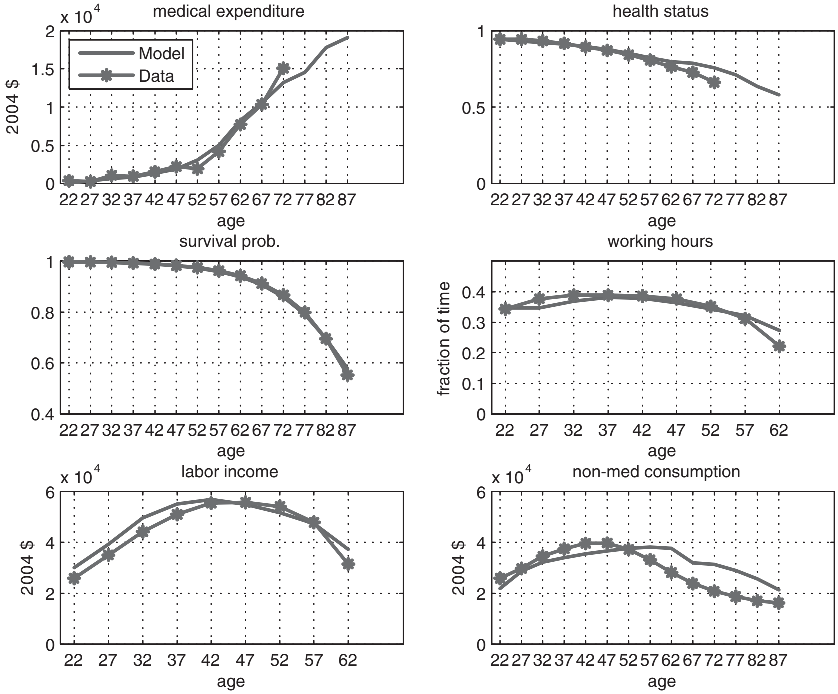

FIGURE 2. Life-cycle profiles: Benchmark model vs. data.

4.8. Factor Prices

The wage rate w is set to be the average wage rate over working ages as estimated from the PSID data as \$12.03.[19] The annual interest rate is set to be 4%.[20] Therefore, we obtain that $r = (1 + 4\%)^5 - 1 = 21.7\%$.

5. BENCHMARK RESULTS

Using the parameter values from Table 1, we compute the model using standard numerical methods.[21] Since we calibrate the model only to target selected aggregate life-cycle ratios, the model-generated life-cycle profiles, which are shown in Figure 2, can be compared with the data to inform us about the performance of the benchmark model.

Figure 2(a) shows the life-cycle profile of health expenditures. Since one model period represents 5 years in real life, a data point is an average for each 5 year bin starting at age 20. Therefore, in the figure, age 22 represents age $j = 1$ in the model and the average for ages 20–24 in the data, age 27 represents age $j = 2$ in the model and the average for ages 25–29 in the data, and so on. As we can see, the model replicates the dramatic increase in medical expenditures in the data. From ages 25–29 to ages 70–74, medical expenditure increases from \$361 to \$15068 in the data, whereas the model predicts that medical expenditures increase from \$330 to \$13194.

Health investment (in conjunction with depreciation) determines the evolution of the health stock. Figure 2(b) displays the life-cycle profile of health status. The model produces decreasing health status over the life-cycle, which is consistent with the data. For example, in the data, average health status (the fraction of individuals who report being healthy) decreases from 0.9445 for ages 20–24 to 0.7625 for ages 60–64. The model predicts a change from 0.9445 to 0.7952.[22]

Since the survival probability is endogenous in the model, Figure 2(c) compares the model-generated survival probability with the data taken from US Life Tables in 2002. The model almost perfectly matches declining survival probabilities over the life-cycle in the data.

The model also does well in replicating other economic decisions over the life-cycle. Figure 2(d) shows the life-cycle profile of working hours. As can be seen, the model replicates the hump shape of working hours. In the data, individuals devote about 34% of their nonsleeping time to working at ages 20–24. The fraction of working time increases to its peak at ages 35–39, and it is quite stable until ages 45–49. It then decreases sharply from about 38% at ages 45–49 to 22% at ages 60–64. In the model, the fraction of working hours reaches its peak (about 38.2%) at ages 35–39 as in the data. It then decreases by 28%, to about 27% at ages 60–64. Since we have a good fit for working hours, we also replicate the labor income profile in the data quite well as can be seen in Figure 2(e).

Figure 2(f) shows the life-cycle profile of consumption (excluding medical expenditure) in the model. Similar to the data displayed in Figure 1 in Fernandez-Villaverde and Krueger (2007), it exhibits a hump shape. Fernandez-Villaverde and Krueger (2007) measure the size of the hump as the ratio of peak consumption to consumption at age 22 and they obtain a ratio of 1.60. In our model, this ratio is 1.7 that is close to the data. A noticeable difference between the model and the data is the sharp drop in consumption right after retirement in the model. The reason is the nonseparability between consumption and leisure in the utility function. Consumption and leisure are substitutes in our benchmark preferences. Retirement creates a sudden increase in leisure and, hence, substitutes for consumption after retirement.[23]

To summarize, our life-cycle model with endogenous health accumulation is able to replicate life-cycle profiles from the Consumer Expenditure Survey (CEX), MEPS, and PSID. First, it replicates the hump shape of consumption. Second, it replicates the hump shape of working hours and labor income. Third and most important, it replicates rising medical expenditures and decreasing health status and survival probabilities over the life-cycle.

6. DECOMPOSITION OF HEALTH INVESTMENT MOTIVES

Based on the success of the benchmark model, we run a series of experiments to quantify the relative importance of the three motives for health investment as shown

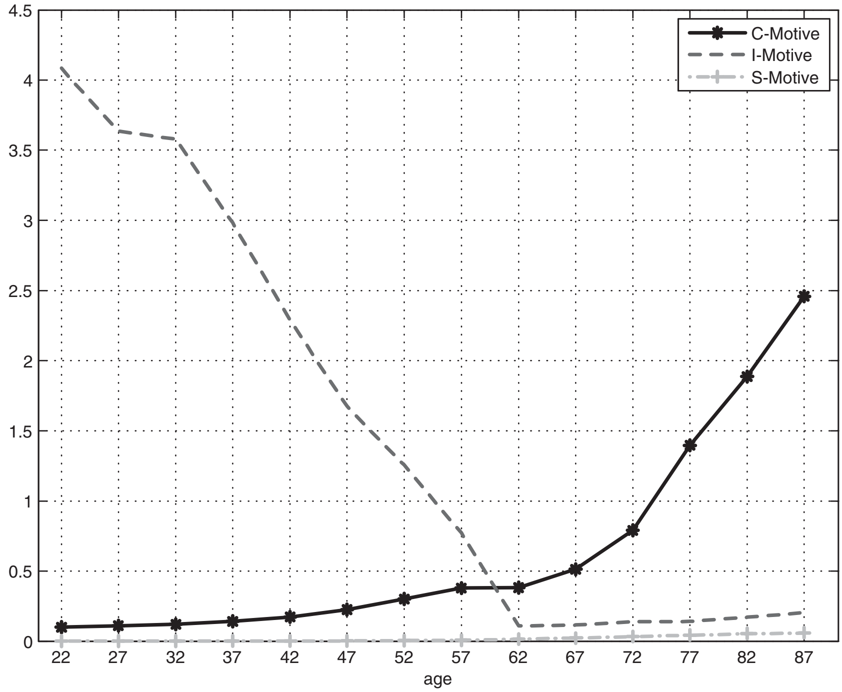

FIGURE 3. Life-cycle profiles of consumption, investment, and survival motive for health investment.

in equation (7). To obtain an idea of the magnitude of each motive in the Euler equation, we directly plot the three terms in equation (7) in Figure 3 generated from the benchmark model. The figure shows that the I-Motive dominates the other two motives prior to the late 50's but is taken over by the C-Motive after. Unlike the other two motives, the I-Motive decreases over the working ages. This is a consequence of the interplay between increasing leisure over working ages and the declining marginal gain of reducing sick time from health improvement [i.e., given our calibration, $s''(h) < 0$] over working ages.

