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## A Health Economic Theory of Occupational Choice, Aging, and Longevity

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# A Health Economic Theory of Occupational Choice, Aging, and Longevity

Holger Strulik*

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**Abstract.** In this paper, I propose a life cycle model of occupational choice with endogenous health behavior, aging, and longevity. Health-demanding work leads to a faster accumulation of health deficits and is remunerated with a hazard markup on wages. Health deficit accumulation is also influenced by unhealthy consumption and health care expenditure. I calibrate the model for a 20 year old average American in 2010 and show the following results, among others. Health-demanding work is ceteris paribus preferred by male, young, and healthy individuals with a relatively low level of education. Health demanding work has a negligible effect on health behavior because income and health investment effects largely offset each other, implying that health effects can be attributed almost fully to the direct health burden of work. Better medical technology induces low-skilled individuals to spend a greater part of their life in health-demanding work and thus increases the health gradient of education. High wealth endowments protect against unhealthy occupational choices. I show robustness of the results in an extension of the model with regard to endogenous retirement.

*Keywords:* occupational choice, health behavior, health deficits, aging, longevity, retirement .

*JEL:* D15, I10, I12, J24, J26.

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# 1. Introduction

There is a growing empirical literature on the relationship between individual occupation and health and longevity but as yet there exists no economic theory of occupational choice and its interaction with health behavior and the accumulation of health deficits. In this paper, I fill this gap by integrating occupational choice in the health deficit model of Dalgaard and Strulik (2014). The health deficit model is a life cycle model with physiological aging and endogenous longevity derived from basic principles of human biology and gerontology. Health deficits are measured by the frailty index (Mitnitski and Rockwood, 2002; Searle et al., 2006). Basic versions of the health deficit model implement the feature that the accumulation of health deficits can be slowed down with health care expenditure and accelerated with unhealthy consumption. Here, we take additionally into account that there is an occupation-specific health toll of work. Individuals can choose between an occupation with relatively low return to education and a high health burden and an occupation with high return to education and low health burden. The occupation with high health burden can be conceptualized as (heavy) manual labor.

Health-demanding work leads to a faster accumulation of health deficits and is rewarded with a hazard markup on wages. Although individuals are allowed to change their occupation hence and forth from one time increment to the next, it will be derived that optimally chosen occupations are changed at most twice in the course of the work life and in most cases only once or never. Occupations can thus be conceptualized as life-course careers. Another decisive feature of the model is that labor productivity decreases with the accumulation of health deficits, which provides a natural explanation for a falling wage-for-age curve for elderly workers. Maintaining a healthy body for work thus provides an additional motive for health investments and healthy behavior (beyond the desire for a long life and the direct utility impact of health status).

I calibrate the model for an average American man and an average American woman and show that health-demanding work is ceteris paribus preferred by male, young, and healthy individuals with a relatively low level of education. I show that, for given preferences and initial health, individuals in health-demanding work accumulate health deficits faster than individuals in less-health demanding work. If, however, low-skilled individuals who prefer health-demanding work are forced to take up less health-demanding work, their health deteriorates even faster. This perhaps surprising result is motivated by two mechanisms: (i) in less health-demanding work, the incentive is lower to stay healthy in order to maintain high productivity, (ii) healthy individuals with low levels of education earn less in less-health demanding work. They thus consume less and experience greater marginal utility from consumption. As the marginal utility from instantaneous consumption increases, the incentive declines to invest in health and to reduce unhealthy consumption.

