Closing Down the Shop: Optimal Health and Wealth Dynamics near the End of Life*

Julien Hugonnier[1,4,5], Florian Pelgrin[2,6] and Pascal St-Amour[3,4,6]

[1]École Polytechnique Fédérale de Lausanne

[2]EDHEC Business School

[3]University of Lausanne, Faculty of Business and Economics (HEC)

[4]Swiss Finance Institute

[5]CEPR

[6]CIRANO

September 19, 2017

*Financial support from the Swiss Finance Institute is gratefully acknowledged. We are thankful to Audrey Laporte, Shang Wu, and seminar participants at the European Workshop on Econometrics, and Health Economics, and the NETSPAR International Pension Workshop for very useful comments and discussions.

Abstract

Near the end of life, health declines, mortality risk increases, and curative is replaced by uninsured long-term care, accelerating the fall in wealth. Whereas standard explanations emphasize inevitable aging processes, we propose a complementary *closing down the shop* justification where agents' decisions affect their health, and the timing of death. Despite strictly preferring to live, individuals optimally deplete their health and wealth towards levels associated with high death risk and indifference between life and death. Reinstating exogenous aging processes reinforces the relevance of closing down. Using HRS data for elders, a structural estimation of the closed-form decisions identifies and tests conditions for these strategies to be optimal, and confirm their economic relevance. We also discuss why policy intervention to reduce the incidence of closing down would neither be effective, nor warranted.

JEL classification: D91, D14, I12

Keywords: End of life; Life cycle; Dis-savings; Endogenous mortality risk; Unmet medical needs; Right to refuse treatment.

1 Introduction

Health declines steadily throughout the life cycle, and falls more rapidly as we approach the last period of life.[1] Because how healthy we are is a significant predictor of future major health onsets,[2] exposure to death risk also increases.[3] Moreover, health spending augments, and changes in composition. Whereas curative expenses (e.g. doctor visits, hospital stays, drugs, ...) tend to stagnate, nursing homes, and other long-term care (LTC) spending increase sharply.[4] LTC expenditures are more income- and wealth-elastic than curative care, and can be associated with comfort care consumption.[5] Furthermore, LTC expenses are not covered by Medicare; out-of-pocket expenses thus increase sharply towards the end of life, leading to a rapid drain in financial resources.[6]

The standard explanations of these joint end-of-life health and wealth dynamics emphasize ineluctable health declines that are driven by the aging process,[7] with mortality risk mechanically increasing as a result. In this context, LTC expenses are mainly accompanying, but not reverting the biological decline in status. Given an exogenous expected remaining life horizon, the wealth management objectives simplify to insuring sufficient resources to reach the end of life and, potentially, leave bequests.

We propose a different perspective that abstracts from the inevitability in end-of-life health and wealth processes. This alternative relies on four modeling hypotheses regarding individual decisions. We assume that agents' choices can affect their health status, through which they can also alter their exposure to mortality risk. We further assume that individuals prefer life over death, and that they make dynamically-consistent choices. Put differently, the agents' decisions are coherent with a remaining life horizon whose distribution is endogenously determined by their decisions. Under these hypotheses, we ask whether the observed dynamics can be rationalized as an optimal relinquishment strategy whereby agents near the end of life choose to *close down the shop*. Under

[1] See Banks et al. (2015, Fig. 5, p. 12), Heiss (2011, Fig. 2, p. 124), Smith (2007, Fig. 1, p. 740), Case and Deaton (2005, Fig. 6.1, p. 186), or Van Kippersluis et al. (2009, Figs. 1, 2, p. 820, 823, 824) for evidence.

[2] Smith (2007, Tabs. 1–3, pp. 747–752).

[3] See Benjamins et al. (2004); Heiss (2011); Smith (2007); Hurd et al. (2001); Hurd (2002b) for evidence and discussion. See also Arias (2014, Tab. B, p. 4) for Life Tables.

[4] De Nardi et al. (2015b, Fig. 3, p. 22).

[5] See also De Nardi et al. (2015b); Tsai (2015); Marshall et al. (2010) for evidence and discussion.

[6] De Nardi et al. (2015a,b); Marshall et al. (2010); Love et al. (2009); French et al. (2006); Palumbo (1999)

[7] See Robson and Kaplan (2007) for discussion of aging and death. See also De Nardi et al. (2015a, 2009), or French and Jones (2011) for examples and applications.

reasonable, and empirically verifiable sufficient conditions, closing down strategies involve selecting a depletion of the health stock, that can eventually be accelerated towards the end, and which will invariably increase the risk of dying. Moreover, wealth is also selected to fall in response to the shorter expected life horizon, thereby reducing disposable resources for health spending. As they approach the end of life, dynamic consistency entails that agents gradually become indifferent between life and death.

The contributions of this paper are twofold. First we build upon a theoretical framework (Hugonnier et al., 2013) to derive the conditions under which closing down the shop *could* take place. This life cycle model features demand for health in the spirit of Grossman (1972), combined with diminishing returns to health spending, exogenous morbidity, and endogenous mortality exposure. Importantly, its use of non-expected utility allows to separately model the agent's attitudes towards the different risks present in the model, and guarantees preference for life over death. The main theoretical novelty of our approach is to prove the optimality of the joint health and wealth depletion processes near the end of life *without recoursing* to exogenous aging processes. Despite preferring to live, our agents optimally close down the shop: They simultaneously act in a manner that *results* in a short terminal horizon, *and* they select a depletion strategy that is consistent with this horizon. It is this simultaneous feedback between decisions and horizon that makes the solution of this model particularly challenging. To our knowledge, this is the first attempt to rationalize end-of-life health and wealth dynamics, rather than model them as ex-post responses to an irreversible sequence of exogenous health and/or wealth declines.[8] Note that this remarkable result does not preclude a biological aging explanation; we show that reintroducing the latter makes closing down even more relevant.

Our second contribution is to assess whether closing down dynamics are empirically relevant. Towards that purpose, we innovate by providing a structural econometric characterization of the health and wealth loci where these strategies are to be expected. This allows us to test conditions, and precisely pinpoint thresholds under which closing down does, or does not take place. Using the observed joint distribution of wealth, and self-reported health levels (ranging between Poor, Fair, Good, Very Good, and Excellent),

[8]Exceptions with endogenous mortality include Pelgrin and St-Amour (2016); Hugonnier et al. (2013); Blau and Gilleskie (2008); Hall and Jones (2007). However, none of these papers focus on end-of-life joint dynamics for health and wealth.

for relatively old agents (75.3 years old on average), our results indicate that *all* agents with nonnegative wealth, and at least Fair health optimally select to close down the shop.

This paper also indirectly contributes to the policy debates on the explosion of end-of-life health expenses. It reinforces arguments against futile end-of-life therapy,[9] and in favor of the right to refuse treatment.[10] Moreover, we show that although it is feasible to reduce the incidence of closing-down, the normative rationale for doing so is unclear. Indeed, because we assess the optimality of closing down strategies in a complete markets environment where both the agent's horizon and his wealth are endogenously determined, the standard arguments for intervention, such as market failure, myopic decisions or redistribution are not applicable in our setting.

The rest of this paper proceeds as follows. We summarize the theoretical model in Section 2. The admissible depletion and accelerating regions of the health and wealth state space are defined, and formally characterized in Section 3. We discuss the effects of aging, of endogenous death risk exposure, and the relevance of policy in Section 4. The empirical evaluation is performed in Section 5, with main results outlined in Section 6, and concluding remarks presented in Section 7.

2 Theoretical framework

Our analysis builds upon on the theoretical framework developed in Hugonnier et al. (2013) to analyze the joint dynamics of health and wealth. The main features of this model and its approximate solution are briefly reproduced here for completeness. Readers who are familiar with this framework may safely skip this presentation and move directly to Section 3.

[9]See Skinner and Wennberg (2000) for evidence of ineffective end-of-life treatment, and Byrne and Thompson (2000) for measures (e.g. advanced directives, compensation for treatment refusal) to reduce its incidence.

[10]The patient's right to refuse treatment is protected under both common law, and the US constitution (Legal Advisors Committee of Concerns for Dying, 1983), and recognized by the AMA (American Medical Association, 2016). Unmet medical needs is found to be prevalent in 23.4% of the population below poverty line (National Center for Health Statistics, 2012, Tab. 79, pp. 272-75.). See also Ayanian et al. (2000); Park et al. (2016) for evidence.

2.1 Economic environment

2.1.1 Health dynamics

The agent's health level evolves according to a stochastic version of the Grossman (1972) demand-for-health model:

$$\mathrm{d}H_t = ((I_t/H_{t-})^\alpha - \delta)\, H_{t-}\mathrm{d}t - \phi H_{t-}\mathrm{d}Q_{st}, \quad H_0 > 0, \tag{1}$$

where $H_{t-} = \lim_{s\uparrow t} H_s$ denotes the agent's health prior to the realization of the health shock, $I_t \geq 0$ represents the agent's flow rate of health spending,[11] and $\alpha \in (0,1)$ is a Cobb-Douglas parameter. The stochastic term $\mathrm{d}Q_{st}$ is the increment of a Poisson process with intensity λ_{s0} that captures the arrival of exogenous health shocks,[12] and $(\delta, \phi) \in (0,1)^2$ are constants that represent the decay rate of health in the absence of shocks, and the fraction of the agent's health that is lost upon the occurence of a sickness shock.

The agent's health level endogenously determines the instantaneous likelihood of his death. More precisely, we let the agent's time of death T_m be the first jump time of a Poisson process Q_{mt} whose arrival intensity is given by

$$\lim_{h\to 0} (1/h) P_t\, [t < T_m \leq t + h] = \lambda_{m0} + \lambda_{m1} H_{t-}^{-\xi_m} \equiv \lambda_m(H_{t-}) \tag{2}$$

for some constants $(\xi_m, \lambda_{m0}, \lambda_{m1}) \in \mathbb{R}^3_+$. In this expression the first term represents the agent's endowed exposure to mortality risk while the second term captures the fact that the agent can influence the distribution of his lifetime by investing in his health. The fact that both ξ_m and λ_{m1} are nonnegative implies that an healthier agent can expect to live longer.[13]

[11] The restriction to positive health investment rates is standard and reflects the fact that the agent cannot monetize his own health.

[12] Hugonnier et al. (2013) consider a more general model in which the arrival intensity of health shocks is a decreasing function of the agent's health level. We focus on the case of a constant arrival intensity to facilitate the presentation but our results can be extended to cover this more general case.

[13] See also Kuhn et al. (2015) for a life cycle model of savings and health expenditures with endogenous mortality rates, or Groneck et al. (2016) for one with exogenous rates, but where rational expectations over survival probabilities are replaced by ambiguous beliefs, with Bayesian learning.

We further assume that the agent's flow rate of income depends on health and is given by

$$Y(H_{t-}) = y_0 + \beta H_{t-} \tag{3}$$

where $(y_0, \beta) \in \mathbb{R}_+^2$ are constants that capture health-independent elements—such as Social Security revenue—and the sensitivity of the agent's income to his health status. The income process (3) allows sufficiently healthy elders to supplement base revenue through labor income and is consistent with increased market participation after age 65.[14]

2.1.2 Investment opportunity set

The agent can continuously invest in three assets: A risk-free asset with constant rate of return $r > 0$, and two risky assets. The first risky asset proxies for the stock market. Its price is denoted by S_t and evolves according to

$$\frac{dS_t}{S_t} = r\mathrm{d}t + \sigma_S\left(\mathrm{d}Z_t + \theta_t \mathrm{d}t\right)$$

where $\mathrm{d}Z_t$ is the increment of a Brownian motion that captures market risk, and $(\sigma_S, \theta) \in \mathbb{R}_+^2$ are constants which represent, respectively, the volatility of market returns and the instantaneous remuneration that investors earn for exposure to market risk.

The second risky asset is an actuarially fair health instantaneous insurance contract that pays one unit of the numéraire upon the occurence of a health shock. The instantaneous return that the agent earns by investing the amount $X_t \geq 0$ in this asset over the time interval $(t, t + \mathrm{d}t]$ is given by

$$X_t\left(\mathrm{d}Q_{st} - \lambda_{s0}\mathrm{d}t\right) \tag{4}$$

[14] Old-age male participation in the labor market has increased from 26% in 1995, to 35% in 2014, 60% of which involves full time work (Bosworth et al., 2016, Figs. II.1, and 2, pp. 7, and 9). See also Bureau of Labor Statistics (2008); Toossi (2015) for further evidence of increased participation of elders in the labor force.

where the first term captures the payment that the agent receives from the insurer upon the occurence of a health shock and the second term captures the instantaneous insurance premium that he pays to the insurer.

Denote by Π_t, and C_t the predictable processes that track the amounts that the agent invests in the stock market, and the amount he consumes per unit of time. With this notation we have that the dynamic budget constraint that governs the evolution of the agent's wealth is

$$\mathrm{d}W_t = (rW_{t-} + Y(H_{t-}) - C_t - I_t)\mathrm{d}t + \Pi_t \sigma_S \left(\mathrm{d}Z_t + \theta \mathrm{d}t\right) + X_t \left(\mathrm{d}Q_{st} - \lambda_{s0}\mathrm{d}t\right). \quad (5)$$

Investment in the riskless asset and the stock market is unconstrained, but we naturally assume that the agent can neither consume negative amounts nor sell insurance by imposing a nonnegativity constraint on both C_t and X_t.

2.1.3 Preferences

We close the model by specifying the agent's preferences. Following Hugonnier et al. (2013) we assume that the continuation utility $U_t = U_t(C)$ to an alive agent of a lifetime consumption schedule C solves a recursive integral equation of the form

$$U_t = E_t \int_t^{T_m} \left(f(C_s, U_s) - \frac{\gamma \sigma_s^2}{2U_s} - \sum_{k=m}^{s} F_k\left(U_s, H_s, \Delta_k U_s\right) \right) \mathrm{d}s \quad (6)$$

where γ is a strictly positive constant that measures the agent's local risk aversion to financial market shocks, $\sigma_t = \sigma_t(U) = \mathrm{d}\langle U, Z\rangle/\mathrm{d}t$ measures the sensitivity of the continuation utility process to these shocks, and

$$\Delta_k U_t = 1_{\{\mathrm{d}Q_{kt} \neq 0\}} \left(U_t - U_{t-}\right)$$

represents the predictable jump in continuation utility triggered by the occurence of a health shock $(k = s)$ or the agent's death $(k = m)$. In the above equation

$$f(C, U) = \frac{\rho U}{1 - 1/\varepsilon} \left(((C - a)/U)^{1-1/\varepsilon} - 1 \right) \quad (7)$$

is the Kreps-Porteus aggregator with elasticity of intertemporal substitution $\varepsilon > 0$, time preference rate $\rho > 0$, and subsistence consumption level $a \geq 0$; and the penalty terms are given by

$$F_k(U, H, \Delta U) = \lambda_k(H) \left[\frac{\Delta U}{U} + \frac{1 - (1 + \Delta U/U)^{1-\gamma_k}}{1 - \gamma_k} \right] U \tag{8}$$

for some constants $\gamma_s > 0$ and $\gamma_m \in [0, 1)$. This recursive preference model not only allows to disentangle the agent's behavior toward intertemporal substitution from his attitude towards risk but, as explained in Hugonnier et al. (2013), it goes one step further than Duffie and Epstein (1992) by allowing to differentiate between the attitudes toward the various sources of risk present in the model. In particular, our specification implies that the agent has constant relative risk aversion $\gamma > 0$ towards financial market risk, $\gamma_s \geq 0$ towards heath risk, and $\gamma_m \in [0, 1)$ towards mortality risk.[15] Importantly, the restriction that $\gamma_m < 1$ guarantees that, irrespective of his attitude towards the other sources of risk, the agent prefers life over death.