In contrast to the I-Motive, the importance of the C-Motive increases monotonically with age. This is because health directly enters into the utility function as a consumption commodity and because health is decreasing over time due to natural depreciation. The scarcity of the health stock late in life pushes up the marginal utility of health and encourages rising health investment. After the early 60's, rising medical expenditures are driven more by the consumption than the I-Motive. Finally, as shown in the figure, although its importance is increasing as people age, the S-Motive is quantitatively much less important than the other two motives.

6.1. Decomposition without Recalibration

Figure 3 gives us some sense of the relative importance of each motive within the benchmark model. In order to see the impact of each motive on endogenously determined medical expenditures, we run a series of counterfactual experiments. In the first three experiments, we isolate each motive within the benchmark model.

The three experiments are as follows. "No C-Motive" is a model in which we shut down the C-Motive by setting $\lambda = 1$, while keeping all other parameters at their benchmark values. Since health status does not enter into the utility function, the first term inside the bracket of equation (7) disappears. "No I-Motive" is a model without the I-Motive that obtains by setting $Q = 0$, while keeping all other parameters at their benchmark values. Since there is no sick time in the model, the second term in equation (7) vanishes. "No S-Motive" is a model without the S-Motive that obtains by setting $\varpi_3 = 0$, while keeping all other parameters at their benchmark values. Because health does not affect survival, the third term in equation (7) vanishes. Notice that when we shut down one motive from the benchmark model, we do *not* recalibrate the model. This helps us to understand the mechanism behind each motive. In addition, since we do not recalibrate the model, the three alternative scenarios mentioned below maintain the same parameter values except for those that have been shut down. This exercise thus helps us to identify the relative importance of each motive in determining medical expenditures at different periods in the life-cycle. We plot the model-generated life-cycle profile of medical expenditure under the three scenarios in Figure 4.

As shown in Figure 4, when compared to the benchmark model, medical expenditures in the No C-Motive model are significantly lower than that the benchmark model throughout the life-course, especially after the late 50's. Hence, the C-Motive accounts for a significant part of medical expenditures. On the other hand, the No I-Motive model predicts even lower medical expenditures than in the No C-Motive and No S-Motive cases prior to the early 40's, implying that the I-Motive is quantitatively more important than the C-Motive in driving up medical expenditures before age 50. However, after the early 50's, the difference between the No I-Motive case and the benchmark model is much smaller than the difference between the No C-Motive case and the benchmark model. It indicates that the I-Motive is dominated by the C-Motive in driving up medical expenditures at later ages. Finally, the No S-Motive model implies that medical expenditures are lower than in the benchmark model with the difference getting bigger as people age, especially towards the end of the life-cycle. The S-Motive is quantitatively much less important than the other two motives, especially when compared to the C-Motive. Overall, the message about the relative importance of each motive in Figure 4 is consistent with the one conveyed in Figure 3.

Differences in medical expenditures determine differences in health status, which in turn, affects survival. Figure 5(a) shows that the No C-Motive model generates a significantly lower health stock than in the benchmark model (and the

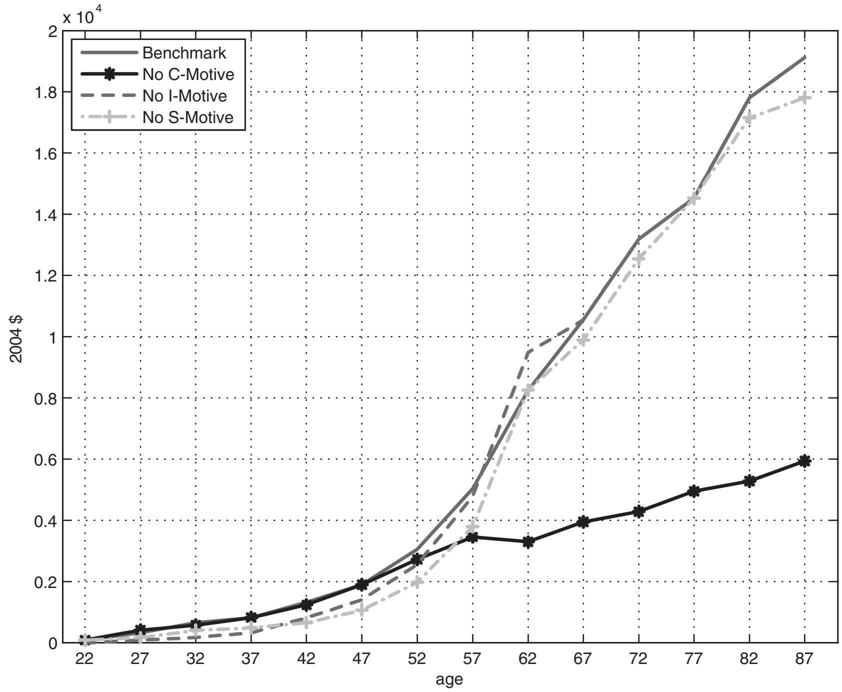

FIGURE 4. Life-cycle profile of medical expenditures: Decomposition without recalibration.

data), particularly after retirement. Consistent with both Figures 3 and 4, the No I-Motive model predicts a lower health stock than that in the No C-Motive and No S-Motive case prior to the late 40's. However, after retirement, the impact of the I-Motive on health status significantly decreases. In contrast, the C-Motive becomes more important that is consistent with Figures 3 and 4.

Finally, Figure 5(b) reports the effect of the three motives on survival. Since the No S-Motive case directly shuts down the role that health plays in survival, we see that the No S-Motive model predicts lower survival throughout the entire life-cycle than that in the benchmark case. The other two motives affect survival indirectly via their effect on health status. The results, however, show that their impact on survival is not quantitatively significant.

To some extent, the low importance of the S-Motive is surprising since one would think an important feature of the value of health is to extend life span [as modeled in Suen (2006) and Zhao (2014)]. However, notice that our model also includes the explicit feature of consumption value for health (i.e., health directly enters into utility function). In other words, health in our model not only extends one's life span, but also improves the *quality* of life. In that sense, the combination of the C-Motive and the S-Motive in our model is isomorphic to the role that health plays in the literature such as Suen (2006) and Zhao (2014). Our decomposition exercise thus provides a deeper understanding of the reason why people value

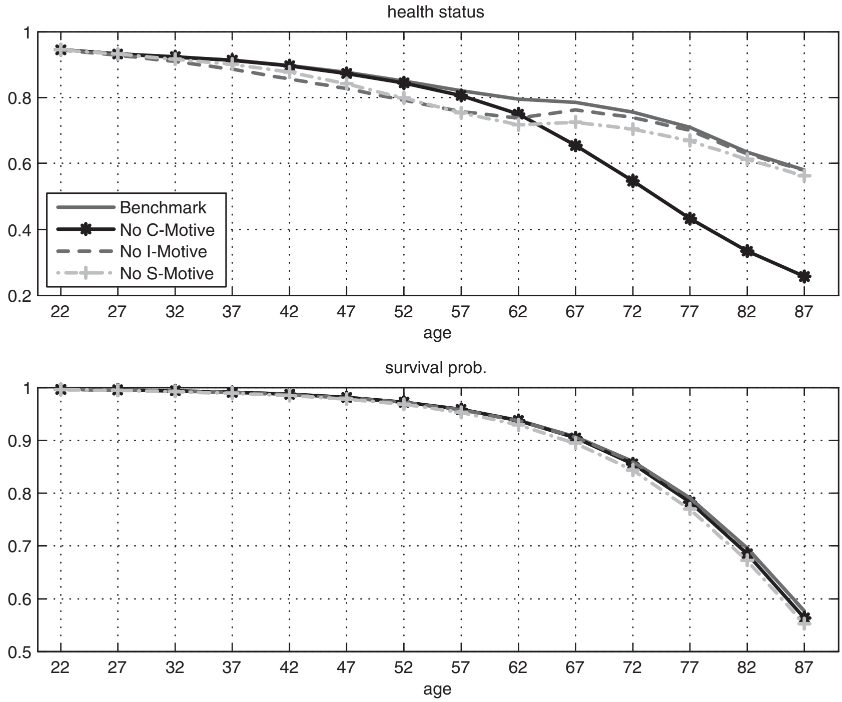

FIGURE 5. Life-cycle profiles of health status and survival probability: Decomposition without recalibration.

health over the life-cycle. By differentiating the C-Motive from the S-Motive, we show that an individual invests in health mainly because health improves the *quality* of life, not because health simply extends the *length* of life. Additionally, notice that the functional form of the survival probability in equation (10) makes the conditional survival probability depend on, not only, health status but also age. In other words, a large of fraction of the declining survival probability over the life-cycle comes from biological aging. This functional form further mitigates the impact of the health stock on the survival probability and, hence, contributes to the marginal importance of the S-Motive.