This paper takes up the discussion by Case and Deaton (2005) and resolves some of the problems raised in explaining occupation-related aging. Case and Deaton adopt a simple version of the health capital model (Grossman, 1972) and conclude that, in addition to some general problematic features it is in particular not well suited to explaining the interactions between individual health status and occupational choice. For example, the health capital model implies that, controlling for education, heavy labor is more likely to be undertaken by unhealthy people and that the health gradient between manual and nonmanual workers diminishes with age. Case and Deaton (2005) identify the counterfactual assumption of health capital depreciation as the main cause of the counterfactual implications of the model, a view also emphasized by McFadden (2005). The health capital model conceptualizes aging as loss of health capital, which depreciates at a certain rate ($\delta$) as individuals grow older such that $H(t+1) = (1-\delta(t))H(t)$, in which $H(t)$ is the health capital stock at age $t$. The depreciation rate $\delta(t)$ may be constant or increasing in age. The health capital model implies that when comparing two individuals of the same age, the individual in better health experiences a faster deterioration in health. This feature generates convergence. It implies that differences in early-life circumstances (fetal origins) are depreciated away as individuals grow older (Almond and Currie, 2011) and that differences of health-burden in early work life are depreciated away in later work life and retirement. Gerontological research, however, supports the opposite: the existence of many health deficits is conducive to the faster development of new health deficits (Mitnitski et al., 2006, Gavrilov and Gavrilova, 1991). The self-productive feature of health deficit accumulation is visible as an exponential increase in health deficits with age (Mitnitski et al., 2002; Mitnitski and Rockwood, 2016; Harttgen et al., 2013; Abeliansky and Strulik, 2018; Abeliansky et al., 2020).

The health deficit model generates the self-productive feature of health deficit accumulation (Dragone and Vanin, 2021). It thus predicts that the health gradient between manual and nonmanual workers increases with age, as observed by Case and Deaton (2005) and confirmed by Abeliansky and Strulik (2021) when health status is measured by the frailty index. The health deficit model furthermore predicts that the health gradient will continue to rise in retirement, after the negative health effects of hard work are gone. The reason is the self-productive nature of health deficit accumulation: manual workers enter retirement with more health deficits, which are conducive to the faster development of additional health deficits.

Aside from eliminating the problematic assumptions and predictions of Case and Deaton's (2005) health capital model of occupational choice, I also extend the theory in various directions. I allow health to affect the age at death and introduce the desire for longevity as an important driver of health behavior and occupational choice. I introduce a retirement period in order to investigate health effects of occupation after retirement. The analysis begins with an exogenous retirement age and is then generalized toward an endogenous choice of retirement in order to investigate the interaction between occupation and retirement. Most importantly, I calibrate the model for an average American man and woman and quantitatively examine the determinants of occupational choice and their impact on health behavior and health outcomes over the life cycle.

The calibrated benchmark individual prefers to spend the whole work life in an occupation with low health burden. An otherwise identical individual with 20 percent less education prefers to spend the first 80 percent of the work life in an occupation with high health burden. The model predicts almost no difference in health behavior (health investments and unhealthy consumption) between the two individuals. The reason is that individuals in health-demanding work have an additional incentive to stay in good health in order to maintain high productivity and to delay leaving the (better paid) health-demanding work. This effect offsets the effect of lower income on health behavior. It means that the predicted health gradient (the individual in health demanding work dies 3 years earlier) can be fully attributed to the direct health burden of work. There is almost no indirect effect from health behavior. Women are predicted to abandon (better paid) health-demanding work earlier in life. This is because women, according the model's calibration, value instantaneous consumption less than men and good health and a long life more than men. Low-skilled women are predicted to lose about half as much life expectancy as men due to health-demanding work.

Less healthy individuals, ceteris paribus, are predicted to engage less or never in health-demanding work and a high wealth endowment protects individuals from choosing unhealthy occupations. Medical progress is predicted to widen health disparities by education and occupation. This is because medical progress motivates low-skilled individuals to stay longer in health-demanding work, which partly offsets the decelerating effect of medical progress on health deficit accumulation.

Aside from Case and Deaton's (2005) study there is hardly any formal discussion of occupational choice in health economics. Cropper (1977) proposes a simple life cycle model of optimal exposure to pollution and Galama and Van Kippersluis (2019) discuss how the optimal level of job-related stress varies over the life cycle. Both models are formulated in the health capital framework. While Cropper focusses explicitly on pollution, Galama and Van Kippersluis develop a comprehensive and flexible state-of-the-art model of health capital accumulation, in which job-related stress is just one of many applications. Cropper predicts that individuals optimally choose high exposure to pollution as young and old workers and low exposure in middle age while Galama and Van Kippersluis predict that individuals optimally choose high stress levels in middle age and low stress as young and old workers. Aside from its setup in the health deficit framework, the present paper differs conceptually from these studies due to its focus on occupations as lifetime careers, which are changed only occasionally and perhaps never. In contrast to the available studies, the focus is on the determinants of occupational choice in a calibrated model and the impact of occupational choice on health behavior and health outcomes over the life cycle.[1]