2.1.4 The decision problem

The agent's decision problem consists in choosing a portfolio, consumption, health insurance and health investment strategy to maximize his lifetime utility. The indirect utility associated with this problem is defined by

$$V(W_t, H_t) = \sup_{(C,\Pi,X,I)} U_t(C)$$

subject to the dynamics of the health process (1) and the budget constraint (5) where $U_t(C)$ is the continuation utility process associated with the lifetime consumption and health investment plan (C, I) through (6).

[15] See also Bommier et al. (2011) for aversion towards temporal (i.e. mortality) risk in a non-separable preferences context.

In the absence of intentional bequests,[16] the continuation utility process defined by (6) becomes zero at death. As a result, we have $\Delta_m U_t = -U_t$ and it follows that the penalty associated with mortality risk satisfies

$$\frac{F_m(U_s, H_s, \Delta_m U_s)}{\lambda_m(H_s)U_s} = \frac{\gamma_m}{1-\gamma_m} \equiv \Phi \in [1, \infty).$$

Using this observation and integrating over the conditional distribution of the agent's time of death, Hugonnier et al. (2013) show that the agent's decision problem, which features incomplete markets and an endogenous random horizon, can be conveniently recast into an equivalent infinite horizon problem with endogenous discounting and complete markets. Specifically, they show that

$$V(W_t, H_t) = \sup_{(C,\Pi,X,I)} \overline{U}_t(C)$$

where the modified continuation utility process $\overline{U}_t = \overline{U}_t(C)$ solves the infinite horizon recursive integral equation given by

$$\overline{U}_t = E_t \int_t^\infty e^{-\int_t^s \lambda_m(H_k)(1+\Phi)\mathrm{d}k} \left(f(C_s, \overline{U}_s) - \frac{\gamma \sigma_s(\overline{U})^2}{2\overline{U}_s} - F_s(\overline{U}_s, H_s, \Delta_s \overline{U}_s) \right) \mathrm{d}s. \quad (9)$$

This formulation brings to light the two distinct channels through which the agent's health status enters his decision problem. First, health can be interpreted as a durable good that generates service flows through the income rate $Y(H_t)$. Second, health determines the instantaneous probability of morbidity shocks and the rate $\lambda_m(H_t)(1+\Phi)$ at which the agent discounts future consumption and continuation utilities.

Remark 1 (Health dependent preferences) One might reasonably object that old agents are likely to be retired and thus do earn labor income. However, this objection is inconsequential for our purposes since the agent's decision problem is iso-morphic to one with health-dependent utility, and constant base income. This results follows by effecting

[16]This assumption is imposed for tractability and can be justified by noting that while bequest motives are potentially relevant in an endogenous mortality setting, empirical evidence suggests that their role in explaining the behavior of agents is debatable. The results of Laitner and Ohlsson (2001) favor altruistic, over unintentional motives in US and Swedish bequests. However, Gan et al. (2015) find that bequests in AHEAD data are best described as accidental or unintentional, Hurd (2002a) finds no clear evidence of a bequest motive behind savings decisions and Hurd (1987) finds no differences in the saving behavior of the elderly who have children compared to those who don't.

the change of variable $\overline{C}_t = C_t - \beta H_{t-}$ throughout the above equations (see Hugonnier et al., 2013, Remark 3 for details).

2.2 Optimal dynamic policies

The endogeneity of the discount rate in (9) implies that the agent's decision problem does not admit a closed-form solution. To circumvent this difficulty Hugonnier et al. (2013) rely on a two step procedure. First, they show that in the exogenous mortality case where $\lambda_{m1} = 0$, the agent's decision problem can be solved in closed form. Second, they use an asymptotic expansion of the solution to the dynamic programming equation around the point $\lambda_{m1} = 0$ to compute the leading order effect of endogenous mortality on the optimal policy. Adapting their results to our setting allows to derive the approximation to the optimal policy.

Proposition 1 (Optimal policy functions) *Assume that conditions (45), (46), and (47) of Appendix A.2 hold true, and define net total wealth as:*

$$N_0(W_{t-}, H_{t-}) = W_{t-} + BH_{t-} + (y_0 - a)/r \tag{10}$$

where $B > 0$ is the smallest solution to (49). Up to a first order approximation the optimal policy functions are given by:

$$I^*(W_{t-}, H_{t-}) = KBH_{t-} + \mathcal{I}_1 H_{t-}^{-\xi_m} N_0(W_{t-}, H_{t-}) \tag{11}$$

and

$$X^*(W_{t-}, H_{t-}) = \phi BH_{t-} + \mathcal{X}_1 H_{t-}^{-\xi_m} N_0(W_{t-}, H_{t-}) \tag{12}$$

$$C^*(W_{t-}, H_{t-}) = a + AN_0(W_{t-}, H_{t-}) + \mathcal{C}_1 H_{t-}^{-\xi_m} N_0(W_{t-}, H_{t-}) \tag{13}$$

$$\Pi^*(W_{t-}, H_{t-}) = (\theta/(\gamma\sigma_S))\, N_0(W_{t-}, H_{t-}) \tag{14}$$

where the constants $(B, A, K, \mathcal{I}_1) \in \mathbb{R}_+^4$, and $(\mathcal{X}_1, \mathcal{C}_1) \in \mathbb{R}^2$ are defined in Appendix A.2.

The optimal rules in proposition 1 are all functions of the agent's health H_{t-}, and net total wealth $N_0(W_{t-}, H_{t-})$ defined in (10) as the sum of his financial assets, and the present value of his future income, net of subsistence consumption expenditures $BH_{t-} +$

$(y_0 - a)/r$. In this expression, B represents the marginal-Q of health, and increases in the health sensitivity β of the agent's income, while falling in the sickness and depreciation parameters $(\lambda_{s0}, \phi, \delta)$.

The first term in the health investment (11) is the optimal policy when mortality is exogenous and is proportional to health capital's economic value BH_{t-}. The second term is positive because controllable mortality provides additional incentives to invest. As will be seen below, the non-monotonic effects of health on $I(W_{t-}, H_{t-})$ induced by the demand for death risk adjustments plays a key role in the nonlinear dynamics for health and wealth.

3 Optimal health and wealth dynamics

We assume from now on that the agent follows the approximate optimal rules prescribed by proposition 1. Consequently, his health and wealth evolve according to the dynamical system formed by (1) and (5) evaluated at the optimal rules (11)–(14). Due to the presence of Brownian financial shocks and Poisson health shock, this bivariate system is stochastic and thus cannot be directly analyzed using standard tools such as phase portraits. To circumvent this difficulty we focus on the instantaneous expected changes in health and wealth that are implied by the approximate optimal rules.[17]

Section 3.1 identifies minimal resources requirements to ensure survival, as well as strict preference for life over death. We next define, and characterize health depletion, as well as speed of depreciation in Section 3.2. We then analyze wealth depletion, as well as implications for closing-down strategies in Section 3.3.

3.1 Admissibility

The optimal rules are defined only over an *admissible* state space, i.e. the set of wealth and health levels such that net total wealth $N_0(W_{t-}, H_{t-})$ is nonnegative in (10). Indeed, observe from optimal consumption (13) that admissibility is required to ensure that consumption $C^*(W_{t-}, H_{t-})$ is above subsistence a. Moreover, as shown in Hugonnier et al. (2013), the homogeneity of the Kreps-Porteus aggregator in (7), and of the penalty

[17] See also Laporte and Ferguson (2007) for an analysis of expected local changes of the Grossman (1972) model with Poisson shocks.

functions in (8) guarantees that the continuation utility (6) is also homogeneous, such that excess consumption and welfare are measured in the same units. Positive excess consumption $C^*(W_{t-}, H_{t-}) - a > 0$ entails positive continuation utility $V(W_{t-}, H_{t-}) > 0$ (versus zero at death), and therefore strict preference for being alive. To ensure that resources are sufficient to cover subsistence consumption, and that life is preferable, positive net total wealth in equation (10) can thus be relied upon to define the admissible region $\mathcal{A}$ as:

$$\mathcal{A} = \{(W, H) \in \mathbb{R} \times \mathbb{R}_+ : W \geq x(H) = -(y_0 - a)/r - BH\}. \tag{15}$$

Moreover, observe from optimal risky holdings (14) that the risky portfolio shares can be written as:

$$\frac{\Pi^*(W_{t-}, H_{t-})}{W_{t-}} = \frac{\theta}{\gamma\sigma_S}\left(1 - \frac{x(H_{t-})}{W_{t-}}\right).$$

As is well-known, portfolio shares are increasing in the financial wealth level W_{t-} (e.g. Wachter and Yogo, 2010), which requires that $x(H_{t-})$ be nonnegative, and consequently, that:

$$(y_0 - a)/r < 0. \tag{16}$$

This restriction is realistic and states that base income y_0 is insufficient to cover subsistence consumption a, such that strictly positive wealth is required for admissibility when labor income is low.[18]

3.2 Optimal health depletion

The expected local change in health capital is given by:

$$\frac{1}{\mathrm{d}t} E_{t-}[\mathrm{d}H_t] = \left[I^h(W_{t-}, H_{t-})^\alpha - \tilde{\delta}\right] H_{t-}, \tag{17}$$

where we denote by $\tilde{\delta} = \delta + \phi\lambda_{s0}$ the sickness-adjusted expected depreciation rate of health. The investment-to-health ratio evaluated at the optimal investment in (11) is

[18] Although not necessary for the main theoretical results, restriction (16) is also tested and confirmed empirically in Section 6, and will be relied upon in the discussion of these results.

given by:

$$I^h(W_{t-}, H_{t-}) = \frac{I^*(W_{t-}, H_{t-})}{H_{t-}} = BK + \mathcal{I}_1 H_{t-}^{-\xi_m - 1} N_0(W_{t-}, H_{t-}). \tag{18}$$

Since our main focus is on end-of-life decumulation, we consider the admissible subset $\mathcal{D}_H \subseteq \mathcal{A}$ of the state space where *health depletion* is expected:

$$\mathcal{D}_H = \left\{ (W, H) \in \mathcal{A} : \frac{1}{\mathrm{d}t} E_{t-}[\mathrm{d}H_t \mid W_{t-} = W, H_{t-} = H] < 0 \right\}. \tag{19}$$

To analyze how fast the health capital is allowed to deplete, we define the *acceleration* subset $\mathcal{AC} \subseteq \mathcal{D}_H$ of the health depletion region where the investment-to-health ratio is an increasing function of health:

$$\mathcal{AC} = \left\{ (W, H) \in \mathcal{D}_H : I_H^h(W, H) > 0 \right\}. \tag{20}$$

Hence for agents with $(W, H) \in \mathcal{AC}$, a positive health gradient of the investment-to-capital ratio (18) entails that health depletion is followed by more important cuts in health investment, leading to declines in $I^h(W, H)$, and further depletion of the health capital in (17) .

The following result characterizes both the health depletion and the acceleration regions of the state space.

Proposition 2 (Health depletion and acceleration) *Assume that the agent follows the approximate optimal rules in proposition 1. Then, the health depletion set $\mathcal{D}_H$ in (19) is non-empty if and only if:*

$$BK < \tilde{\delta}^{1/\alpha}. \tag{21}$$

Under condition (21):

1. *The health depletion zone is given by:*

$$\mathcal{D}_H = \{(W, H) \in \mathcal{A} : W < y(H)\}, \tag{22}$$

where the health depletion locus is

$$y(H) = x(H) + DH^{1+\xi_m}, \qquad (23)$$
$$D = \mathcal{I}_1^{-1}\left[\tilde{\delta}^{1/\alpha} - BK\right] > 0.$$

2. *The accelerating region* (20) *is given by:*

$$\mathcal{AC} = \{(W, H) \in \mathcal{D}_H : W < \min\left[y(H), z(H)\right]\}, \qquad (24)$$

where the acceleration locus is

$$z(H) = x(H) + \frac{BH}{1+\xi_m}. \qquad (25)$$

Condition (21) refers to a high expected depreciation of the health capital relative to its marginal-Q and is particularly relevant for elders. Indeed, Appendix A.2 shows that $BK < \beta$, such that a sufficient condition for (21) is:

$$\beta < \tilde{\delta}^{1/\alpha}. \qquad (26)$$

Condition (26) states that expected health depreciation $\tilde{\delta} = \delta + \phi\lambda_{s0}$ is high relative to the health-dependent income contribution β, and is appropriate for end-of-life characterization. A high depreciation in the absence of investment (δ), or conditional upon sickness (ϕ), a high likelihood of morbidity shocks (λ_{s0}), as well as a low adjustable component in income (β) are all to be expected in the last years of life.[19]

A violation of condition (21) entails that there are no admissible regions of the state space where health is expected to fall. Indeed, observe that $(\tilde{\delta}^{1/\alpha} - BK)$ is the expected depletion in the absence of mortality control. As shown earlier, allowing for endogenous mortality increases the incentives for investment. If expected depletion is negative (i.e. health is expected to grow) in the absence of mortality control, it is even more so when exposure to death risk can be adjusted, and consequently, there are no admissible regions where health depletion is optimal. Equivalently, this restriction ensures that the constant

[19]Note further that condition (26) is also more stringent than, and therefore induces the required transversality condition (45) in Appendix A.1, a necessary condition for finiteness of the present value of labor income.

D is positive in equation (23), such that $y(H) \geq x(H), \forall H$, and the admissible health depletion subset $W < y(H)$ is therefore everywhere non-empty.