6.2. Decomposition with Recalibration

The dominance of the C-Motive that we have seen, however, might be a result of a mechanical implication of the model. The reason is that the C-Motive is the only motive with a first-order effect on the agents' decision problem via preferences. As a result, it should play the most important role in the calibration and, so removing it will generate the biggest loss in terms of model fit. To mitigate this concern and hence to evaluate the overall importance of each motive, a better exercise is to *recalibrate* the three scenarios mentioned above to give each model a chance to match the data moments again. With the model being recalibrated and returned to the same starting point and by looking at the fit of these three recalibrated models separately, one will be able to determine the overall importance of each motive. In other words, if the model can be easily recalibrated to match the data again while shutting down a specific motive, this shows that this motive is not quantitatively important. Otherwise, it is.

To implement the exercise, we recalibrate nine out of sixteen calibrated parameters in Table 1 for each alternative model. The spirit of recalibration requires us to recalibrate all five parameters on preference (β, ψ, ρ, λ, and $\underline{c}$) since they are the most relevant parameters related to the first-order effect and the other four decision-related technological parameters: B, ξ for health production, and Q, γ for the sick time function. The remaining seven parameters, ϖ_0, ϖ_1, ϖ_2, and ϖ_3, govern the survival probability and d_0, d_1, and d_2 determine the age-dependent depreciation rate of health. They are relatively much more "exogenous" to the nine "behavioral" parameters we recalibrate in the sense that they are determined largely by biological processes rather than economic behavior. Therefore, we choose not to recalibrate them so that each alternative model faces the same "biological" parameter values as in the benchmark model.[24]

We plot the model-generated life-cycle profile of medical expenditures under the benchmark and under three alternative recalibrated models in Figure 6. The figure shows a somewhat different message compared to Figure 4. Both the "No I-Motive" and "No S-Motive" models can almost replicate the benchmark model (and hence the data) except in later ages. In contrast, the "No C-Motive" model, although matched with the moment conditions in Table 2 to our best effort, cannot replicate the life-cycle profile of medical expenditures in the benchmark model and data. Even after mitigating the possible mechanical advantage of the C-motive, it still dominates all other possible drivers of the rise in medical expenditures over the life-cycle. Figure 6, thus, confirms the overall importance of the C-Motive in driving up health investment over the life-cycle.

7. COUNTERFACTUAL POLICY EXPERIMENTS

Our benchmark model offers a quantitative analysis of health investment over the life-cycle in a framework featuring various roles of health. Our focus on the life-cycle enables us to make statements about how policies will affect health investment behavior over the *life-cycle* and distribute medical resources *across* generations and individuals, which is something that previous work on health investment does not do. With various roles of health in the model, we are also able to provide a comprehensive analysis of the possible impact of different policies on health expenditures and health status.

The model setting allows us to consider three sets of policy changes. First, our benchmark model summarizes the subsidized nature of the US health insurance system. The government can impact behavior by changing the coverage rates of

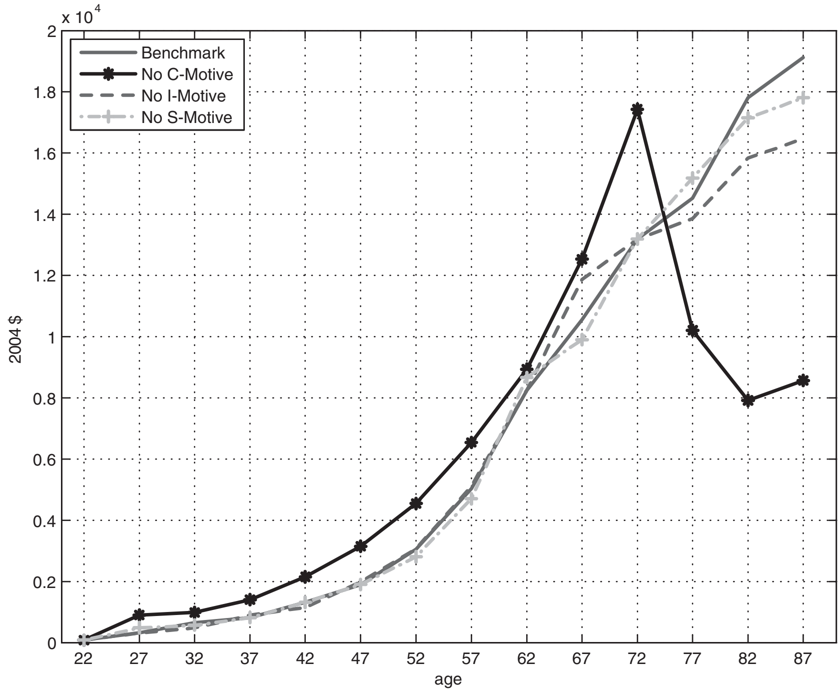

FIGURE 6. Life-cycle profiles of medical expenditure: Decomposition with recalibration.

public health insurance, ϕ_p and ϕ_m. Second, from equations (7) and (8), one can see that Social Security policy as embedded in the parameters, $\{\tau_{ss}, \kappa, j_R\}$, will affect the I-Motive for working age people. We have learned from the preceding section that this motive is important in determining medical expenditures prior to retirement. Third, the government can also indirectly affect health investment by encouraging technological change in the medical sector via increases in B.

In this section, we run a series of counterfactual experiments that quantitatively investigate the effects of these policies on health investment behavior. In addition, we are also able to show the impacts of the policies on the aggregate medical expenditure-to-national income ratio and social welfare. However, as we emphasized in the introduction, due to the partial equilibrium structure of the model, we have to provide a caveat when interpreting these results on aggregate ratios and welfare.

7.1. Subsidized Health Insurance

The benchmark framework in Section 2 explicitly models the heavily subsidized nature of medical spending in the United States. A natural question one could ask is how changes in health insurance coverage rates (ϕ_m and ϕ_p) affect medical expenditures. In this section, we run an experiment in which we decrease both

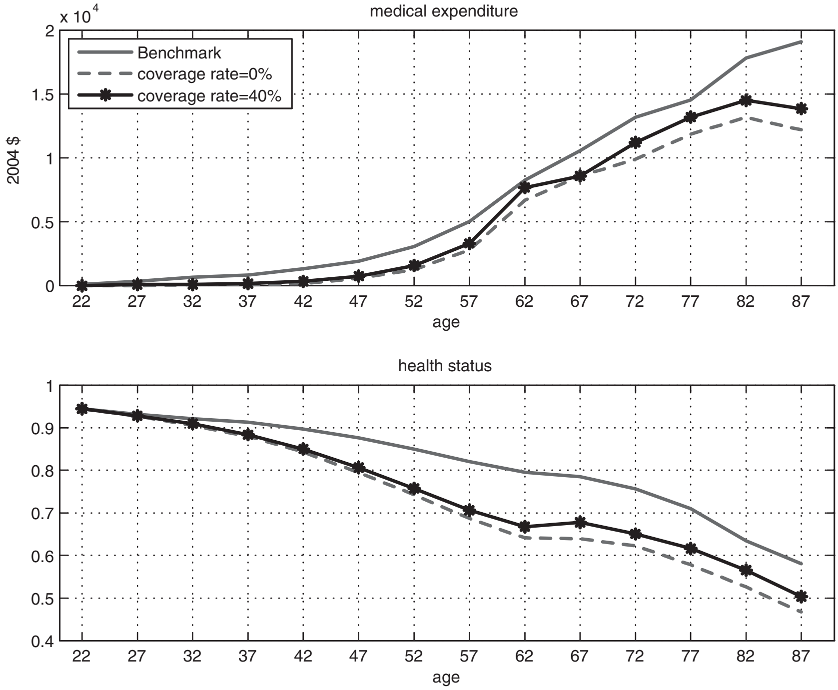

FIGURE 7. Life-cycle profiles of medical expenditures and health status: Reduce coverage rate.

coverage rates from their benchmark value of 80% to 40% and 0%, respectively, while keeping the other parameters constant at their benchmark values.