The empirical literature on occupational health effects begins with the influential work of Michael Marmot (and coauthors). Based initially on longitudinal studies of British civil servants and then extended in other directions, Marmot argues that occupational status is mainly associated with health status due to job-related stress, social status, and a sense of being in control of one's life (e.g. Marmot et al., 1991, 1997, Marmot, 2005). Mackenbach et al. (2003) showed that that ratio of mortality rates for manual and non-manual workers increased over time in a sample of six European countries. An early health-economic study by Gueorguieva et al. (2009) examined self-rated health for a sample of older workers from seven waves of the Health and Retirement Survey (HRS) and found health effects of occupation on the level of health but not on the speed of aging. Fletcher et al. (2011) constructed measures of physical demands and environmental stress of job characteristics for a sample of US households and found negative effects on self-reported health of individuals working in jobs with high physical

[1] The paper is also more broadly related to other studies that investigate health behavior and health outcomes in the context of endogenous longevity, e.g. Grossman (1972); Ehrlich and Chuma (1990); Ehrlich (2000); Murphy and Topel (2006); Hall and Jones (2007), and Kuhn et al. (2011, 2015).

demands or harsh conditions, in particular for women and older workers. Morefield et al. (2011) investigated health transitions and observe that workers in physically more demanding jobs are more likely to transit from good to bad health but do not have different probabilities of health improvements. As Case and Deaton (2005), they found that the health differential between blue and white collar workers increases with age. The observed health transitions are consistent with the health deficit model when health transitions are conceptualized as a Markov chain (Mitnitski et al., 2006; Grossmann and Strulik, 2019).

Kelly et al. (2014) examined occupational effects on health behavior and found that blue collar work early in life is associated with increased probabilities of obesity and smoking, and decreased physical activity later in life. Combining data from the health and retirement study with expert ratings of job demands, Schmitz (2016) provided evidence for a persistent health gap between blue and white collar workers, which loses significance after controlling for physical and psychosocial job demands. Ravesteijn et al. (2016) investigated health satisfaction in a panel of German workers. Controlling for individual fixed effects, they showed that health of blue collar workers declines more strongly with age than that of white collar workers, corroborating the results from Case and Deaton and Morefield et al. An increasing health gradient is also observed when occupations are classified according to the degree of physical workload and by degree of job control. Controlling for selection by lagged health, they argue that at least 60 percent of the association between occupation and health is explained by selection. Nicholas et al. (2020) show that lifetime exposure to occupational demands affects health and disability later in life. Abeliansky and Strulik (2021) computed the frailty index for individuals from a panel of European countries and found that blue collar workers, workers with little education, and workers in occupations with high physical or psychosocial burden display more health deficits and accumulate health deficits faster. While the age-occupation interaction loses significance with entry into retirement, workers in occupations of high health burden continue to age faster in retirement because they entered retirement with more health deficits. The presence of many health deficits in retirement leads to faster aging due to the self-productive nature of health deficit accumulation.

A problem that is emphasized in nearly all empirical studies is endogenous selection into occupations. The present paper provides an alternative approach to identify selection effects by computing comparative dynamics of the calibrated model. Computational experiments make it possible to observe life cycle behavior and health outcomes of one and the same individual twice, in the self-selected (optimal) occupation and in another life with a pre-assigned occupation.

The remainder of the paper is organized as follows. In the next Section, I set up the model and derive the dynamic equations that govern life cycle behavior and occupational choice. In Section 3, the model is calibrated for an average 20-year-old American man in the year 2010. Section 4 presents the main results. In Section 5, the model is extended to include an endogenous retirement decision. In Section 6, the model is applied to occupational choice and health behavior of women. Section 7 concludes the paper.