The health dynamics characterized by proposition 2 can be analyzed through the phase diagram in Figure 1. First, the admissible region $\mathcal{A}$ is bounded below by the red $x(H)$ locus (15), with complementary non-admissible area $\mathcal{NA}$ in shaded red region. The $W-$intercept of $x(H)$ is given by the net present value of base income deficit $-(y_0 - a)/r$ which is positive under (16), whereas its $H-$ intercept is given by $\bar{H}_1 = -(y_0 - a)/(rB) > 0$. The negative slope of the admissible locus suggests a natural tradeoff between minimal health and wealth.[20] Importantly, the previous discussion of admissibility reveals that the red $x(H)$ locus is characterized by zero net total wealth, consumption at subsistence level, and a complete indifference between life and death.

Second, equation (22) states that the health depletion region $\mathcal{D}_H$ is the shaded green area located below the green $y(H)$ locus (23). Under condition (21), we show in Appendix B.2.1 that the $y(H)$ locus is U-shaped, and attains a unique minimum at $\bar{H}_3$ given by:

$$\bar{H}_3 = \left(\frac{B}{D(1+\xi_m)} \right)^{\frac{1}{\xi_m}} > 0. \tag{27}$$

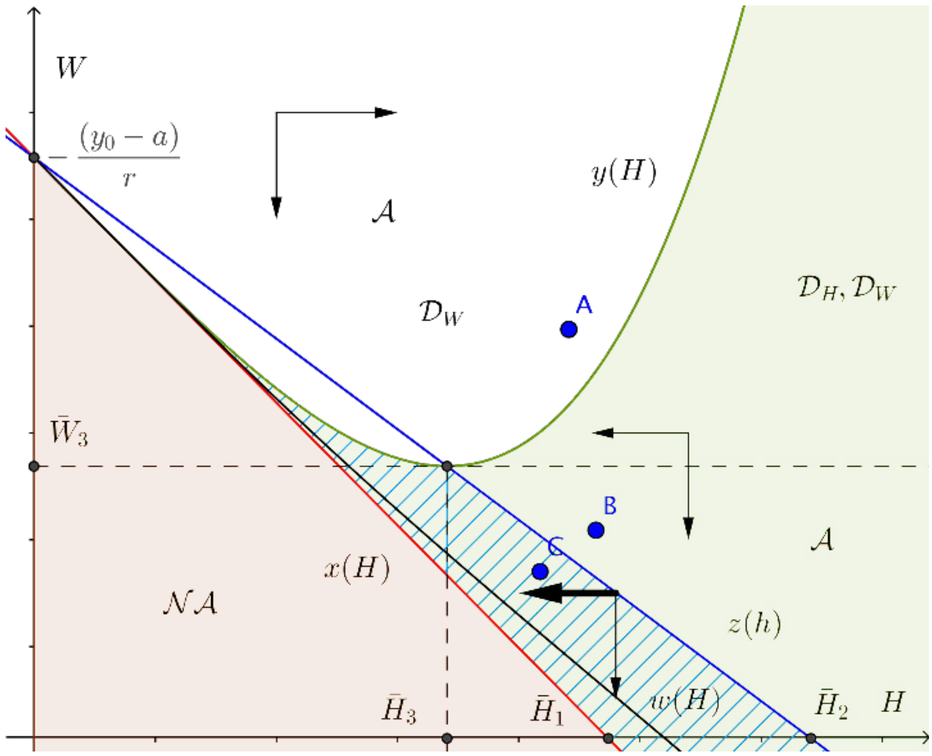
The reasons for the non-monotonicity stem from the effects of H on $I^h(W, H)$. On the one hand, better health raises the value of the health capital BH, and therefore net total wealth $N_0(W, H)$, thereby increasing the investment to capital ratio I^h in (18). Constant (and zero) growth thus requires an offsetting reduction in W. On the other hand, being healthier lowers the incentives for investing to control for mortality risk, and therefore reduces I^h. Constant growth thus requires increasing W. The analysis of the $y(H)$ locus in (23) reveals that the net total wealth effect is dominant at low health ($H < \bar{H}_3$), whereas the mortality risk effect dominates for healthier agents ($H > \bar{H}_3$).

Third, the accelerating locus $z(H)$ in (25) is plotted as the blue line in Figure 1; the accelerating region is the dashed blue subset of $\mathcal{D}_H$. Appendix B.2.2 shows that this locus intersects the $x(H), y(H)$ loci at the same $-(y_0 - a)/r$ intercept, and that it intersects the $H-$axis at $\bar{H}_2 = \bar{H}_1(1 + \xi_m)/\xi_m > \bar{H}_1$; consequently, the admissible accelerating region $x(H) < W < z(H)$ is non-empty for all health levels. Moreover, it also intersects the

[20] See also Finkelstein et al. (2013, 2009) for evidence and discussion regarding health effects on marginal utility.

health depletion locus $y(H)$ at its unique minimal value $\bar{H}_3$ in (27). Therefore, all agents with $H < \bar{H}_3$ in the depletion region are also in the accelerating subset.

Figure 1: Joint health and wealth dynamics



Notes: Non-admissible set $\mathcal{NA}$: shaded red area under red $x(H)$ line, admissible $\mathcal{A}$ is area above $x(H)$. Health depletion set $\mathcal{D}_H$: shaded green area under green $y(H)$ green curve. Acceleration set $\mathcal{AC}$: hatched green area under blue $z(H)$ curve. Wealth depletion set $\mathcal{D}_W$: area above $w(H)$ black curve.

The local expected dynamics of health are represented by the horizontal arrows in Figure 1 with agents A, B, and C described by their respective health and wealth statuses. First, agent A is sufficiently rich (i.e. $W > y(H)$), and can expect a growth in health. Agent B is poorer, and is located in the $\mathcal{D}_H$ region in which the health stock is expected to fall. In particular, there exists a threshold wealth level $\bar{W}_3 = y(\bar{H}_3)$ below which *all* agents, regardless of their health status, expect a health decline. Second, agent B in the health depletion region $\mathcal{D}_H$ is nonetheless sufficiently rich and healthy ($W > z(H)$) to optimally slow down – but not reverse – the depreciation of his health capital (i.e. $I_H^h < 0$). However, for agent C, wealth is below the $z(H)$ locus such that the health depletion accelerates (i.e. $I_H^h > 0$, illustrated by the thick vector) as falling health is accompanied by further cuts in the investment-to-health ratio. The health dynamics thus crucially depend on the wealth levels and dynamics, an issue we now address.

3.3 Optimal wealth depletion

Since the expected net return on actuarially fair insurance contracts (4) is zero, the expected changes in wealth is:

$$\begin{aligned}\frac{1}{\mathrm{d}t}E_{t-}[\mathrm{d}W_t] = &[rW_{t-} + Y(H_{t-}) - C^*(W_{t-}, H_{t-}) - I^*(W_{t-}, H_{t-}) \\ &+\Pi^*(W_{t-}, H_{t-})\sigma_S\theta] \,.\end{aligned} \tag{28}$$

In parallel with our earlier analysis of $\mathcal{D}_H$ in (19), the *wealth depletion* region of the admissible state space $\mathcal{D}_W \subseteq \mathcal{A}$ can be defined as:

$$\mathcal{D}_W = \left\{ (W, H) \in \mathcal{A} : \frac{1}{\mathrm{d}t}E_{t-}[\mathrm{d}W_t \mid W_{t-} = W, H_{t-} = H] < 0 \right\}, \tag{29}$$

and is characterized by the following result.

Proposition 3 (Wealth depletion) *Assume that the agent follows the approximate optimal rules in proposition 1, and that condition (21) in proposition 2 is verified. Then, the wealth depletion set $\mathcal{D}_W$ in (29) is non-empty if and only if there exists health levels H such that:*

$$l(H) = A - \frac{\theta^2}{\gamma} - r + (\mathcal{I}_1 + \mathcal{C}_1)\, H^{-\xi_m} > 0. \tag{30}$$

Under condition (30), the wealth depletion zone is given by:

$$\mathcal{D}_W = \{(W, H) \in \mathcal{A} : W > w(H)\}\,, \tag{31}$$

where the wealth depletion locus is

$$w(H) = \frac{x(H)[l(H) + r]}{l(H)} + \frac{k(H)}{l(H)}, \tag{32}$$

$$k(H) = y_0 - a + H(\beta - KB). \tag{33}$$

Condition (30) requires sufficiently high spending patterns for admissible wealth to fall. Indeed, observe that sufficient conditions for $l(H) > 0, \forall H$ are that preferences are elastic with respect to inter-temporal substitution, and that the marginal propensity to consume is high relative to the returns on financial assets:

$$\varepsilon > 1, \tag{34}$$

$$A > \frac{\theta^2}{\gamma} + r. \tag{35}$$

The assumption of a high elasticity of inter-temporal substitution in (34) guarantees that $\mathcal{C}_1 \geq 0$ in (52), and therefore that consumption (13) is high. Moreover, we can rely on the definition of the marginal propensity to consume A in (51) to rewrite condition (35) as:

$$\varepsilon(\rho - r) + (\varepsilon - 1)\frac{\lambda_{m0}}{1 - \gamma_m} > (1 + \varepsilon)\frac{\theta^2}{2\gamma}.$$

Since $\gamma_m \in [0, 1)$, the sufficient conditions (34), and (35) entail that impatience ρ is high, and/or the unconditional risk of dying λ_{m0} is high, and/or the aversion to death risk γ_m is high, all of which are relevant for end-of life analysis.[21]

The wealth depletion locus $w(H)$ in (32) is represented as the black curve in Figure 1, and equation (31) states that the wealth depletion region $\mathcal{D}_W$ is the area above this locus, with corresponding wealth dynamics captured by the vertical arrows. Appendix B.3 establishes that this locus has the same $H-$ intercept $-(y_0 - a)/r$, and it must lie above the admissibility locus $x(H)$. Moreover, under sufficient conditions (34), and (35) the $w(H)$ locus must lie below the health depletion locus $y(H)$. All three agents A, B, and C thus expect their wealth to fall. Others located at very low wealth levels in the $\mathcal{AC}$ region where rapidly receding health expenses $I(W, H)$ in (28) allow for expected increases in wealth. Since $w(H)$ is located between the admissible, and the health depletion loci, the joint depletion region ($\mathcal{D}_W \cap \mathcal{D}_H$) is non-empty for every H under sufficient conditions (34), and (35), i.e. there exists an admissible range of W for which agents optimally expect both their health and their wealth to fall.

[21]Note further that the sufficient condition (35) is more stringent than, and therefore induces the transversality condition (46).

These joint end-of-life dynamics of health and wealth are consistent with a deliberate *closing down the shop* strategy when the conditions in propositions 2, and 3 are verified. Sufficiently rich and healthy agents ($W > y(H)$) postpone health declines by investing more in their health. However, falling wealth is optimally chosen which eventually leads agents to enter the $\mathcal{D}_H$ region where health depletion is also selected.[22] Depreciation of the health stock accelerates once falling health and wealth draws agents into the $\mathcal{AC}$ region. Our model thus supports threshold effects whereby falling health is initially slowed down, and then accelerated, and is thus consistent with the accelerating deterioration in health observed after age 70 in the data (see footnote 1). Moreover, although we do not distinguish between various inputs in health care, such behavior would be consistent with an end-of-life change in the composition of health expenses towards more comfort, and less curative care (De Nardi et al., 2015b; Marshall et al., 2010). From the endogenous death intensity (2), falling health is invariably accompanied by an increase in mortality, and a decline towards the admissible locus $x(H)$ characterized by zero net total wealth, subsistence consumption, and indifference between life and death. Importantly, this optimal relinquishment occurs even when life is strictly preferred. Indeed, as discussed earlier, the non-separable preferences (6) ensure strictly positive continuation utility under life (versus zero under death). The agents we are considering therefore have no proclivity in favor of premature death.

4 Discussion

4.1 Effects of aging

Our discussion of end-of-life dynamics for health and wealth has thus far abstracted from the aging process in identifying conditions under which closing-down is an optimal strategy. This approach was deliberately selected in order to single-out the optimal dynamics effects from those associated with age, yet is admittedly incomplete in omitting the effects of biological declines in elders. However, as the following discussion illustrates,

[22]It is worth noting that the optimal risky asset holdings in (14) are positive when net total wealth, and risk premia are both positive. Moreover, the investment in (11) is monotone increasing in wealth, such that a sufficiently long sequence of high positive returns on financial wealth could pull the agents away from the depletion region $\mathcal{D}_H$. Put differently, falling health, and higher mortality is locally expected, yet is not absolute for agents in the depletion region. We will return to this issue in the discussion of the simulation exercise presented below.

incorporating aging does not fundamentally alter our analysis, but rather only reinforces our previous results.

Towards that aim, the model can be modified to account for realistic aging processes involving age-increasing depreciation, sickness, and death risks exposure, as well as age-decreasing heath-income sensitivity, and ability to alter death risk exposure:

$$\begin{aligned} \dot{\delta}_t, \dot{\phi}_t, \dot{\lambda}_{s0t}, \dot{\lambda}_{m0t} \geq 0 \\ \dot{\beta}_t, \dot{\lambda}_{m1t} \leq 0. \end{aligned} \tag{36}$$

Under this modification, Hugonnier et al. (2013) shows that the optimal rules in Theorem 1 remain valid, although with age-dependent parameters $(B_t, A_t, K_t, \mathcal{I}_{1t})$, and $(\mathcal{X}_{1t}, \mathcal{C}_{1t})$ that can be solved in closed-form reproduced in Appendix A.3. More importantly, our previous analysis of the local dynamics remains applicable if we modify the admissible, accelerating, health, and wealth depletion loci of the state-space accordingly:

$$\begin{aligned} x_t(H) &= -\frac{(y_0 - a)}{r} - B_t H, \\ y_t(H) &= x_t(H) + D_t H^{1+\xi_m}, \\ D_t &= \frac{\tilde{\delta}_t - B_t K_t}{\mathcal{I}_{1t}} \\ z_t(H) &= x_t(H) + \frac{B_t H}{1+\xi_m}, \\ w_t(H) &= \frac{x_t(H)[l_t(H) + r]}{l_t(H)} + \frac{k(H)}{l_t(H)}, \\ l_t(H) &= A_t - \frac{\theta^2}{\gamma} - r + (\mathcal{I}_{1t} + \mathcal{C}_{1t})\, H^{-\xi_m}, \\ k_t(H) &= y_0 - a + H(\beta - K_t B_t). \end{aligned}$$

Using the properties of the optimal rules, it can be shown that the aging process (36) induces an age-increasing marginal propensity to consume $\dot{A}_t \geq 0$ when the high substitution elasticity condition (34) is verified. Intuitively, an increasing exposure to death risk encourages elders with high elasticity to accelerate consumption, and deplete financial wealth. The aging process also generates age-decreasing $\dot{B}_t, \dot{K}_t, \dot{L}_{mt}, \dot{\mathcal{I}}_{1t} \leq 0$; it follows directly that D_t is age-increasing. Intuitively, age-increasing depreciation, sickness exposure, and consequences, as well as falling income returns on health all concur to lower its shadow price B_t for elders.