Figure 7(a) shows that by reducing the health insurance coverage rates, ϕ_m and ϕ_p, simultaneously, medical expenditures decrease quite significantly over the entire life-course. This decrease is especially pronounced in late ages. This subsidy to medical expenditures makes medical care cheaper relative to nonmedical consumption and hence encourages more usage of health care (the relative price of medical goods to nonmedical consumption is $1 - \phi^j$). Thus, reducing it makes individuals more cautious when using medical services. This can be seen clearly when one looks at the Euler equation (7). Notice that reducing the coverage rate ϕ^j decreases the right-hand side of equation (7), which represents marginal benefit of health investment. Lower medical expenditures over the life-cycle also lead to worse health status, as shown in Figure 7(b).

On the aggregate level, as shown in Table 3, when we reduce insurance coverage rates, individuals are more cautious when using medical services, which leads to a substantial reduction in the medical expenditure-to-national income ratio from 16.0% to 11.2% at $\phi_p = \phi_m = 40\%$ and to 9.4% at a zero coverage rate. Reducing insurance coverage rates also makes investment in physical capital relatively

TABLE 3. Selected aggregate variables: Reduce insurance coverage rate

ϕ_p, ϕ_m	τ_{med}	M/Y	K/Y	n	h	Y_ϕ/Y_{ben}	CEV
0	0	9.4%	3.4	0.335	0.729	1.16	7.77%
40%	3.9%	11.2%	3.1	0.338	0.748	1.09	3.72%
80%	9.5%	16.0%	2.5	0.347	0.815	1.00	0

more attractive compared to investment in health capital, which encourages asset holdings and hence increases the capital-to-wealth ratio.

Finally, we calculate the welfare implications of different insurance coverage rates compared to the benchmark model. First, following Imrohoroglu et al. (1995), we use the expected life time utility of a newborn

$$U(c, l, h) = \mathbf{E} \sum_{j=1}^{J} \beta^{j-1} \left[\prod_{k=1}^{j} \varphi_k(h_k) \right] u(c_j, l_j, h_j)$$

to measure social welfare, with the period utility function defined as in equation (11). For the benchmark model, we have the allocation (c^b, l^b, h^b) and the associated utility $U(c^b, l^b, h^b)$. For each policy change, we have the new allocation (c^*, l^*, h^*) and the associated utility $U(c^*, l^*, h^*)$. Then, following the literature [e.g., Conesa et al. (2009), Fehr et al. (2013)], the welfare consequence of switching from the steady-state benchmark allocation (c^b, l^b, h^b) to an alternative allocation (c^*, l^*, h^*), or the consumption equivalent variation (CEV) of the policy change is

$$\text{CEV} = \left[\frac{U(c^*, l^*, h^*)}{U(c^b, l^b, h^b)} \right]^{1/(1-\sigma)} - 1.$$

We report the CEV calculation in the eighth column of Table 3. It shows that reducing insurance coverage rates and hence the subsidy of medical consumption brings a significant welfare gain to the economy. Reducing insurance coverage rates encourages individuals to invest more in physical capital, which leads to higher output (shown in the seventh column in Table 3). This is the main source of the welfare gain.

7.2. Changing the Replacement Ratio

Changing the replacement ratio is often cited as a means of shoring-up Social Security in the United States and elsewhere. Clearly, such a policy would affect Social Security taxes and benefits, but whether it would affect medical expenditures remains an open question. In this section, we run a counterfactual experiment where we change the replacement ratio, κ, from its benchmark level of 40% to 0%, 20%, and 60%, respectively, while keeping the other parameters at their benchmark values.

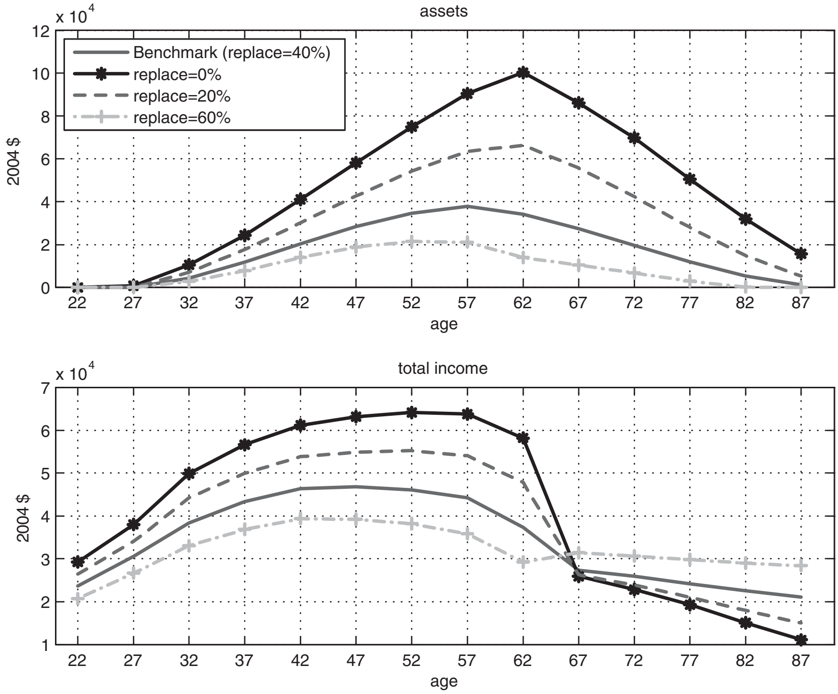

FIGURE 8. Life-cycle profiles of assets and total income: Changing replacement ratio.

TABLE 4. Selected aggregate variables: Different replacement ratio

κ	τ_{ss}	b (2004$)	M/Y	K/Y	n	h	Y_κ/Y_{ben}	CEV
0%	0%	0	13.6%	5.2	0.347	0.835	1.24	6.98%
20%	7.82%	9, 445	14.6%	3.9	0.349	0.826	1.12	3.50%
40%	15.61%	18, 761	16.0%	2.5	0.347	0.815	1.00	0
60%	23.40%	27, 922	18.3%	1.4	0.347	0.813	0.92	−3.87%

Figure 8 shows the life-cycle profiles of asset holdings and total income (labor plus capital income) generated by different values of κ. In our model, the main motive for savings is to support consumption (both nonmedical and medical consumption) in old age. Therefore, it is not surprising to see that a lower replacement ratio, which implies lower Social Security benefits after retirement (see the third column in Table 4), will induce agents to save more over the entire life-cycle. This is consistent with findings in Imrohoroglu et al. (1995). The effect is also shown in Table 4; as the replacement ratio κ decreases, the capital-to-wealth ratio K/Y increases. Partly due to a lower tax rate τ_{ss} caused by lower κ (shown in the second column in Table 4) and partly due to higher asset holdings, Figure 8(b) shows

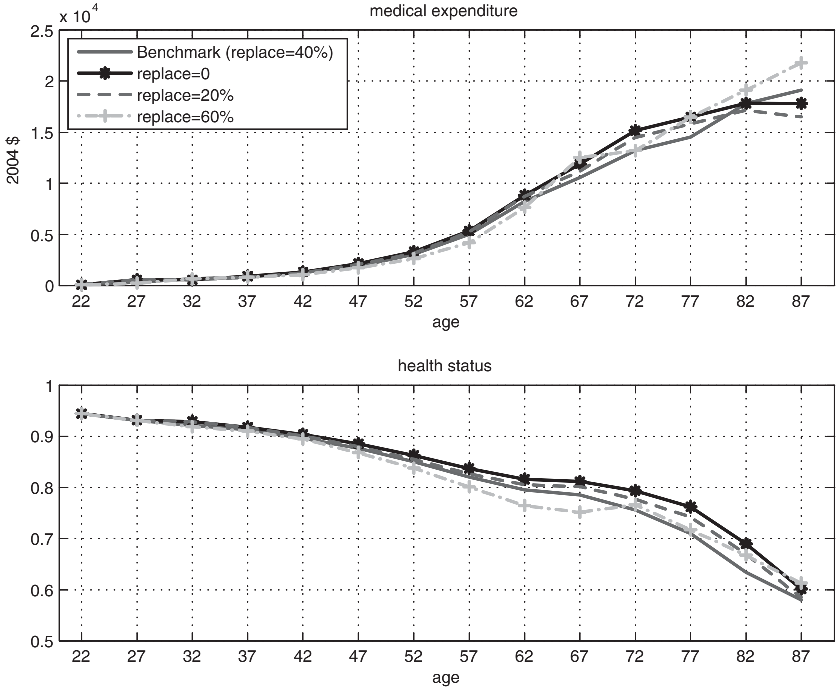

FIGURE 9. Life-cycle profiles of medical expenditures and health status: Different replacement ratio.

that total income during working ages is also higher when the replacement ratio is smaller.