These age-related dynamics reinforce the incidence of our health depletion strategies. First, decreasing shadow price, and increasing expected depreciation rates imply that the modified necessary and sufficient condition (21), $B_t K_t < \tilde{\delta}_t^{1/\alpha}$ for non-empty $\mathcal{D}_H$ is more likely for elders. Moreover, whereas the intercept $-(y_0 - a)/r$ is unaffected by age, an age-decreasing B_t causes a counter-clockwise rotation in the admissible $x_t(H)$, and accelerating $z_t(H)$ loci in Figure 2. This implies that independently from their health and wealth dynamics, the aging process (36) is pushing the indifference $\mathcal{NA}_t$, and accelerating $\mathcal{AC}_t$ subsets closer to the agents A, B, and C. In addition, an age-increasing D_t implies that the health depletion locus $y(H)$ is also rotating counter-clockwise, leading to decreases in $\bar{H}_{3t} = B_t/(D_t(1+\xi_m))$, and increases in $\bar{W}_{3t} = y_t(\bar{H}_{h3t})$. Put differently, aging now makes health depletion optimal for more individuals, including agent A, and makes accelerating decumulation optimal for agents B, and C.

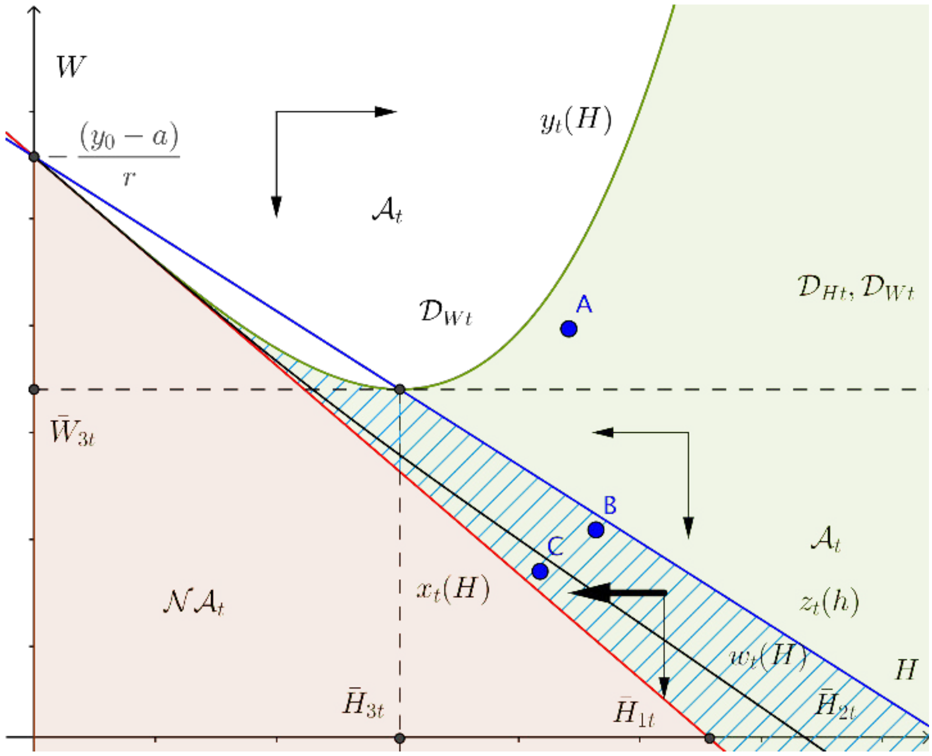
Similarly, an age-increasing marginal propensity to consume A_t entails that the sufficient closing-down condition (35) for non-empty $\mathcal{D}_W$ is more easily met. *Ceteris paribus*, optimal wealth depletion is thus made more likely at given health and wealth with the passing of age. The precise effects on the wealth depletion loci $w_t(H)$ are however more difficult to establish due to the conflicting impact of age on $A_t, \mathcal{I}_{1t}$, and because the effect on $\mathcal{C}_{1t}$ is ambiguous.

We conclude that whereas closing-down is optimal independently of aging, the latter reinforces the incentives for optimal health, and wealth depletion. Put differently, closing-down is complementary to an exogenous biological deterioration in health associated with age.

4.2 Exogenous mortality

A related concern is whether or not agents approaching the end of life can adjust their exposure to death risk through their health spending. To address this issue, we re-evaluate the health and wealth dynamics by removing the endogenous component in the death intensity in the death intensity (2). As the following result makes clear, purely exogenous death exposure alter the state space segments, but not the ultimate conclusion that closing-down is optimal.

Figure 2: Joint health and wealth dynamics: Effects of aging



Notes: Effects of aging process (36). Non-admissible set $\mathcal{NA}_t$: shaded red area under red $x_t(H)$ line, admissible $\mathcal{A}_t$ is area above $x_t(H)$. Health depletion set $\mathcal{D}_{Ht}$: shaded green area under green $y_t(H)$ green curve. Acceleration set $\mathcal{AC}_t$: hatched green area under blue $z_t(H)$ curve. Wealth depletion set $\mathcal{D}_{Wt}$: area above $w_t(H)$ black curve.

Proposition 4 (Exogenous mortality) *Assume that the agent follows the optimal rules in proposition 1, but that the exposure to mortality risk can not be adjusted, i.e.* $\lambda_{m1} = 0$. *Then, the health depletion set is non-empty if and only if condition (21) is verified, under which:*

1. *health depletion is expected everywhere in the admissible set:*

$$\mathcal{D}_H = \mathcal{A}, \tag{37}$$

2. *the accelerating subset is empty:*

$$\mathcal{AC} = \emptyset, \tag{38}$$

3. *the wealth depletion set is non-empty if and only if condition* (35) *is verified, under which* $\mathcal{D}_w$ *remains delimited by* (31)*, where the wealth depletion locus is modified as:*

$$w(H) = \frac{x(H)[l + r]}{l} + \frac{k(H)}{l} > x(H), \tag{39}$$

$$l = A - \frac{\theta^2}{\gamma} - r \tag{40}$$

and $k(H)$ *remains as in* (33).

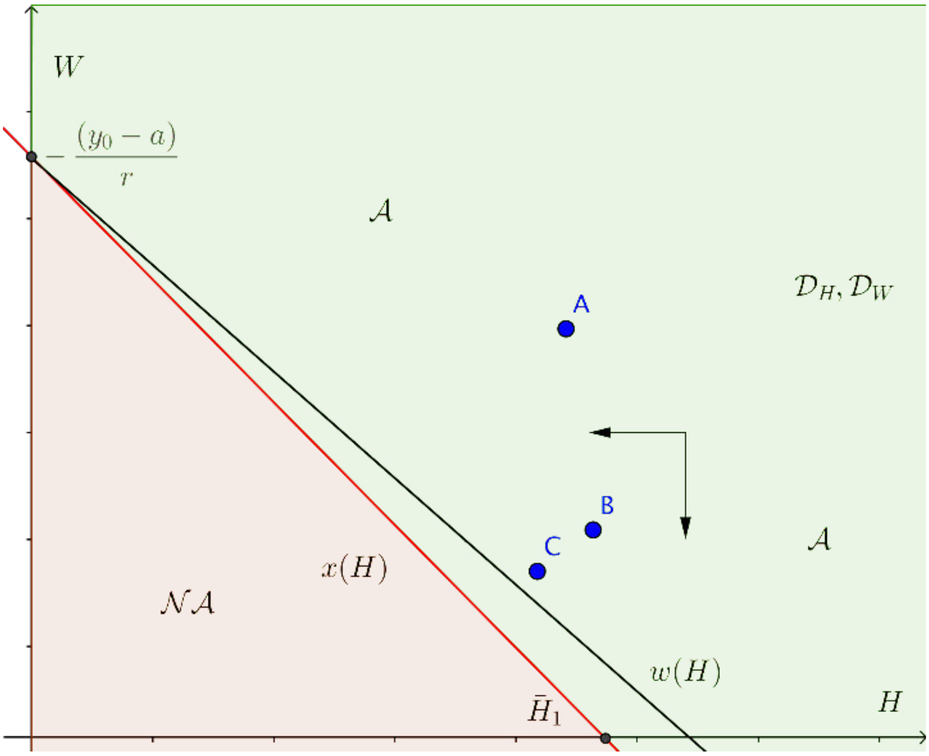
The corresponding dynamics are illustrated in Figure 3. For reasons discussed earlier, setting the endogenous death intensity parameter $\lambda_{m1} = 0$ reverts the model to its order-0 solutions. In particular, it implies that $\mathcal{I}_1 = 0$, such that the investment to health ratio (18) is now constant, and expected depletion obtains throughout the state space under condition (21). It follows that all individuals in the admissible subset – such as agents A, B, and C – expect health to deplete as stated in (37). Second, a constant investment-to-health capital ratio I^h does not respond to health levels; consequently no accelerating region exists, as stated in (38). Third, the order-zero solution for consumption also implies that $\mathcal{C}_1, \mathcal{I}_1 = 0$ in (30). Substituting in (32) reveals that the $w(H)$ locus (39) is now a straight line which lies above the admissible locus $x(H)$ under condition (35). As health depletion is the entire admissible set, the joint health and wealth depletion is everywhere non-empty.

4.3 Reducing the prevalence of closing-down strategies

Assuming that such an objective is warranted (e.g. for public health policy purposes), the prevalence of closing-down strategies could potentially be reduced through income transfers. One instrument that can be used towards that aim is the base income y_0 which can be altered through Social Security, or consumption floor policies.

Figure 4 illustrates the effects of increasing base income to $y_1 > y_0$. Comparing with Figure 1 reveals that such an increase in y_0 lowers the intercept to $-(y_1 - a)/r$. It follows that the four loci are shifted downwards, leading to lower $\bar{H}_1, \bar{H}_2$, and $\bar{W}_3$, but without affecting $\bar{H}_3$. If we take as given the current health and wealth distribution, admissibility is increased, and the prevalence of the health depletion $\mathcal{D}_H$ is theoretically reduced, with all three agents A, B, and C now out of the health depletion region.

Figure 3: Joint health and wealth dynamics: Exogenous mortality

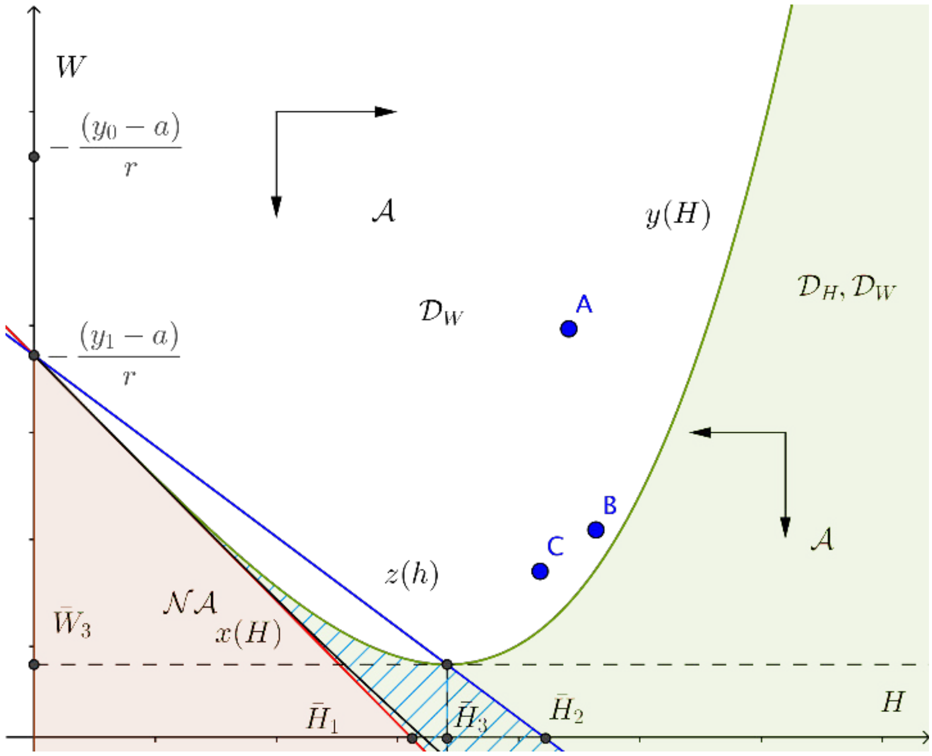


Notes: Effects of exogenous mortality $\lambda_{m1} = 0$. Non-admissible set $\mathcal{NA}$: shaded red area under red $x(H)$ line, admissible $\mathcal{A}$ is area above $x(H)$. Health depletion set $\mathcal{D}_H$: shaded green area under green $y(H)$ green curve. Wealth depletion set $\mathcal{D}_W$: area above $w(H)$ black curve.

Nonetheless, whereas the tools for reducing the incidence of closing down are available, the normative arguments in favor of intervention are less clear. Indeed, the traditional rationale of myopia or market incompleteness can hardly be invoked since closing down is obtained as a dynamically consistent strategy under a complete markets setting.[23] Moreover, poor agents are subject to faster depreciation of their health capital and higher mortality risk. However, redistribution arguments cannot be invoked to the extent that poverty, and life expectancy are both endogenously determined as an optimal choice.

[23]See Kuhn et al. (2015) for moral hazard in annuity markets as a separate incentive for intervening in an endogenous mortality model with optimal savings, health spending, and retirement.

Figure 4: Joint health and wealth dynamics: Base income policy



Notes: Effects of increasing base income to $y_1 > y_0$. Non-admissible set $\mathcal{NA}$: shaded red area under red $x(H)$ line, admissible $\mathcal{A}$ is area above $x(H)$. Health depletion set $\mathcal{D}_H$: shaded green area under green $y(H)$ green curve. Acceleration set $\mathcal{AC}$: hatched green area under blue $z(H)$ curve. Wealth depletion set $\mathcal{D}_W$: area above $w(H)$ black curve.

5 Empirical evaluation

The optimal health and wealth depletion strategy that we have identified is arguably more appropriate for agents nearing death, than for younger ones. Indeed, a high sickness-augmented depreciation rate for the health capital, and a low ability to generate labor revenues (condition (26)) both seem legitimate for old agents in the last period of life, yet less so for younger ones. Moreover, a high marginal propensity to consume (condition (35)), as well as a base income deficit relative to subsistence consumption (condition (16)) are suitable for elders nearing end of life. Using a database of relatively old individuals (HRS), we next verify empirically whether or not these conditions are valid, and whether the admissible, depletion, and acceleration subsets have economic relevance. Having shown in Section 4.1 that aging only reinforces the incidence of closing-down, we again abstract from age and resort to the constant parameters case discussed in Section 3 for the empirical evaluation. From that perspective, abstracting from ageing thus makes it more difficult to identify any relevance for closing-down.

5.1 Econometric model

We perform a structural estimation of the deep parameters of the theoretical framework in order to compute the regions of the state space. The econometric model assumes that agents follow the optimal rules in Section 2.2, and that they are heterogeneous only with respect to their health, and wealth statuses, i.e. the deep parameters are considered to be the same across individuals. This assumption is required for identification, and is justifiable since we are considering a relatively homogeneous subset of old individuals, thereby ruling out potential cohort effects.

The tri-variate nonlinear structural econometric model that we estimate over a cross-section of agents $j = 1, 2, \ldots, n$ is the optimal investment (11), and the risky asset holdings (14), to which we append the income equation (3) :

$$I_j = KBH_j + \mathcal{I}_1 H_j^{-\xi_m} N_0(W_j, H_j) + u_j^I, \tag{41}$$

$$\Pi_j = (\theta/(\gamma\sigma_S))\, N_0(W_j, H_j) + u_j^\Pi, \tag{42}$$

$$Y_j = y_0 + \beta H_j + u_j^Y, \tag{43}$$

where net total wealth $N_0(W, H)$ is given in (10), the parameters $(K, \mathcal{I}_1, B)$ are outlined in Appendix A.2, and where (u_j^I, u_j^Π, u_j^Y) are correlated error terms. Data limitations discussed in Section 5.2 explain why optimal insurance (12), and consumption (13) are omitted from the econometric model.

A subset of the technological, distributional, and preference parameters are estimated using the joint system (41), (42) and (43), imposing the regularity conditions (45), (46), and (47) outlined in Appendix A.1. The identification of the deep parameters is complicated by significant non-linearities. Consequently, not all the parameters can be estimated, and we calibrate a subset. Certain calibrated parameters (i.e. μ, r, σ_S, ρ)

are set at standard values from the literature. For others however (i.e. ϕ, γ_m, γ_s), scant information is available, and we rely on a thorough robustness analysis.[24]

The estimation approach is an iterative two-step ML procedure. In a first step, the convexity parameter ξ_m is fixed and a maximum likelihood approach is conducted on the remaining structural parameters. In a second step, the latter are fixed and the likelihood function is maximized with respect to ξ_m. The procedure is iterated until a fixed point is reached for all the estimated structural parameters.

The likelihood function is written by assuming that there exist some cross-correlation between the three equations, i.e. $\text{Cov}(u_j^I, u_j^\Pi, u_j^Y) \neq 0$. For the first two equations, the cross-correlation can be justified by the fact that we use an approximation of the exact solution (see Hugonnier et al., 2013, for details). Moreover, our benchmark case assumes that the three dependent variables are continuous. However, the observed risky holdings Π_j contain a significant share of zero observations. For that reason, we also experiment a mixture model specification in which the asset holdings variable is censored (Tobit) and the other two dependent variables (investment and income) are continuous, resulting in qualitatively similar results.[25]

5.2 Data

The database used for estimation is the 2002 wave of the Health and Retirement Study (HRS, Rand data files). This data set is the last HRS wave with detailed information on total health spending; subsequent waves only report out-of-pocket expenses. Under OOP ceilings, total health expenses I are not uniquely identified for insured agents. Even though the HRS contains individuals aged 51 and over, we restrict our analysis to elders (i.e. agents aged 65 and more), with positive financial wealth (9,817 observations, with mean age 75.3). In doing so, we avoid endogenizing the insurance choice X_t in (4) which can be considered as exogenous under near-universal Medicare coverage. Unfortunately, this data set does not include a consumption variable, so that we omit equation (13) from the econometric model.

[24] These alternative estimates, which are available upon request, are reasonably robust, with main interpretations qualitatively unaffected.

[25] Note however that our structural model neither rules out zero holdings, nor does predict a Tobit-based specification for the portfolio equation.

We construct financial wealth W_j as the sum of safe assets (checking and saving accounts, money market funds, CD's, government savings bonds and T-bills), bonds (corporate, municipal and foreign bonds and bond funds), retirement accounts (IRAs and Keoghs), and risky assets (stock and equity mutual funds) Π_j. Health status H_j is evaluated using the self-reported general health status, where we express the polytomous self-reported health variable in real values with increments of 0.75 corresponding to: 0.5 (poor), 1.25 (fair), 2.00 (good), 2.75 (very good), and 3.50 (excellent).[26]

Health investments I_j are obtained as the sum of medical expenditures (doctor visits, outpatient surgery, hospital and nursing home, home health care, prescription drugs and special facilities), and out-of-pocket medical expenses (uninsured cost over the two previous years). Finally, we resort to wage/salary income Y_j, to which we add any Social Security revenues. The estimates presented below are obtained for a scaling of 10^{-6} applied to all nominal variables (I_j, W_j, Π_j, Y_j).

We report the sample statistics in Table 1, while Table 2 reports the median values stratified by wealth quintiles, and self-reported health. Overall, these statistics confirm earlier findings. In particular, financial wealth seems to be relatively insensitive to health,[27] health investment increases slowly in wealth, but falls sharply in health,[28] whereas risky asset holdings are higher for healthier and wealthier agents.[29]

6 Results

We start with a presentation of the deep parameters estimates in Section 6.1, followed by an evaluation of the empirical relevance of Closing Down in Section 6.2. We close this section with a discussion of the implications of our results for policy in Section ??.

[26]Self-reported health has been shown to be a valid predictor of the objective health status (Benítez-Silva and Ni, 2008; Crossley and Kennedy, 2002; Hurd and McGarry, 1995).

[27]See Hugonnier et al. (2013); Michaud and van Soest (2008); Meer et al. (2003); Adams et al. (2003) for additional evidence.

[28]Similar findings with respect to wealth (e.g. Hugonnier et al., 2013; Meer et al., 2003; DiMatteo, 2003; Gilleskie and Mroz, 2004; Acemoglu et al., 2013) and health (e.g. Hugonnier et al., 2013; Smith, 1999; Gilleskie and Mroz, 2004; Yogo, 2009) have been discussed elsewhere.

[29]Similar positive effects of wealth on risky holdings have been identified in the literature (e.g. Hugonnier et al., 2013; Wachter and Yogo, 2010; Guiso et al., 1996; Carroll, 2002) whereas positive effects of health have also been highlighted (e.g. Hugonnier et al., 2013; Guiso et al., 1996; Rosen and Wu, 2004; Coile and Milligan, 2009; Berkowitz and Qiu, 2006; Goldman and Maestas, 2013; Fan and Zhao, 2009; Yogo, 2009).

6.1 Structural parameters

Table 3 reports the calibrated, and estimated deep parameters (panels a–d), the induced parameters that are relevant for the various subsets (panel e), as well as the sufficient conditions that are relevant to propositions 2, and 3 (panel f). The standard errors indicate that all the estimates are precisely estimated, and are significant at the 5% level.

First, the law of motion parameters in panel a are consistent with significant diminishing returns to the health production function ($\alpha = 0.69$). Moreover, depreciation is important ($\delta = 7.2\%$), and sickness is rather consequential, with an additional depreciation of $\phi = 1.1\%$ suffered upon realization of the health shock.

Second, in panel b the intensity parameters indicate a high, and significant likelihood of health shocks ($\lambda_{s0} = 0.29$). The death intensity (2) parameters reject the null of exogenous exposure to death risk ($\lambda_{m1}, \xi_m \neq 0$), validating the assumption that agent's health decisions are consequential for their expected life horizon. These parameters are also realistic with respect to expected longevity. In particular, Hugonnier et al. (2013) show that an age-t person's remaining life expectancy can be computed using:

$$\ell(H_{t-}) = (1/\lambda_{m0})(1 - \lambda_{m1}\kappa_0 H_{t-}^{-\xi_m}), \quad \text{where } \kappa_0 = [\lambda_{m0} - F(-\xi_m)]^{-1} > 0,$$

where $F(\cdot)$ is defined in (44). The average age in our HRS sample is 75.3 years which can be added to $\ell(H)$ to obtain the expected longevity as an out-of-sample validity check. The predicted value of 76.02 years is remarkably close to the expected lifetime in 2002.[30]

Third, the returns parameters (μ, r, σ_S) are calibrated at standard values in panel c. The income parameters of equation (3) are both significant, and indicative of a positive health effects on income ($\beta \neq 0$), while the the base income y_0 is estimated to a value of $8,200 in 2002 dollars. Fourth, the preference parameters in panel d suggest a significant subsistence consumption a of $12,700, which is larger than base income y_0. Both subsistence, and base income values are realistic.[31] Our estimate of the intertemporal elasticity ε is larger than one, as required for sufficient condition (34), and as identified by others using micro data.[32] Aversion to financial risk is realistic ($\gamma = 2.78$), whereas aversion to mortality and morbidity risks are calibrated in the admissible range

[30]The expected lifetimes for 2002 were 77.3 for all, 74.5 for men, and 79.9 for women (Arias, 2004).
[31]For example, the 2002 poverty threshold for elders above 65 was $8,628 (source: U.S. Census Bureau).
[32]For example, Gruber (2013) finds estimates centered around 2.0, relying on CEX data.

$(0 < \gamma_m < 1)$, and similar to the values set by Hugonnier et al. (2013). Finally, the subjective discount rate is set at usual values ($\rho = 2.5\%$). Overall, we conclude that the estimated structural parameters are economically plausible.

6.2 Induced parameters and relevance of closing down

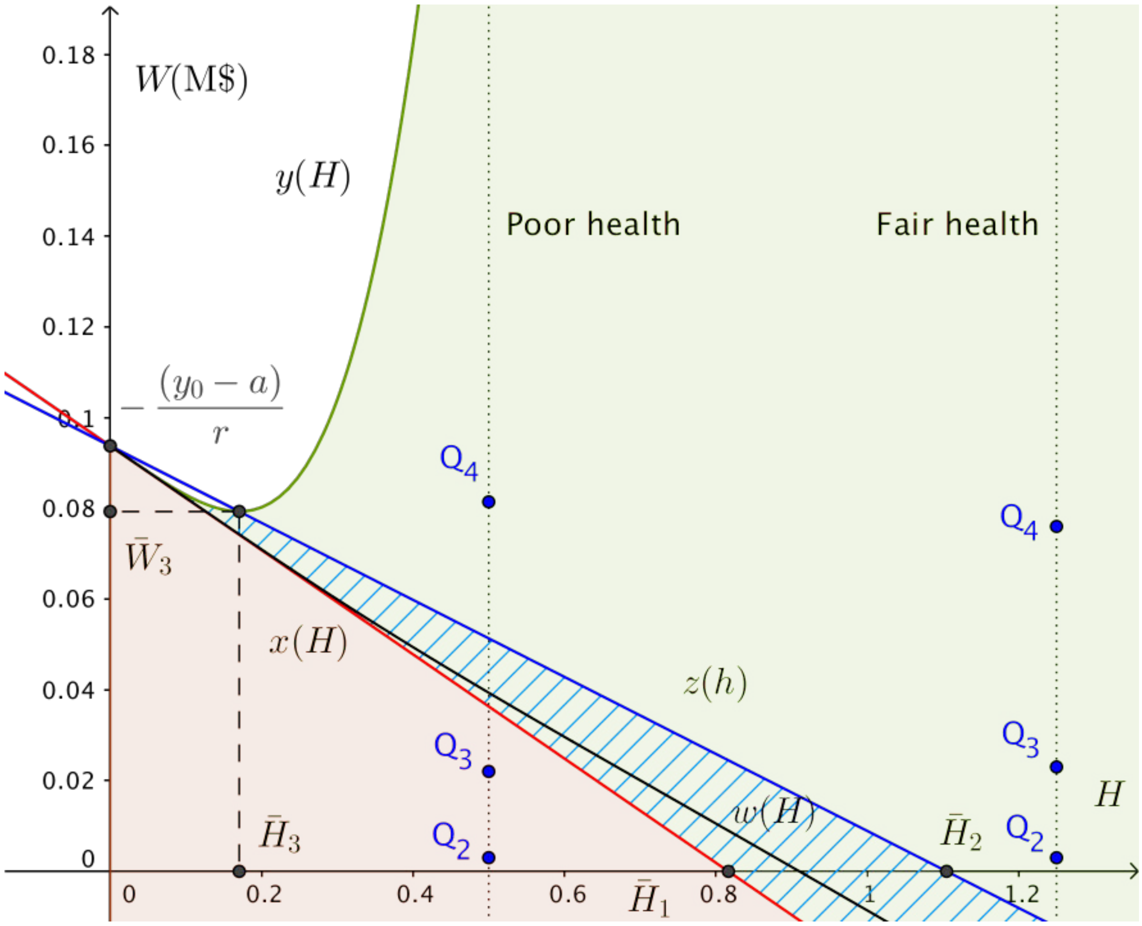
Table 3.e reports the induced parameters that are relevant for the admissible, depletion and accelerating subsets. Table 3.f shows that the two sufficient conditions for our theoretical results are verified at these induced parameters. These composite parameters allow us to evaluate the values of the four loci $x(H)$, $y(H)$, $z(H)$, and $w(H)$ at the various self-reported health levels in Table 4, and to plot the corresponding subsets in Figure 5 using the same scaling as the one for the estimation. Finally, we can rely on the joint distribution in Table 2 in order to plot the quintile values of wealth as blue dots for Q_i for the poor ($H = 0.5$), and fair ($H = 1.25$) health statuses.

First, the large negative value for $(y_0 - a)/r$ corresponds to a capitalised base income deficit of 92,900\$ in 2002 dollars, and confirms that condition (16) is verified. Moreover, we identify a relatively large marginal-Q of health $B = 0.1148$ in panel e, suggesting that health depletion can remain optimal despite health being very valuable.[33] Second, the value for D in Table 3.e is large, and significant. From the definition of $y(H)$ in (22), a large value of D also entails a very steep health depletion locus in Figure 5. It follows that its minimum is attained at a low $\bar{H}_3 = 0.1743$, with corresponding realistic value of $\bar{W}_3 = \$78{,}100$. Since this value is larger than most observed wealth levels (see Tables 1 and 2), it follows that the bulk of the population is located in the health depletion subset. Moreover, our estimates are consistent with a narrow accelerating region $\mathcal{AC}$. Indeed, the values for $B, (y_0 - a)/r, \xi_m$ are such that intercepts $\bar{H}_1, \bar{H}_2$ are relatively low (i.e. between Fair, and Poor self-reported health), and close to one another (less than one discrete increment of 0.75). This feature of the model is reassuring since we would expect accelerating phases where agents are cutting down expenses in the face of falling health to coincide with the very last periods of life where health is very low.