Figure 9 shows the life-cycle profiles of medical expenditures and health status for different κ. Panel (a) shows that a lower replacement ratio generally leads to higher medical expenditures during working ages. To understand the intuition of this quite surprising result, we have to refer back to the Euler equation (7). For working age agents, we know that the I-Motive is

$$\left((1-\tau_{\text{ss}}-\tau_{\text{med}})w\varepsilon_{j+1}\frac{\partial u}{\partial c_{j+1}} + \frac{\kappa w \varepsilon_{j+1}}{j_R - 1} \right.$$

$$\left. \times \sum_{p=j_R}^{J}\left(\beta^{p-j-1}\left[\prod_{k=j+2}^{p}\varphi_k(h_k)\right]\frac{\partial u}{\partial c_p}\right)\right) s'(h_{j+1}).$$

Note that both the Social Security tax rate τ_{ss} and the replacement ratio κ enter the expression. The government must balance its budget since the Social Security system is self-financing. Therefore, a lower replacement ratio also leads to a lower Social Security tax rate τ_{ss} as shown in the second column of Table 4. A lower

τ_{ss} tends to increase the magnitude of the I-Motive by increasing current after-tax labor income. In contrast, a lower κ in the same term tends to reduce the magnitude of I-Motive. Its impact, however, is lower since it affects utility via its impact on future labor income that is the base for Social Security benefits, which is discounted by both the time preference and the conditional survival probability. Therefore, other things equal, a lower κ leads to a higher I-Motive for working age agents, and hence results in higher medical expenditures. Another channel that affects health investment is total income. With substantially higher asset holdings for lower values of κ, total income is higher, which is also shown in the eighth column of Table 4. For example, for $\kappa = 0$, total income is about 24% higher than the benchmark case with $\kappa = 40\%$. Since medical care is a normal good, higher income leads to higher medical expenditures due to income effect.

However, notice that this pattern is overturned toward the end of the life-cycle. Medical expenditures under a replacement ratio of 40% (benchmark case) are higher than medical expenditures under a replacement ratio of either 0% or 20% after the early 80's. Moreover, medical expenditure under a replacement ratio of 60% are higher than the medical expenditure when generated by any other lower replacement ratio after the late 70's. Our intuition here is that, because the Social Security system redistributes resources from workers to retirees, retirees have a higher marginal propensity to consume medical goods.[25] Therefore, higher replacement ratios drives up medical expenditures, especially at late ages since the redistribution effect dominates. This is the main point made in Zhao (2014). This exercise confirms it quantitatively.

Since a lower κ, in general, generates higher medical expenditures over the life-cycle, it is not surprising to see in Figure 9(b) that a lower κ also leads to better health. Hence, as shown in the seventh column of Table 4, which computes average health status from age 20 to 90, when κ decreases from 40% to zero, average health status for ages 20–90 increases from 0.815 to 0.835.

The sizable changes in medical expenditures over the life-cycle caused by different replacement ratios also translate to sizable changes in aggregate medical expenditures. As shown in the fourth column of Table 4, when κ decreases from 40% to zero, the M/Y ratio decreases from 16.0% to 13.6%. This is somewhat counter-intuitive since smaller κ increases medical expenditures over the major part of life-cycle. However, this puzzle is resolved once we consider that lower κ increases capital accumulation but does not decrease labor supply (the sixth column shows the average fraction of working hours in discretionary time over working age),[26] so the denominator of the ratio increases by a greater amount than the numerator (which is shown in the eighth column for comparison of GDP to the benchmark level).

Finally, we report the CEV for each policy change in the ninth column of Table 4. The results show that, in the current model, a reduction in the replacement ratio improves welfare and that a zero replacement ratio, i.e., privatization of Social Security, delivers the highest social welfare. These results are consistent with other findings in literature such as Kotlikoff et al. (1999)

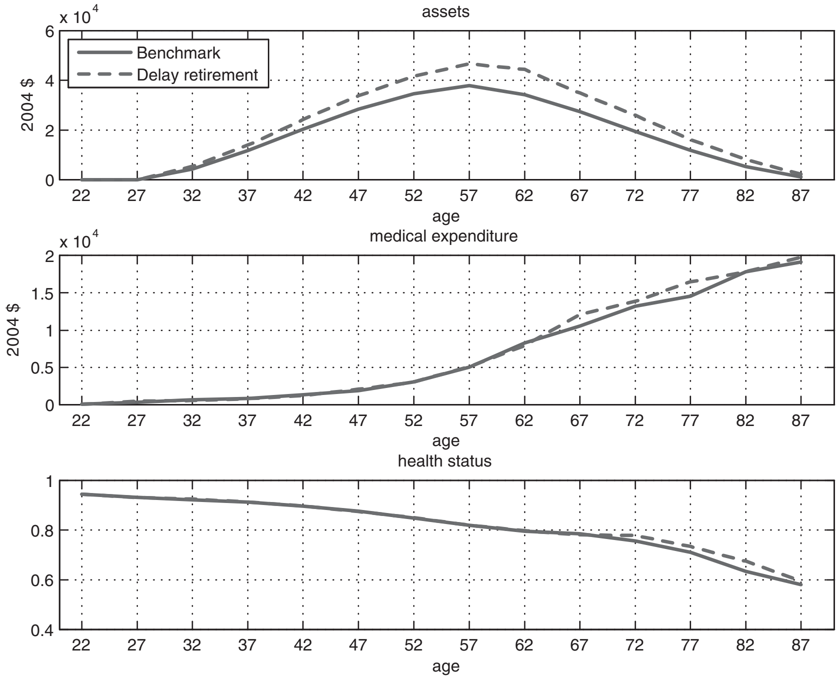

FIGURE 10. Life-cycle profiles of assets, medical expenditures, and health status: Delaying retirement age.

and Imrohoroglu and Kitao (2009). Importantly, neither of these papers models health.

7.3. Delaying Retirement

Many proposals to reform Social Security suggest that the retirement age will have to be postponed by a few years. In this section, we run an experiment in which we delay the retirement age j_R by one more period from $j_R = 10$ to $j_R = 11$, while keeping the other parameters at their benchmark values. This corresponds to an increase in the retirement age from 65 to 70.

Figure 10 shows the life-cycle profiles of assets, medical expenditures, and health status when the retirement age is delayed for one period in the model. Panel (a) shows that due to the delay, an individual increases asset holdings over the life-cycle. The main reason is that now the agent works for a longer period and, hence, her labor income increases enabling her to save more. Panels (b) and (c) show that this policy change would not significantly affect medical expenditures and health status.

On the aggregate level, as shown in Table 5, we can see that by delaying retirement, the number of workers increases and the pool of retirees shrinks.

TABLE 5. Selected aggregate variables: Delaying retirement age

j_R	τ_{ss}	b (2004$)	M/Y	K/Y	n	h	Y_{j_R}/Y_{ben}	CEV
10	15.61%	18,761	16.0%	2.5	0.347	0.815	1.00	0
11	10.72%	18,237	15.0%	2.7	0.352	0.823	1.11	1.95%

Accordingly, the Social Security tax rate τ_{ss} significantly decreases. The Social Security benefit, however, does not decrease much. The reformed Social Security system decreases the medical expenditure-to-national income ratio from 16.0% to 15.0%. This decrease is not due to changes in medical expenditures, but rather increases in total income as shown in the eighth column of the table, which in turn is due to increases in both capital accumulation and labor supply as shown in the fifth and sixth column of the table.[27] Finally, since higher income leads to higher consumption and better health, delaying the retirement age increases social welfare, which is equivalent to a 1.95% increase in the allocation of consumption-leisure-health as compared to the benchmark one.