Finally, as expected from proposition 3, the estimated wealth depletion locus $w(H)$ is lying between the $x(H)$, and $y(H)$ loci. It is also very low, confirming that most of the

[33] Adapting the theoretical valuation of health in Hugonnier et al. (2013, Prop. 3) reveals that an agent at the admissible locus (i.e. with $N_0(W, H) = 0$) would value a 0.10 increment in health as $w_h(0.10, W, H) = 0.10. * B * 10^6 = \$11{,}480$.

Figure 5: Estimated depletion, accelerating, and non-admissible regions



Notes: Non-admissible set $\mathcal{NA}$: shaded red area under red $x(H)$ line. Health depletion set $\mathcal{D}_H$: shaded green area under green $y(H)$ green curve. Acceleration set $\mathcal{AC}$: hatched green area under blue $z(H)$ curve. Wealth depletion set $\mathcal{D}_W$: area above $w(H)$ black curve. Position of loci, and areas evaluated at estimated parameters in Table 3. Quintile levels for wealth quintiles $Q_2, \ldots Q_4$ are taken from Table 2, and are reported as blue points for health levels poor, and fair.

agents are also in the wealth depletion region. It follows that unless very wealthy, and very unhealthy, the bulk of the population would be located in the $(\mathcal{D}_H \cap \mathcal{D}_W)$ regions. Indeed, as Table 4 makes clear, *all* the population with at least a Fair level of health, and non-negative financial wealth is located in the joint health and wealth depletion. Put differently, our estimates unambiguously confirm the empirical relevance of optimal closing-down strategies.

6.3 Simulation analysis

The analysis presented thus far has completely abstracted from exogenous depletion processes associated with aging, and has focused upon local expected changes for health and wealth. To assess whether such small anticipated depletion translate into realistic life cycle paths for health and wealth, we conduct a Monte-Carlo simulation exercise described in further details in Appendix C. To summarize, the simulated life cycles draw initial health and wealth statuses from the observed joint distribution at age 75, and for a sample of 1,000 individuals. Next, for each period, a common financial shock is drawn, whereas agent-specific sickness, and death shocks are drawn using the corresponding exogenous morbidity, and the endogenous mortality Poisson distributions. The health and wealth statuses are updated via the theoretical optimal rules in proposition 1, and the process is replicated for 1,000 times. The sample means are finally computed using only the alive individuals at each age, and for separate sub-samples of poor (low initial wealth), and rich (high initial wealth) agents.

Figure 6 plots the resulting mean values for the optimal life cycles for financial wealth W_t (panel a), health level H_t (panel b), the share of survivors (panel c), as well as the net total wealth $N_0(W_t, H_t)$ (panel d). Unsurprisingly, these results confirm all our previous findings. Consistent with the data, our simulated life cycles feature a rapid end-of-life depletion of both health (Banks et al., 2015; Case and Deaton, 2005; Smith, 2007; Heiss, 2011), and wealth (De Nardi et al., 2015b; French et al., 2006). Indeed, the optimal strategy is to bring down net total wealth $N_0(W_t, H_t)$ to zero (i.e. reach the lower limits of admissible set $\mathcal{A}$) at terminal age at which stage agents are indifferent between life and death (panel d). This objective is attained by running down wealth (panel a) very rapidly (consistent with our finding of low $w(H)$ locus), and a somewhat slower decline for health (panel b). These pro-factual life cycle profiles confirm that the Closing Down model can reproduce the data even without the self-reinforcing incidence of biological aging.

Contrasting rich versus poor cohorts reveals that, as expected, wealth (panel a), and health (panel b) depletion is faster for the poor (in red, right-hand side axis) than for the rich (in blue, left-hand side axis), except towards age 80 where unhealthy poor agents have died, and only the healthy poor agents survive. The health differences with the rich are therefore attenuated with age through an attrition effect. The shortlived increase in wealth for poor and unhealthy agents after age 80 occurs as they exit the $\mathcal{D}_W$ region below the $w(H)$ locus. The joint health and wealth depletion means that low-wealth individuals approach the non-admissible subset more rapidly. Moreover, worse health entails that exposure to death risk is higher for the poor, resulting in lower survivorship (panel c), consistent with stylized facts.[34] These results again accord with the model predictions: poor and rich agents exhaust net total wealth and therefore become indifferent between life and death (panel d) by the time they approach the zero expected remaining lifetime. Put differently, our simulations indicate that agents entering the last period of life optimally select an expected lifespan given current health and wealth, and choose allocations that are consistent with optimal closing down. High initial wealth thus has a moderating effect on the speed of the depletion, but not on its ultimate outcome.

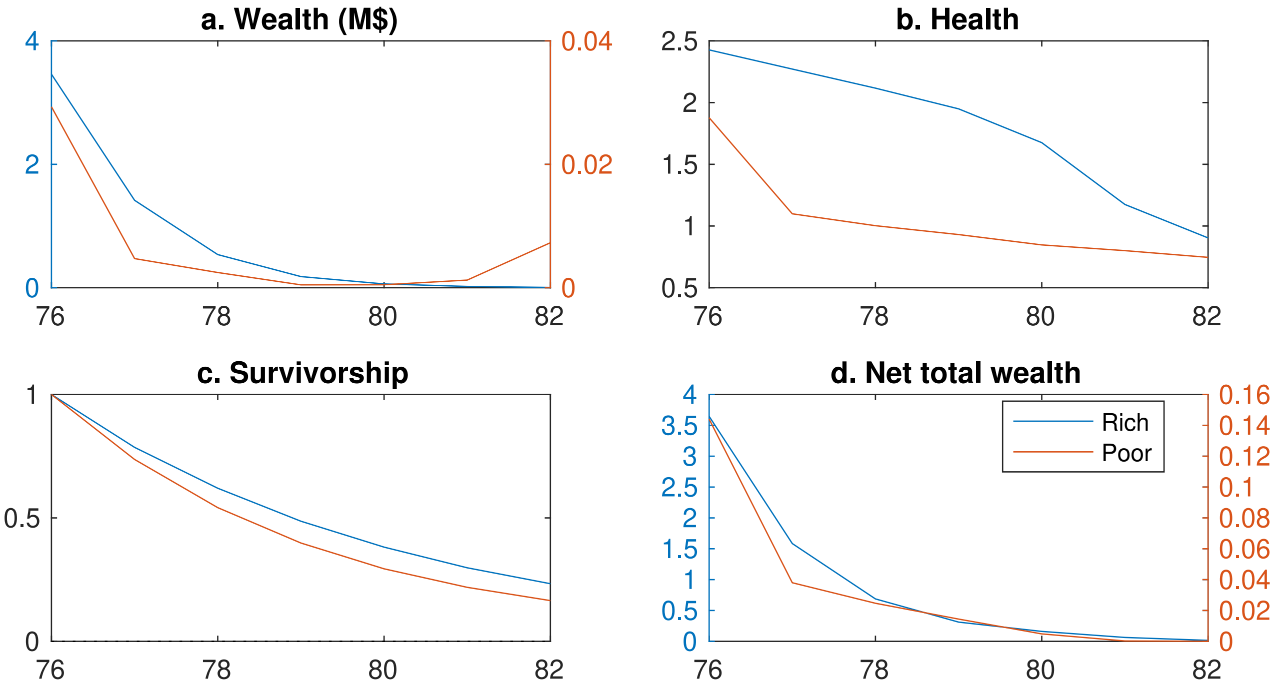


Figure 6: Simulated optimal paths

Notes: Mean values for simulated optimal life cycles taken over surviving admissible agents from an initial population of 1,000 agents with 1,000 replications. Rich ($W_{t=76} \geq 2^{nd}$ tercile, blue lines, left-hand scale in panels a, d), and poor ($W_{t=76} \leq 1^{st}$ tercile, red lines, right-hand scale in panels a, d).

[34] For example, longevity for males from a 1940 cohort in HRS based on deciles of career earnings are 73.3 years (1st decile), 77.9 (3rd decile), 81.8 (6th decile), and 84.6 (10th decile) (Bosworth et al., 2016, Tab. IV-4, p. 87).

7 Conclusion

Health status, and financial wealth both fall rapidly as agents approach the end of life. Traditional explanations for these joint dynamics emphasize inevitable biological declines in health that are induced by the aging process; falling wealth then results from uninsured spending on comfort care (e.g. long-term, or nursing home), rather than on insured curative care expenses.

We consider optimal dynamics that are complementary to those induced by biological deteriorations. We rely on analytical solutions to a life cycle model of optimal health spending and insurance, portfolio, and consumption to study these end-of-life paths. This framework allows us to elicit the conditions under which individuals may find it optimal to close down the shop. Despite a strict preference for life, this strategy involves depleting financial resources, as well as running down, and eventually accelerating the fall in their health, and leads them to a state where the probability of dying is high, and where agents are indifferent between life and death.

Unless they are sufficiently healthy and wealthy, we show that closing down is optimal when exogenous depreciation of their health capital, as well as exogenous mortality risk, or aversion to that risk are sufficiently high. To ascertain the economic relevance of our results, we perform a structural estimation of the life cycle model, relying on a sample of relatively old agents in the HRS. The results confirm two elements. First, the parametric restrictions tests confirm that closing down is *potentially* optimal. Second, they also show that this depletion strategy is *actually* optimal for the bulk of the population approaching the end of life.

Our discussion first reinstates realistic aging processes to show that the latter make our optimal dynamic strategies even more relevant. Put differently, aging is not a substitute to, but is a reinforcing complement to closing-down. Second, we show that removing the ability to adjust death risk exposure late in life does not fundamentally alter our key results. Finally, assuming such an objective is warranted, the incidence of closing down strategies could be reduced by increasing base income (e.g. through enhanced Social Security, Medicaid, or minimal revenue programs). However, whereas the positive arguments are readily obtained, the normative reasons for intervening are much less clear. Indeed, continuous depletion of the health stock leading to high death risks, and indifference between life and death is optimally selected, even in the case of agents with no predisposition for early death. Moreover, this downward spiral is obtained in a complete markets setting, such that no market failure argument for intervention can be invoked. Finally, end-of-life poverty is endogenously determined as an optimal state such that redistributive rationales for intervening cannot be made.

References

Acemoglu, Daron, Amy Finkelstein, and Matthew J. Notowidigdo (2013) 'Income and health spending: Evidence from oil price shocks.' *Review of Economics and Statistics* 95(4), 1079 – 1095

Adams, Peter, Michael D. Hurd, Daniel McFadden, Angela Merrill, and Tiago Ribeiro (2003) 'Healthy, wealthy, and wise? tests for direct causal paths between health and socioeconomic status.' *Journal of Econometrics* 112(1), 3–56

American Medical Association (2016) 'AMA policy on provision of life-sustaining medical treatment.' https://www.ama-assn.org/about-us/code-medical-ethics

Arias, Elizabeth (2004) 'United States life tables, 2004.' *National Vital Statistics Report* 53(6), 1–40

_ (2014) 'United States life tables, 2010.' *National Vital Statistics Report* 63(7), 1–62

Ayanian, John Z., Joel S. Weissmann, Eric C. Schneider, Jack A. Ginsburg, and Alan M. Zaslasky (2000) 'Unmet health needs of uninsured adults in the United States.' *Journal of the American Medical Association* 284(16), 2061–2069

Banks, James, Richard Blundell, Peter Levell, and James P. Smith (2015) 'Life-cycle consumption patterns at older ages in the US and the UK: can medical expenditures explain the difference?' IFS Working Papers W15/12, Institute for Fiscal Studies

Benítez-Silva, Hugo, and Huan Ni (2008) 'Health status and health dynamics in an empirical model of expected longevity.' *Journal of Health Economics* 27(3), 564–584

Benjamins, Maureen Reindl, Robert A Hummer, Isaac W Eberstein, and Charles B Nam (2004) 'Self-reported health and adult mortality risk: An analysis of cause-specific mortality.' *Social Science & Medicine* 59(6), 1297 – 1306

Berkowitz, Michael K., and Jiaping Qiu (2006) 'A further look at household portfolio choice and health status.' *Journal of Banking and Finance* 30(4), 1201–1217

Blau, David M., and Donna B. Gilleskie (2008) 'The role of employee health insurance in the employment behavior of older men.' *International Economic Review* 49(2), 475–514

Bommier, Antoine, Marie-Louise Leroux, and Jean-Marie Lozachmeur (2011) 'On the public economics of annuities with differential mortality.' *Journal of Public Economics* 95(78), 612 – 623

Bosworth, Barry P., Gary Burtless, and Kan Zhang (2016) 'Later retirement, inequality in old age, and the growing gap in longevity between rich and poor.' Economic Studies at Brookings, Brookings Institute

Bureau of Labor Statistics (2008) 'Older workers.' BLS Spotlight on statistics, U.S. Department of Labor, July

Byrne, Margaret M., and Peter Thompson (2000) 'Death and dignity: Terminal illness and the market for non-treatment.' *Journal of Public Economics* 76(2), 263 – 294

Carroll, Christopher D. (2002) 'Portfolios of the rich.' In *Household Portfolios,* ed. Luigi Guiso, Michael Haliassos, and Tullio Jappelli (Cambridge MA: MIT Press) chapter 10, pp. 389–429

Case, Anne, and Angus Deaton (2005) 'Broken down by work and sex: How our health declines.' In *Analyses in the Economics of Aging,* ed. David A. Wise (Chicago: University of Chicago Press) chapter 6, pp. 185 – 205

Coile, Courtney, and Kevin Milligan (2009) 'How household portfolios evolve after retirement: The effect of aging and health shocks.' *Review of Income and Wealth* 55(2), 226 – 248

Crossley, Thomas F., and Steven Kennedy (2002) 'The reliability of self-assessed health status.' *Journal of Health Economics* 21(3), 643–658

De Nardi, Mariacristina, Eric French, and John Bailey Jones (2009) 'Life expectancy and old age savings.' *American Economic Review* 99(2), 110–115

— (2015a) 'Savings after retirement: A survey.' Working Paper 21268, National Bureau of Economic Research, June

De Nardi, Mariacristina, Eric French, John Bailey Jones, and Jeremy McCauley (2015b) 'Medical spending of the U.S. elderly.' Working Paper 21270, National Bureau of Economic Research, June

DiMatteo, Livio (2003) 'The income elasticity of health care spending: A comparison of parametric and nonparametric approaches.' *European Journal of Health Economics* 4(1), 20–29

Duffie, Darrell, and Larry G. Epstein (1992) 'Stochastic differential utility.' *Econometrica* 60(2), 353–394

Fan, Elliott, and Ruoyun Zhao (2009) 'Health status and portfolio choice: Causality or heterogeneity?.' *Journal of Banking and Finance* 33(6), 1079 – 1088

Finkelstein, Amy, Erzo F.P. Luttmer, and Matthew J. Notowidigdo (2009) 'Approaches to estimating the health state dependence of the utility function.' *American Economic Review* 99(2), 116 – 121