7.4. Encouraging Health Care Technological Change

Technological improvement in health care services has been cited as a major reason for the rising medical expenditure-to-GDP ratio in the United States [see Suen (2006)]. There are a variety of policies that the government can pursue that could possibly accelerate this technological change [e.g., more funding for the National Institute of Health, tax favorable treatment on research and development (R&D) in drugs, etc.]. We now investigate what would happen in the current model if the medical service sector TFP increases.

In our benchmark model, the TFP of medical care technology is calibrated to be 0.98. We analyze two hypothetical scenarios. First, B increases by 10% (to 1.078) and then to 20% (to 1.176). We keep all other parameters at their benchmark values.

Figure 11(a) shows that increasing B reduces medical expenditures over the life-cycle, especially after the mid 50's. However, panel (b) in the same figure reports that health status improves despite health investment decreasing, which indicates that the efficiency of health investment increases. This is consistent with the original Grossman model.

Why does an increase in B reduce medical expenditures over the life-cycle? Notice that B affects the marginal product of medical expenditure in the health production technology, $g'(m_j)$. Therefore, on one hand an increase in B raises $g'(m_j)$ in the Euler equation (7) and hence increases the marginal benefits of health investment that, in turn, leads to higher medical expenditures over the life-cycle. On the other hand, under our calibration, the elasticity of substitution between health and the nonmedical consumption–leisure combination is strong enough so that improving health leads to an increase in nonmedical consumption, which

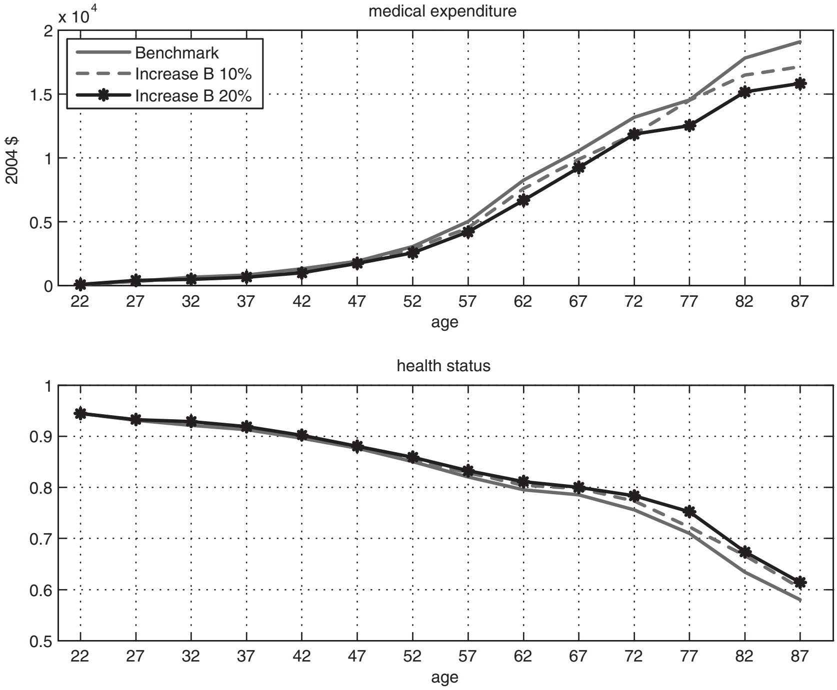

FIGURE 11. Life-cycle profiles of medical expenditures and health status: Increase B.

TABLE 6. Selected aggregate variables: Increase TFP of health care

B	M/Y	K/Y	n	h	Y_ϕ/Y_{ben}	CEV
0.680	16.0%	2.5	0.347	0.815	1.000	0
0.748	14.7%	2.5	0.345	0.824	1.008	0.56%
0.816	13.5%	2.6	0.344	0.831	1.013	1.05%

"crowds out" medical consumption. Under our calibrated parameter values, the latter dominates the former channel.[28]

Finally, by raising GDP (shown in the sixth column in Table 6), nonmedical consumption (the C/Y ratio increases by 0.44% and 1.08%, respectively, for two cases), and health status (shown in the fifth column of Table 6), increasing B increases social welfare by 0.56% and 1.05%, respectively.

To summarize, based on the current model, policies that try to reduce subsidies to health insurance, shore-up Social Security either by lowering the replacement ratio or by delaying the retirement age, and improve technological productivity decrease medical expenditures over the life-cycle and reduce the medical expenditure-to-GDP ratio. All of these policies deliver welfare gains when compared to the current system. Among those policies, reducing insurance subsidies and the Social Security replacement ratio have the largest impacts on medical expenditures and social welfare.

8. CONCLUSIONS

We studied the life-cycle behavior of health investment and its effects on other aspects of consumer behavior. Specifically, we asked ourselves what drives the increase in medical expenditures over the life-cycle. Three motives for health investment were considered. First, health delivers a flow of utility each period (the C-Motive). Second, better health enables people to allocate more time to productive or pleasurable activities (the I-Motive). Third, better health increases longevity (the S-Motive). We calibrated an overlapping generations model with endogenous health investment, worker heterogeneity, and a realistically modeled health insurance system by matching various ratios from the model and US data. We found that the calibrated model fits key life-cycle profiles of consumption, working hours, health status, medical expenditures, and survival very well.

Based on the success of the benchmark model, we ran a decomposition exercise to quantify the relative importance of each motive. We found that, overall, the C-Motive plays a much more important role in shaping health expenditures over the life-cycle. Focusing on different episodes of the life-cycle, we found that the I-Motive is more important than the C-Motive and S-Motive until the 40's. After that, the C-Motive is the dominant force behind health investment. In other words, younger people invest in their health because better health allows them to enjoy more leisure or to work more, whereas older people invest in their health because better health improves their quality of life. Finally, the S-Motive is quantitatively less important than the other two motives.

We conducted a series of counterfactual experiments to investigate how government policies that reduce health insurance coverage rates, shore-up Social Security, and accelerate technological progress in medicine affect the life-cycle behavior of health investment, and the aggregate medical expenditure-to-GDP ratio. We found that all of these policies decrease medical expenditures over the life-cycle and reduce the medical expenditure-to-GDP ratio. They also yield welfare gains as compared to the benchmark system. Among those policies, reducing insurance coverage rates and the Social Security replacement ratio have a much more significant impact on medical expenditures and social welfare than the other policies.

Our model can be extended along several dimensions. First, we assumed exogenous factor prices for simplicity. Therefore, the model does not capture feedback effects from factor prices. Future work could extend the model by allowing for endogenous factor prices in order to investigate general equilibrium effects. Second, we assumed a mandatory retirement at age 65 in the model. In the future, researchers may want to endogenize retirement to shed light on the effects of health on retirement behavior in a setting with endogenous health. Finally, there is no health uncertainty in the model. Adding uncertainty would allow us to analyze the effects of health insurance against idiosyncratic medical expenditure shocks on an individual's health investment. It will also generate more heterogeneity in medical expenditures across individuals of the same age. We leave those topics for future research.

NOTES

1. Although we acknowledge that there are a variety of ways in which health investment can take place, such as exercising, sleeping, and eating healthy, this paper considers only expenditures on medical services since our main focus is on medical expenditures. Moreover, recent work by Podor and Halliday (2012) shows that the life-cycle profile of exercise is flat suggesting that exercise is of little importance when considering life-cycle economic behavior. For an alternative model with both medical expenditure and time inputs for health production, see He and Huang (2013). However, their model does not have life-cycle feature.

2. This paper also contributes to a literature on life-cycle economic behavior that has largely been concerned with savings and consumption motives but has paid relatively less attention to the life-cycle motives for health-related behaviors and, particularly, expenditures on medical care. There is a vast literature that has attempted to better understand whether and when consumers behave as buffer stock or certainty equivalent agents [e.g., Carroll (1997), Gourinchas and Parker (2002)], as well as the extent to which savings decisions are driven by precautionary motives [e.g., Hubbard et al. (1994), Palumbo (1999), Gourinchas and Parker (2002)]. Much of the earlier literature on these topics has been elegantly discussed in Deaton (1992). However, very little is known about the motives for expenditures on medical care within a life-cycle context. In this paper, we attempt to fill this void.

3. There is also a substantial literature that has incorporated health into computational life-cycle models as an *exogenous* process. Some model it as an exogenous state variable [Rust and Phelan (1997), French (2005), De Nardi et al. (2010)], others model it essentially as an exogenous income shock [Palumbo (1999), Imrohoroglu and Kitao (2012), Jeske and Kitao (2009), Kopecky and Koreshkova (2014), De Nardi et al. (2010)].

4. Ozkan (2010) develops a general equilibrium life-cycle model of health capital to study the effect of income inequality on life-cycle profiles of medical expenditures across income groups.

5. Notice that different from the literature such as Imrohoroglu et al. (1995), Huggett (1996), Huang et al. (1997), and Cagetti and De Nardi (2008) that treat survival probabilities as exogenous, the conditional survival probabilities here are endogenously determined by health status, which again in the model is endogenously determined by the state variables. Because of the endogenous survival probabilities, the age share in the current paper is also endogenously determined. In particular, it is also determined by the cross-sectional distribution of individual states in each age group. See the details of the determination of age shares in Section 2.5.

6. Notice that the health investment technology $g(m)$ should not affect the three motives *separately* since $g'(m_j)$ is a term outside the bracket in equation (7). In addition, adding health shock to health accumulation equation (5) would not affect the three motives *separately* since it only affects $g'(m_j)$. Therefore, the main results of our decomposition in Section 6 would not change significantly if we add idiosyncratic health shock into the benchmark model.

7. We took our data on labor income, hours, and health status for all years that they were available between the years 1968 and 2005. We were careful to construct our profiles from data that were based on the same variable definition across survey years to ensure comparability across waves. The questions that were used to construct the variables do differ somewhat across waves, and so we did not use all waves from 1968–2005 to construct our profiles. For labor income, we used 1968–1993, 1997–1999, and 2003–2005. For hours, we used 1968–1993 and 2003–2005. For health status, we used 1984–2005; the health status question was not asked until 1984.

8. We did not calculate these profiles beyond ages 75 because the PSID does not have reliable data for later ages due to high rates of attrition among the very old. There are other data sources such as

the Health and Retirement Survey (HRS) that do have better data on the elderly, but unfortunately the HRS does not have any data on the earlier part of the life-cycle that is crucial for our analysis. We chose the PSID over the HRS as it had more comprehensive information over a much larger part of the life-cycle than the HRS.

9. We were careful not to use MEPS data prior to 2003 since it has been well documented that there has been a tremendous amount of medical inflation over the past 15 to 20 years. As such, we were concerned that this may have altered the age profile of medical expenditures.

10. Age typically affects mortality once we partial out self-reported health status (SRHS). This is true, for example, in the National Health Interview Survey.

11. See also Zhao (2014).

12. Consumption data are taken from Fernandez-Villaverde and Krueger (2007), who use the CEX data set. The reason why λ can help to identify consumption-to-labor income ratio is because λ affects the share of consumption vs. health in utility function. Health in turn affects labor income via the I-Motive. Therefore, λ could have impact on consumption expenditure vs. labor income.

13. The reason why parameter ψ significantly affects the ratio of medical expenditures of ages 55–74 to ages 20–54 is following. We know that consumption peaks at early 50's and declines after [see Figure 2(f)]. The relationship between consumption and health in the utility function therefore could affect the speed of the decline of consumption after age 55. The more complementary between health and consumption (i.e., lower ψ), the quicker health decreases after age 55 since the decline of consumption exacerbates the declining health status. To compensate this decline, individuals would have to increase their health investment. Therefore, we should see a higher ratio of medical expenditures for ages older to younger than 55. This ratio thus helps to pin down parameter ψ.

14. Hall and Jones (2007) show that the estimates of VSL in the literature range from about 2 million to 9 million dollars. We calculate VSL following Hall and Jones (2007), i.e., VSL is equal to the marginal cost of saving a life, which is defined as $1/(\partial\varphi_j/\partial m_j)$ for age j. Kniesner et al. (2012) used PSID data to estimate VSL and found it is in the range of 4 to 10 million US dollar. Our number is also in line with the estimates from Zhao (2014).

15. We choose to match the ratios of health status in earlier ages here is to leave the match of health status in later life-cycle as out-of-sample prediction. The calibration here thus avoids data-fitting problem.

16. Data are from the National Health Accounts (NHA).

17. This ratio is calculated based on the data from Figures 1(a)–(d).

18. According to OECD data, American workers, on average, worked 1,800 hours per year in 2004, which is equivalent to about 225 working days. Sick leave roughly accounts for 2.1% of these working days. This number is very close to the one reported in Gilleskie (1998).

19. We first divide annual labor income for ages 20 to 64 from Figure 1(a) by the annual working hours from Figure 1(b) to obtain wage rates $w\varepsilon_j\eta$ across ages. We then divide the average wage rate over working ages ($\frac{w\sum_\eta \sum_{j=1}^{j_R-1}\varepsilon_j\eta}{j_R-1}$) by the product of average age-efficiency $\frac{\sum_{j=1}^{j_R-1}\varepsilon_j}{j_R-1}$ and average (age-independent) idiosyncratic productivity shock $(0.67+1.45)/2$ to obtain average wage rate w, which is \$12.03.

20. 4% is a quite common target for the return to capital in life-cycle models. See, for example, Fernandez-Villaverde and Krueger (2011).

21. The computational method is similar to the one used in Imrohoroglu et al. (1995).

22. In the computation, health stock h is discretized in the range of [0, 1]. The initial health stock h_1 is set to be 0.9445 that is the fraction of the population aged 20–24 who report being healthy in the data.

23. A sudden drop in consumption after retirement is common in the literature that uses nonseparable utility functions, e.g., Conesa et al. (2009). Bullard and Feigenbaum (2007) show that consumption–leisure substitutability in household preferences may help explain the hump shape of consumption over the life-cycle. As evidence, when we use an alternative preference with a separable utility function between consumption and leisure in an unreported experiment with the deterministic version of the model, we obtain a much smoother consumption profile around retirement age.

24. In an unreported exercise, together with the nine recalibrated "behavioral" parameters, we also recalibrate ω_3 that governs the sensitivity of health stock to survival probability for each scenario (except for "No S-Motive" case). We find the results are very similar to the one reported in Figure 6.

25. As an evidence of the redistribution effect, as shown in Figure 8(b), total income of retirees is higher when replacement ratio κ is higher.

26. Lower tax rate τ_{ss} will make individuals increase labor supply due to substitution effect. However, lower tax will also have strong income effect that leads to reduction of labor supply. The income effect cancels out the substitution effect. Therefore, labor supply in the sixth column of Table 4 remains almost constant across different κ.

27. Sixth column shows the average labor supply (as a fraction of discretionary time) for ages 20–65.

28. In an unreported experiment, when we set $\psi = -900$ and hence elasticity of substitution between health and c–l combination is extremely small ($= 0.001$), the change in health would not induce significant change in nonmedical consumption. Therefore, the "crowding-out" effect is eliminated. The impact of B on M/Y ratio is mainly determined by the first channel. As we expect, in that case, M/Y increases to 16.3% when B increases by 10%. On the other hand, if we set $\psi = 0$ so that elasticity of substitution is much larger than its benchmark value, we strengthen the "crowding-out" effect. Therefore, M/Y ratio decreases even more significantly to 11.45% when B increases by 10%.

REFERENCES

Attanasio, Orazio, Sagiri Kitao and Giovanni L. Violante (2010) Financing medicare: A general equilibrium analysis. In *Demography and the Economy*, pp. 333–366. Chicago, IL: University of Chicago Press.

Baker, Michael, Mark Stabile and Catherine Deri (2004) What do self-reported, objective, measures of health measure? *Journal of Human Resources* 39, 1067–1093.