— (2013) 'What good is wealth without health? The effect of health on the marginal utility of consumption.' *Journal of the European Economic Association* 11(s1), 221–258

French, Eric, and John Bailey Jones (2011) 'The effects of health insurance and self-insurance on retirement behavior.' *Econometrica* 79(3), 693–732

French, Eric, Mariacristina De Nardi, John Bailey Jones, Olesya Baker, and Phil Doctor (2006) 'Right before the end: Asset decumulation at the end of life.' *Federal Reserve Bank of Chicago Economic Perspectives* 30(3), 2 – 13

Gan, Li, Guan Gong, Michael Hurd, and Daniel McFadden (2015) 'Subjective mortality risk and bequests.' *Journal of Econometrics* 188(2), 514 – 525. Heterogeneity in Panel Data and in Nonparametric Analysis in honor of Professor Cheng Hsiao

Gilleskie, Donna B., and Thomas A. Mroz (2004) 'A flexible approach for estimating the effects of covariates on health expenditures.' *Journal of Health Economics* 23(2), 391 – 418

Goldman, Dana, and Nicole Maestas (2013) 'Medical expenditure risk and household portfolio choice.' *Journal of Applied Econometrics* 28(4), 527 – 550

Groneck, Max, Alexander Ludwig, and Alexander Zimper (2016) 'A life-cycle model with ambiguous survival beliefs.' *Journal of Economic Theory* 162(Supplement C), 137 – 180

Grossman, Michael (1972) 'On the concept of health capital and the demand for health.' *Journal of Political Economy* 80(2), 223–255

Gruber, Jonathan (2013) 'A tax-based estimate of the elasticity of intertemporal substitution.' *Quarterly Journal of Finance* 3(1), 1 – 20

Guiso, Luigi, Tullio Jappelli, and Daniele Terlizzese (1996) 'Income risks, borrowing constraints, and portfolio choice.' *American Economic Review* 86(1), 158–172

Hall, Robert E., and Charles I. Jones (2007) 'The value of life and the rise in health spending.' *Quarterly Journal of Economics* 122(1), 39–72

Heiss, Florian (2011) 'Dynamics of self-rated health and selective mortality.' *Empirical Economics* 40(1), 119 – 140

Hugonnier, Julien, Florian Pelgrin, and Pascal St-Amour (2013) 'Health and (other) asset holdings.' *The Review of Economic Studies* 80(2), 663–710

Hurd, Michael D. (1987) 'Savings of the elderly and desired bequests.' *American Economic Review* 77(3), 298–312

_ (2002a) 'Are bequests desired or accidental.' Working Paper Series DRU-3010, RAND, January

_ (2002b) 'Portfolio holdings of the elderly.' In *Household Portfolios,* ed. Luigi Guiso, Michael Haliassos, and Tullio Jappelli (Cambridge MA: MIT Press) pp. 431–472

Hurd, Michael D., and Kathleen McGarry (1995) 'Evaluation of the subjective probabilities of survival in the Health and Retirement Study.' *Journal of Human Resources* 30(0), s268–s292. Supplement

Hurd, Michael D., Daniel McFadden, and Angela Merrill (2001) 'Predictors of mortality among the elderly.' In 'Themes in the economics of aging' NBER Conference Report series (Chicago and London: University of Chicago Press) pp. 171–97

Kuhn, Michael, Stefan Wrzaczek, Alexia Prskawetz, and Gustav Feichtinger (2015) 'Optimal choice of health and retirement in a life-cycle model.' *Journal of Economic Theory* 158(Part A), 186 – 212

Laitner, John, and Henry Ohlsson (2001) 'Bequest motives: A comparison of sweden and the united states.' *Journal of Public Economics* 79(1), 205 – 236

Laporte, Audrey, and Brian S. Ferguson (2007) 'Investment in health when health is stochastic.' *Journal of Population Economics* 20(2), 423 – 444

Legal Advisors Committee of Concerns for Dying (1983) 'The right to refuse treatment: A model act.' *American Journal of Public Health* 73(3), 918–921

Love, David A., Michael G. Palumbo, and Paul A. Smith (2009) 'The trajectory of wealth in retirement.' *Journal of Public Economics* 93(1-2), 191–208

Marshall, Samuel, Kathleen M. McGarry, and Jonathan S. Skinner (2010) 'The risk of out-of-pocket health care expenditure at end of life.' Working paper 16170, National Bureau of Economic Research

Meer, Jonathan, Douglas L. Miller, and Harvey S. Rosen (2003) 'Exploring the health-wealth nexus.' *Journal of Health Economics* 22(5), 713–730

Michaud, Pierre-Carl, and Arthur van Soest (2008) 'Health and wealth of elderly couples: Causality tests using dynamic panel data models.' *Journal of Health Economics* 27(5), 1312–1325

National Center for Health Statistics (2012) *Health, United States, 2011: With Special Feature on Socioeconomic Status and Health* (Hyattsville, MD: United States

Department of Health and Human Services. Centers for Disease Controls and Prevention)

Palumbo, Michael G. (1999) 'Uncertain medical expenses and precautionary saving near the end of the life cycle.' *Review of Economic Studies* 66(2), 395–421

Park, Sojung, BoRin Kim, and Soojung Kim (2016) 'Poverty and working status in changes of unmet health care need in old age.' *Health Policy* pp. –. forthcoming

Pelgrin, Florian, and Pascal St-Amour (2016) 'Life cycle responses to health insurance status.' *Journal of Health Economics* 49, 79–96

Robson, Arthur J., and Hillard S. Kaplan (2007) 'Why do we die? Economics, biology, and aging.' *American Economic Review* 97(2), 492 – 495

Rosen, Harvey S., and Stephen Wu (2004) 'Portfolio choice and health status.' *Journal of Financial Economics* 72(3), 457–484

Skinner, Jonathan S., and John Wennberg (2000) 'How much is enough? efficiency and medicare spending in the last six months of life.' In *The Changing Hospital Industry: Comparing For-Profit and Not-for-Profit Institutions,* ed. David M. Cutler (University of Chicago Press) chapter 5, pp. 169–194

Smith, James P. (1999) 'Healthy bodies and thick wallets: The dual relation between health and economic status.' *Journal of Economic Perspective* 13(2), 145–166

_ (2007) 'The impact of socioeconomic status on health over the life-course.' *Journal of Human Resources* 42(4), 739 – 764

Toossi, Mitra (2015) 'Labor force projections to 2024: the labor force is growing, but slowly.' *Monthly Labor Review*

Tsai, Yuping (2015) 'Social security income and the utilization of home care: Evidence from the social security notch.' *Journal of Health Economics* 43, 45 – 55

Van Kippersluis, Hans, Tom Van Ourti, Owen O'Donnell, and Eddy van Doorslaer (2009) 'Health and income across the life cycle and generations in Europe.' *Journal of Health Economics* 28, 818–830

Wachter, Jessica A., and Motohiro Yogo (2010) 'Why do household portfolio shares rise in wealth?.' *Review of Financial Studies* 23(11), 3929 – 3965

Yogo, Motohiro (2009) 'Portfolio choice in retirement: Health risk and the demand for annuities, housing, and risky assets.' NBER Working Paper 15307, National Bureau Of Economic Research, September

A Parametric restrictions

A.1 Regularity and transversality restrictions

Define the following elements:

$$
\begin{aligned}
\chi(x) &= 1 - (1-\phi)^{-x}, \\
F(x) &= x(\alpha B)^{\frac{\alpha}{1-\alpha}} - x\delta - \lambda_{s0}\chi(-x), \\
L_m &= \left[(1-\gamma_m)(A - F(-\xi_m))\right]^{-1} > 0.
\end{aligned} \tag{44}
$$

The theoretical model is solved under three regularity and transversality conditions that are reproduced for completeness:

$$
\beta < \left(r + \tilde{\delta}\right)^{\frac{1}{\alpha}}, \tag{45}
$$

$$
\max\left(0; r - \frac{\lambda_{m0}}{1-\gamma_m} + \theta^2/\gamma\right) < A, \tag{46}
$$

$$
0 < A - \max\left(0, r - \frac{\lambda_{m0}}{1-\gamma_m} + \theta^2/\gamma\right) - F(-\xi_m), \tag{47}
$$

where $\tilde{\delta} = \delta + \phi\lambda_{s0}$, the consumption parameter A, and the price of health B, are defined in (51), and in (49).

A.2 Closed-form solutions for optimal rules parameters

The closed-form expression for the parameters in the optimal rules are obtained as follows. The parameters of the optimal investment in (11) are:

$$
\begin{aligned}
K &= \alpha^{\frac{1}{1-\alpha}} B^{\frac{\alpha}{1-\alpha}} \geq 0, \\
\mathcal{I}_1 &= \lambda_{m1}\left(\xi_m K/(1-\alpha)\right) L_m \geq 0,
\end{aligned} \tag{48}
$$

where the price of health $B \geq 0$ solves:

$$
\begin{aligned}
g(B) &= \beta - (r + \delta + \phi\lambda_{s0})B - (1 - 1/\alpha)\left(\alpha B\right)^{\frac{1}{1-\alpha}} \\
&= \beta - (r + \tilde{\delta})B + \left(\frac{1-\alpha}{\alpha}\right) BK = 0
\end{aligned} \tag{49}
$$

subject to:

$$g'(B) = -(r+\tilde{\delta}) + (\alpha B)^{\frac{\alpha}{1-\alpha}}$$
$$= -(r+\tilde{\delta}) + \frac{BK}{\alpha B} < 0. \tag{50}$$

Combining (49) and the sign restriction (50) thus implies that:

$$BK < \beta.$$

Finally, the insurance parameter in (12) is given as:

$$\mathcal{X}_1 = \lambda_{m1}\chi(\xi_m)\left(1/\gamma_s - 1\right)L_m \gtreqless 0,$$

while the consumption parameters in (13) are:

$$A = \varepsilon\rho + (1-\varepsilon)\left(r - \frac{\lambda_{m0}}{1-\gamma_m} + \frac{\theta^2}{2\gamma}\right) \geq 0, \tag{51}$$

$$\mathcal{C}_1 = \lambda_{m1}A(\varepsilon - 1)L_m \gtreqless 0. \tag{52}$$

A.3 Incorporating aging

Hugonnier et al. (2013, Thm. 3, 4) show that it is possible to adapt the model to allow time variation in certain key parameters. In particular, for age-dependent intensities, $\lambda_{m0t}, \lambda_{m1t}, \lambda_{s0t}, \lambda_{s1t}, \eta_t$, depreciation δ_t, ϕ_t, and health sensitivity of income β_t, the closed-form expressions for the optimal rules parameters become age-dependent as well. The parameters of the optimal investment in (11) are:

$$K_t = \alpha^{\frac{1}{1-\alpha}} B_t^{\frac{\alpha}{1-\alpha}} \geq 0,$$
$$\mathcal{I}_{1t} = \lambda_{m1}\left(\xi_m K_t/(1-\alpha)\right)L_{mt} \geq 0,$$

where the age-dependent marginal propensity to consume, and price of health solve:

$$\dot{A}_t = A_t^2 - \left(\varepsilon\rho + (1-\varepsilon)\left(r - \nu_{m0t} + \theta^2/(2\gamma)\right)\right)A_t,$$
$$\dot{B}_t = (r + \delta_t + \phi_t\lambda_{s0t})B_t + (1-1/\alpha)(\alpha B_t)^{\frac{1}{1-\alpha}} - \beta_t,$$

subject to the boundary condition:

$$\lim_{t\to\infty}(r - \nu_{m0t} + \theta^2/(2\gamma) - A_t) < 0,$$
$$\lim_{t\to\infty}((\alpha B_t)^{\frac{\alpha}{a-\alpha}} - r - \delta_t - \phi_t \lambda_{s0t}) < 0.$$

where we have set $\nu_{m0_t} = \lambda_{m0t}/(1-\gamma_m)$. The endogenous mortality adjustment term L_{mt} solves:

$$L_{mt} = \int_t^\infty e^{-\int_t^\tau (A_s - F_s(-\xi_m))ds} \lambda_{m1\tau}/(1-\gamma_m) d\tau,$$

subject to boundary condition:

$$\lim_{t\to\infty}(F_t(-\xi_m) - \max(0, r - \nu_{0t} + \theta^2/(2\gamma)) - A_t) < 0,$$

where:

$$\chi_t(x) = 1 - (1 - \phi_t)^{-x},$$
$$F_t(x) = x(\alpha B_t)^{\frac{\alpha}{1-\alpha}} - x\delta_t - \lambda_{s0t}\chi_t(-x)$$

The other age-dependent parameter for the insurance parameter in (12) is given as:

$$\mathcal{X}_{1t} = \lambda_{m1t}\chi_t(\xi_m)\left(1/\gamma_s - 1\right) L_{mt} \gtreqless 0,$$

while the age-dependent consumption parameter in (13) are:

$$\mathcal{C}_{1t} = \lambda_{m1t} A_t(\varepsilon - 1) L_{mt} \gtreqless 0.$$

B Proofs

B.1 Proposition 1

See Hugonnier et al. (2013, Thm. 2) for the general case, and evaluate the optimal policies at the restricted exogenous morbidity case $\lambda_{s1} = 0$.

B.2 Proposition 2

B.2.1 Health depletion

First, substituting the investment-to-capital ratio (18) in the expected local change for health (17), and using the definition of net total wealth (10) shows that:

$$\frac{1}{\mathrm{d}t}E_{t-}[\mathrm{d}H_t \mid W_{t-} = W, H_{t-} = H] = \left\{\left[BK + \mathcal{I}_1 H^{-\xi_m - 1} N_0(W, H)\right]^{\alpha} - \tilde{\delta}\right\} H,$$
$$< 0 \iff W < y(H) = x(H) + DH^{1+\xi_m},$$

where $D = \mathcal{I}_1^{-1}\left[\tilde{\delta}^{1/\alpha} - BK\right]$.

Assume that necessary and sufficient condition (21) is violated. Because $\mathcal{I}_1 > 0$ in (48), we have that $D < 0$. Consequently, we have that $y(H) \leq x(H), \forall H$, and it follows that

$$\mathcal{D}_H = \{(W, H) \in \mathcal{A} : W < y(H)\} = \emptyset.$$

Hence a non-empty health depletion set obtains if and only if restriction (21) is verified, under which $D > 0$.

Second, observe that the health depletion locus is characterized by:

$$y_H(H) = -B + (1 + \xi_m)DH^{\xi_m} \begin{cases} < 0, & \text{if } H < \bar{H}_3, \\ = 0, & \text{if } H = \bar{H}_3, \\ > 0, & \text{if } H > \bar{H}_3, \end{cases} \quad \text{and}$$
$$y_{HH}(H) = \xi_m(1 + \xi_m)DH^{\xi_m - 1} > 0.$$

The locus $y(H)$ is therefore convex, and U-shaped under condition (21), and attains a unique minimum at $\bar{H}_3$ in the (H, W) space, where $\bar{H}_3$ is given in (27), with corresponding wealth level $\bar{W}_3 = y(\bar{H}_3)$.