Bloom, David E., David Canning and J. Sevilla (2005) Health and Economic Growth: Reconciling the Micro and Macro Evidence. Center on Democracy, Development and the Rule of Law working papers 42.

Bound, John (1991) Self-reported versus objective measures of health in retirement models. *Journal of Human Resources* 26, 106–138.

Bullard, James and James Feigenbaum (2007) A leisurely reading of the life-cycle consumption data. *Journal of Monetary Economics* 54, 2305–2320.

Cagetti, Marco and Mariacristina De Nardi (2008) Wealth inequality: Data and models. *Macroeconomic Dynamics* 12, 285–313.

Cagetti, Marco and Mariacristina De Nardi (2009) Estate taxation, entrepreneurship, and wealth. *American Economic Review* 99, 85–111.

Carroll, Christopher D. (1997) Buffer-stock saving and the life cycle/permanent income hypothesis. *Quarterly Journal of Economics* 112, 1–55.

Conesa, Juan Carlos, Sagiri Kitao and Dirk Krueger (2009) Taxing capital? Not a bad idea after all! *American Economic Review* 99, 25–48.

De Nardi, Mariacristina, Eric French and John Bailey Jones (2010) Why Do the Elderly Save? The Role of Medical Expenses. *Journal of Political Economy* 118, 39–75.

De Nardi, Mariacristina, Eric French, John Bailey Jones and McCauley Jeremy (2015) Medical spending on the U.S. elderly. National Bureau of Economic Research, working paper 21270.

Deaton, Angus (1992) *Understanding Consumption*. New York: Oxford University Press.

Fehr, Hans, Manuel Kallweit and Fabian Kindermann (2013) Should pensions be progressive. *European Economic Review* 63, 94–116.

Feng, Zhigang (2012). Macroeconomic consequences of alternative reforms to the health insurance system in the US. doi:10.2139/ssrn.2037058.

Fernandez-Villaverde, Jesus and Dirk Krueger (2007) Consumption over the life cycle: Facts from consumer expenditure survey data. *Review of Economics and Statistics* 89, 552–565.

Fernandez-Villaverde, Jesus and Dirk Krueger (2011) Consumption and saving over the life cycle: How important are consumer durables? *Macroeconomic Dynamics* 15, 725–770.

Finkelstein, Amy, Erzo F. P. Luttmer and Matthew J. Notowidigdo (2013) What good is wealth without health? The effect of health on the marginal utility of consumption. *Journal of the European Economic Association* 11, 221–258.

Fonseca, Raquel, Michaud Pierrecarl, Galama Titus and Kapteyn Arie (2009). On The Rise of Health Spending and Longevity. IZA discussion paper #4622.

French, Eric (2005) The effects of health,wealth, and wages on labour supply and retirement behaviour. *Review of Economic Studies* 72, 395–427.

Gilleskie, Donna B. (1998) A dynamic stochastic model of medical care use and work absence. *Econometrica* 66, 1–45.

Gourinchas, Pierre-olivier and Jonathan A. Parker (2002) Consumption over the life-cycle. *Econometrica* 70 , 47–89.

Grossman, Michael (1972) On the concept of health capital and the demand for health. *Journal of Political Economy* 80, 223–55.

Hall, Robert E. and Charles I. Jones (2007) The value of life and the rise in health spending. *Quarterly Journal of Economics* 122, 39–72.

Hansen, Gary (1993) The cyclical and secular behaviour of the labour input: Comparing efficiency units and hours worked. *Journal of Applied Econometrics* 8, 71–80.

He, Hui and Kevin X. D. Huang (2013) Why do Americans Spend so Much More on Health Care than Europeans?–A General Equilibrium Macroeconomic Analysis, Vandebilt University, working paper no. 15-00003.

Heathcote, Jonathan, Kjetil Storesletten and Giovanni L. Violante (2010) The macroeconomic implications of rising wage inequality in the United States. *Journal of Political Economy* 118, 681–722.

Huang, He, Selahattin Imrohoroglu and Thomas J. Sargent (1997) Two computations to fund social security. *Macroeconomic Dynamics* 1, 7–44.

Huang, Kevin X. D. and Gregory W. Huffman (2014) Unemployment and welfare implications of the current US tax treatment of employer-provided medical insurance. *Macroeconomic Dynamics* 18, 1547–1580.

Hubbard, Glenn, Jonathan S. Skinner and Stephen P. Zeldes (1994) The importance of precautionary motives in explaining individual and aggregate saving. *Journal of Monetary Economics* 40, 59–125.

Huggett, Mark (1996) Wealth distribution in life-cycle economies. *Journal of Monetary Economics* 38, 469–494.

Imrohoroglu, Ayse, Selahattin Imrohoroglu and Douglas H. Joines (1995) A life cycle analysis of social security. *Economic Theory* 6, 83–114.

Imrohoroglu, Selahattin and Sagiri Kitao (2012) Social security reforms: Benefit claiming, labor force participation, and long-run sustainability. *American Economic Journal: Macroeconomics* 4, 96–127.

Imrohoroglu, Selahattin and Sagiri Kitao (2009) Labor supply elasticity and social security reform. *Journal of Public Economics* 93, 867–878.

Jeske, Karsten and Sagiri Kitao (2009) U.S. tax policy and health insurance demand: Can a regressive policy improve welfare? *Journal of Monetary Economics* 56, 210–221.

Jung, Juergen and Chung Tran (2009) The macroeconomics of health savings accounts. Towson University, Department of Economics, working paper 2010-12.

Jung, Juergen and Chung Tran (2010) Medical Consumption Over the Life-Cycle: Facts from a U.S. Medical Expenditure Panel Survey. doi: 10.2139/ssrn.1560484.

Kashihara, David and Carper Kelly (2008) National Health Care Expenses in the US Civilian Non-Institutionalized Population, 2009. Medical Expenditure Panel Survey Statistical Brief #229.

Kniesner, Thomas, W. Kip Viscusi, Christopher Woock and James P Ziliak (2012) The value of a statistical life: Evidence from panel data. *Review of Economics and Statistics* 94, 74–87.

Kopecky, Karen A. and Koreshkova Tatyana (2014) The impact of medical and nursing home expenses on savings. *American Economic Journal: Macroeconomics* 6, 29–72.

Kotlikoff, Laurence J., Kent Smetters and Jan Walliser (1999) Privatizing social security in the United States—comparing the options. *Review of Economic Dynamics* 2, 532–574.

Lillard, Lee A. and Robert J. Willis (1978) Dynamic aspects of earning mobility. *Econometrica* 46, 985–1012.

Lovell, Vicky (2004) No Time to be Sick: Why Everyone Suffers When Workers Don't have Paid Sick Leave. IWPR Publication B242p, Institute for Women's Policy Research.

Meara, Ellen, Chapin White and David M. Cutler (2004) Trends In medical spending by age, 1963–2000. *Health Affairs* 23, 176–183.

Meghir, Costas and Luigi Pistaferri (2004) Income variance dynamics and heterogeneity. *Econometrica* 72, 1–32.

Ozkan, Serdar (2010) Income Differences and Health Care Expenditures Over the Life-Cycle. Unpublished mimeo.

Palumbo, Michael G. (1999) Uncertain medical expenses and precautionary saving near the end of the life cycle. *Review of Economic Studies* 66, 395–421.

Podor, Melinda and Timothy Halliday (2012) Health status and the allocation of time. *Health Economics* 21, 514–527.

Rust, John and Christopher Phelan (1997) How social security and Medicare affect retirement behavior in a world of incomplete markets. *Econometrica* 65, 781–831.

Smith, James P. (2007) The impact of socioeconomic status on health over the life-course. *The Journal of Human Resources* 42, 739–764.

Suen, Richard (2006) Technological Advance and the Growth in Health Care Spending. Unpublished mimeo.

Viscusi, W. Kip and William N. Evans (1990) Utility functions that depend on health status: Estimates and economic implications. *American Economic Review* 80, 353–374.

Yogo, Motohiro (2016) Portfolio choice in retirement: Health risk and the demand for annuities, housing, and risky assets. *Journal of Monetary Economics* 80, 17–34.

Zhao, Kai (2014) Social security and the rise in health spending. *Journal of Monetary Economics* 64, 21–37.