B.2.2 Acceleration

Taking the derivative of the investment-to-health ratio (18) with respect to H and rearranging shows that the accelerating region can be characterized by:

$$\begin{aligned} I_H^h(W,H) &= -(1+\xi_m)H^{-\xi_m-2}\mathcal{I}_1 N_0(W,H) + H^{-\xi_m-1}\mathcal{I}_1 B \\ &> 0 \iff W < z(H) = x(H) + \frac{BH}{1+\xi_m}. \end{aligned}$$

Since $B, \xi_m > 0$, $x(H) \leq z(H)$, i.e. this locus lies above the $x(H)$ locus, and is therefore admissible, i.e. $\mathcal{AC} \subset \mathcal{A}$. Observe furthermore that $z(0) = x(0) = y(0) = -(y_0 - a)/r$, and that:

$$z(H) - y(H) = H\left[\frac{B}{1+\xi_m} - DH^{\xi_m}\right] \begin{cases} > 0, & \text{if } H < \bar{H}_3 \\ = 0, & \text{if } H = \bar{H}_3 \\ < 0, & \text{if } H > \bar{H}_3 \end{cases}$$

again using the definition of $\bar{H}_3$ in (27). Consequently, the $z(H)$ locus is downward-sloping, has the same intercept and intersects $y(H)$ at its unique minimal value $\bar{H}_3$, and lies above (below) the $y(H)$ locus for $H < \bar{H}_3$ ($H > \bar{H}_3$). It follows that the acceleration set (i.e. the health depletion subset where $I_H^h > 0$) is the entire $\mathcal{D}_H$ for $H \in [0, \bar{H}_3]$, and otherwise the area between $y(H), z(H)$, as given in (24), and (25).

B.3 Proposition 3

B.3.1 Non-empty wealth depletion

Observing that the expected net return on actuarially fair insurance contracts (4) is zero, we can use the definition of net total wealth (10), and substitute the optimal investment (11), as well as the optimal consumption (13), and risky portfolio (14) in the expected local change for wealth (28) to obtain:

$$\begin{aligned} \frac{1}{\mathrm{d}t} E_{t-}[\mathrm{d}W_t \mid W_{t-} = W, H_{t-} = H] &= \{rW + k(H) - N_0(W,H)[l(H) + r]\} \\ &< 0 \iff Wl(H) > x(h)[l(H) + r] + k(H), \end{aligned}$$

where,

$$l(H) = \left[A - \frac{\theta^2}{\gamma} - r + (\mathcal{I}_1 + \mathcal{C}_1)\, H^{-\xi_m}\right],$$
$$k(H) = (y_0 - a) + H(\beta - BK),$$

as given in (30), (33).

Assume that necessary and sufficient restriction (30) is violated such that $l(H) < 0$, then $E_{t-}[\mathrm{d}W_t \mid W_{t-} = W, H_{t-} = H]/\mathrm{d}t < 0$ obtains if:

$$W < w(H) = \frac{x(H)[l(H) + r]}{l(H)} + \frac{k(H)}{l(H)}.$$

Since $l(H) < 0$, it follows that

$$w(H) \le x(H) \iff x(H)r + k(H) \ge 0.$$

Relying on the definition of $g(B)$ in (49), and from necessary and sufficient condition (21) shows that

$$\begin{aligned} x(H)r + k(H) &= H[\beta - B(r + K)] \\ &= HB[\tilde{\delta} - K/\alpha] \\ &= HB[\tilde{\delta} - (BK)^{\alpha}] > 0. \end{aligned}$$

When (30) is violated and $l(H) < 0$ the wealth depletion zone thus simplifies to:

$$\mathcal{D}_W = \{(W, H) \in \mathcal{A} : W < w(H)\} = \emptyset$$

since $w(H) \le x(H)$. Consequently, a non-empty wealth depletion set obtains if and only if restriction (30) is verified, and is delimited by:

$$\mathcal{D}_W = \{(W, H) \in \mathcal{A} : W > w(H)\},$$

where $w(H)$ is given by (32), as stated. It is straightforward to show that:

$$\lim_{H\to 0}\frac{l(H)+r}{l(H)}=1,\quad \lim_{H\to 0}\frac{k(H)}{l(H)}=0, \implies \lim_{H\to 0} w(H)=x(0)=-(y_0-a)/r$$

such that the $w(H)$ shares the same intercept with $x(H), y(H), z(H)$, and which is nonnegative under condition (16).

B.3.2 Non-empty joint health and wealth depletion

We can also show that conditions (26), (34), and (35) – that are sufficient for non-empty $\mathcal{D}_H, \mathcal{D}_W$ – are also sufficient for a non-empty joint depletion set ($\mathcal{D}_W \cap \mathcal{D}_H$). This simplifies to showing:

$$\begin{aligned} w(H) \leq y(H) &\iff rx(H)+k(H) \leq l(H)DH^{1+\xi_m} \\ &\iff \beta - Br - \tilde{\delta}^{1/\alpha} \leq DH^{\xi_m}\left[A-\frac{\theta^2}{\gamma}-r\right]+\mathcal{C}_1 D \end{aligned}$$

Since $\beta < \tilde{\delta}^{1/\alpha}$ under (26), the left-hand side is negative, whereas $D > 0$. Moreover (34) implies that $\mathcal{C}_1 \geq 0$, whereas the right-hand term in square bracket is also positive under condition (35). It follows that the right-hand side is positive, and consequently sufficient for $w(H) \leq y(H)$, as required.

B.4 Proposition ??

First, setting $\lambda_{m1} = 0$ results in the first-order adjustment $\mathcal{I}_1 = 0$ in (48). Consequently, the investment-to-capital ratio in (18) is constant, and given by $I^h = BK$. Substituting in (17) reveals that so is the expected growth rate:

$$E_{t-}[\mathrm{d}H_t] = \left[(BK)^{\alpha} - \tilde{\delta}\right] H_{t-}\mathrm{d}t,$$

and that the latter is negative under condition (21) for all admissible health and wealth levels. Consequently, the health depletion subset corresponds to the entire admissible set, as stated in (37). Moreover, a constant I^h implies that it is orthogonal to the health status; consequently no accelerating region exists as stated in (38).

Finally, setting $\lambda_{m1} = 0$ also sets $\mathcal{I}_1, \mathcal{C}_1 = 0$ in equation (30) for $l(H)$. Condition (35) implies that $l > 0$ in (40), and as showed in Appendix B.3, is necessary and sufficient for $\mathcal{D}_W \neq \emptyset$. The wealth depletion locus $w(H)$ is modified accordingly by using l in (39). Because the health depletion set is the entire admissible set, the conditions relating $w(H)$, and $y(H)$ are irrelevant, and the joint health and wealth depletion set is everywhere non-empty.

C Monte-Carlo simulation

The Monte-Carlo framework used to simulate the dynamic model is as follows:

1. Relying on a total population of $n = 1{,}000$ individuals, we initialize the health and wealth distributions at base age $t = 75$ using the observed unconditional distribution for health $\mathcal{P}(H)$, as well as the conditional wealth distribution $\mathcal{P}(W \mid H)$.

2. We simulate individual-specific Poisson health shocks $\mathrm{d}Q_s \sim P(\lambda_{s0})$, as well as a population-specific sequence of Brownian financial shocks $\mathrm{d}Z \sim N(0, \sigma_s^2)$ over a 10-year period $t = 75, \ldots, 85$.

3. At each time period $t = 75, \ldots, 85$, and using our estimated and calibrated parameters:

   (a) For each agent with health H_t, we generate the Poisson death shocks with endogenous intensities $\mathrm{d}Q_m \sim P[\lambda_m(H_t)]$, and keep only the surviving agents, with positive wealth (as imposed in the estimation) for the computation of the statistics.

   (b) We verify admissibility, for each agent with health and wealth (H_t, W_t) and keep only surviving agents in the admissible region.

   (c) We use the optimal rules $I(W_t, H_t), c(W_t, H_t), \Pi(W_t, H_t), X(H_{t-})$, as well as income function $Y(H_t)$, and the sickness and financial shocks $\mathrm{d}Q_{st}, \mathrm{d}Z_t$ in the stochastic laws of motion $\mathrm{d}H_t, \mathrm{d}W_t$.

(d) We update the health and wealth variables using the Euler approximation:

$$H_{t+1} = H_t + \mathrm{d}H_t(H_t, I_t, \mathrm{d}Q_{st})$$
$$W_{t+1} = W_t + \mathrm{d}W_t\left[W_t, c(W_t, H_t), I(W_t, H_t), \Pi(W_t, H_t), X(W_t, H_t), \mathrm{d}Q_{s,t}, \mathrm{d}Z_t\right]$$

4. We replicate the simulation 1–3 for 1,000 times.

5. We rely on age-76 wealth to separate sub-samples as:

   - Poor: $W_{76} \leq$ first tercile,
   - Rich: $W_{76} \geq$ second tercile,

   in order to compute the sub-sample means using only agents who are alive, and within the admissible subset.

D Tables

Table 1: HRS data statistics

	Mean	Std. dev.	Min	Max
Wealth (W)	12 739	35 318	0.1	1 001 201
Investment (I)	1 840	4 604	0	113 449
Risky holdings (Π)	6 965	29 239	0	1 000 000
Income (Y)	3 884	5 527	0	131 212
Health (H)	2.03	0.86	0.5	3.5
Age (t)	75.29	7.51	65	107

Notes: Statistics for HRS data (in 2002 $ for nominal variables) used in estimation. Scaling for self-reported health is 0.5 (Poor), 1.25 (Fair), 2.00 (Good), 2.75 (Very good), and 3.5 (Excellent).

Table 2: HRS data statistics (cont'd)

Variable	Wealth quintile				
	1	2	3	4	5
	a. Poor health ($H = 0.5$)				
Financial wealth (W)					
- Quintile	0.000	0.051	0.075	0.519	100.012
- Median	0.000	0.030	0.220	0.814	2.930
Investment (I)	0.379	0.417	0.469	0.427	0.615
Risky holdings (Π)	0.005	0.079	0.216	0.485	0.800
	b. Fair health ($H = 1.25$)				
Financial wealth (W)					
- Quintile	0.000	0.030	0.210	0.983	71.000
- Median	0.000	0.030	0.230	0.760	3.400
Investment (I)	0.255	0.254	0.233	0.252	0.266
Risky holdings (Π)	0.000	0.046	0.253	0.514	0.782
	c. Good health ($H = 2.0$)				
Financial wealth (W)					
- Quintile	0.010	0.100	0.402	1.407	45.000
- Median	0.000	0.040	0.220	0.770	3.300
Investment (I)	0.157	0.149	0.156	0.129	0.168
Risky holdings (Π)	0.002	0.082	0.299	0.510	0.824
	d. Very good health ($H = 2.75$)				
Financial wealth (W)					
- Quintile	0.040	0.222	0.720	2.100	71.000
- Median	0.000	0.040	0.230	0.840	3.500
Investment (I)	0.100	0.112	0.106	0.105	0.107
Risky holdings (Π)	0.011	0.107	0.368	0.604	0.854
	e. Excellent health ($H = 3.5$)				
Financial wealth (W)					
- Quintile	0.050	0.280	0.874	2.800	100.120
- Median	0.000	0.050	0.210	0.800	3.820
Investment (I)	0.137	0.065	0.063	0.105	0.091
Risky holdings (Π)	0.010	0.131	0.350	0.520	0.861

Notes: Quintile, and median values of wealth, and mean values (investment, risky holdings), measured in 100K$ (year 2002) per health status, and wealth quintiles for HRS data used in estimation.

Table 3: Estimated and calibrated parameter values

Parameter	Value	Parameter	Value	Parameter	Value
		a. Law of motion health (1)			
α	0.6940^{*}	δ	0.0723^{*}	ϕ	0.011^{c}
	(0.1873)		(0.0366)		
		b. Sickness and death intensities (2)			
λ_{s0}	0.2876^{*}	λ_{m0}	0.2356^{*}		
	(0.1419)		(0.0844)		
λ_{m1}	0.0280^{*}	ξ_m	2.8338^{*}		
	(0.0108)		(1.1257)		
		c. Income and wealth (3), (5)			
y_0	$0.0082^{*\$}$	β	0.0141^{*}		
	(0.0029)		(0.0059)		
μ	0.108^{c}	r	0.048^{c}	σ_S	0.20^{c}
		d. Preferences (6), (7)			
a	$0.0127^{*\$}$	ε	1.6738^{*}	γ	2.7832^{*}
	(0.0063)		(0.6846)		(1.3796)
ρ	0.025^{c}	γ_m	0.75^{c}	γ_s	7.40^{c}
		e. State space subsets (15), (23), (25), (32)			
$(y_0 - a)/r$	$-0.0929^{*\$}$	B	0.1148^{*}	$\bar{H}_1$	0.8093^{*}
D	4.5088^{*}	$\mathcal{I}_1$	0.0053^{*}	K	0.0022^{*}
$\bar{H}_3$	0.1743^{*}	$\bar{W}_3$	$0.0781^{*\$}$	$\bar{H}_2$	1.0460^{*}
$\mathcal{C}_1$	0.1115^{*}	A	0.6336^{*}		
		f. Sufficient conditions (26), (35) (must be negative)			
$\beta - \tilde{\delta}^{1/\alpha}$	-0.0086^{*}	$\theta^2/\gamma + r - A$	-0.5533^{*}		

Notes: *: Estimated structural and induced parameters (standard errors in parentheses), significant at 5% level; *c*: calibrated parameters; \$: In \$M.

Table 4: Estimated values of loci

Level	H	% Pop.	$\mathcal{A}$ $x(H)$	$\mathcal{D}_H$ $y(H)$	$\mathcal{AC}$ $z(H)$	$\mathcal{D}_W$ $w(H)$
Poor	0.50	10.7	0.04	0.35	0.05	0.04
Fair	1.25	21.1	−0.05	10.56	−0.01	−0.03
Good	2.00	31.5	−0.14	64.15	−0.08	−0.11
Very good	2.75	26.9	−0.22	217.74	−0.14	−0.18
Excellent	3.50	9.9	−0.31	549.12	−0.20	−0.26

Notes: Values (in MM$) of admissible $\mathcal{A} : W \geq x(H)$; health depletion $\mathcal{D}_H : W < y(H)$; accelerating $\mathcal{AC} : W < \min[y(H), z(H)]$; and wealth depletion $\mathcal{D}_W : W > w(H)$ at observed health levels.