## 2. The Model

Individuals allocate their labor supply to more or less health-demanding occupations. At any time, individuals have one unit of labor at their disposal. If they work, they choose the share $z$ of time allocated to health demanding work, $0 \leq z \leq 1$. Suppose the return on education is higher in less health-demanding occupations and that, controlling for education, experience, and health status, the markup of wages is higher in health-demanding occupation, i.e. that there is markup for occupational health hazards (see Rosen, 1986, for the theory of compensating wage differentials). Specifically let $w_0$ denote a base wage and $m_j(S, D, t)$ the markup in occupation $j$ of the base wage depending on schooling $S$, health deficits $D$, and experience (age) $t$; $j \in \{L, H\}$ indicates the health burden of the occupation, which may be low ($L$) or high ($H$). The negative impact of health deficits on wages ($\partial m_j / \partial D < 0$) captures productivity effects of aging and health effects on income from sick leave. Let $\psi$ denote the hazard markup such that labor income of an individual with education $S$, age $t$, and health deficits $D$ is obtained as

$$w(S, D, t) = w_0 \left[ z \psi m_H(S, D, t) + (1 - z) m_L(S, D, t) \right]. \tag{1}$$

The health toll of occupations is integrated into the health deficit model (Dalgaard and Strulik, 2014, Strulik, 2018) which, based on foundations in gerontology, assumes that individuals accumulate health deficits in a quasi-exponential way, i.e. that exponential growth of health deficits $D$ can be reduced by health investment $h$ and amplified by unhealthy consumption $u$. In order to focus on occupational choice we assume that education is a given parameter (see Strulik, 2018, for endogenous education in the health deficit model). Here we additionally take into account that working in unhealthy conditions leads to the accumulation of more health deficits. Specifically, health deficits evolve according to

$$\dot{D} = \mu \left( D - Ah^{\gamma} + Bu^{\omega} + Ez - a \right), \tag{2}$$

in which $\mu$ is the (natural) force of aging. The parameters $A > 0$ and $0 < \gamma < 1$ characterize the state of medical technology and the parameters $B > 0$ and $\omega > 1$ characterize the unhealthiness of unhealthy consumption; $a$ is an environmental constant (a residual). The new part here is the contribution of unhealthy work $z$ to health deficit accumulation, which is measured by the parameter $E > 0$. The assumption that $z$ contributes linearly to health deficits together with the feature that (1) is also linear in $z$ will lead to bang-bang solutions for labor allocation (see below for details). This means that, at any instant of time, all labor is either fully allocated to health-demanding work ($z = 1$) or not at all ($z = 0$). This feature creates plausible working life patterns in which individuals work either fully engaged in health demanding work (e.g. in construction or coal mining) or in less health-demanding work (office work).

Individuals work until retirement at which point they will receive a pension of $w_R$ based on their previous labor income $w$. We neglect labor supply at the intensive margin and in the benchmark model furthermore assume that retirement is exogenous. This restrictive assumption is made for expositional purpose, in order to disentangle mechanisms, and it will be abolished in the extended model. Individuals spend their income on health neutral consumption $\tilde{c}$, unhealthy consumption $u$, health care $h$ and saving for retirement and health expenditure in old age such that their budget constraint is given by

$$\dot{k} = rk + w\ell + w_R(1 - \ell) - \tilde{c} - qu - p\phi h, \tag{3}$$

in which $k$ is household wealth, $r$ is the interest rate, $q$ is the price of unhealthy goods, $p$ is the price of health care, $\phi$ is the out-of-pocket ratio, and $\ell$ is an indicator function that assumes the value of 1 when the individual is working and 0 otherwise.

Individuals experience utility from consumption and disutility from work. We assume a constant elasticity of intertemporal substitution for aggregate consumption $c$, which is conceptualized as a weighted sum of health neutral and unhealthy consumption, $c \equiv \tilde{c} + \alpha u$, in which $\alpha$ is the utility weight (preference) for unhealthy consumption. Lifetime utility is thus given by

$$V = \int_0^T \mathrm{e}^{-\rho t} \left[ \left( \frac{\mathrm{D}}{D} \right)^{\epsilon} \frac{(\tilde{c} + \alpha u)^{1-\sigma} - 1}{1 - \sigma} - \beta \ell \right] \mathrm{d}t,$$

in which $\rho$ is the time preference rate, $\beta$ is the weight for disutility from work, and $1/\sigma$ is the elasticity of intertemporal substitution. Following Finkelstein et al. (2013) and Schuenemann et al. (2017a), we assume that (marginal) utility of consumption is reduced by the accumulation of health deficits. The parameter $\underline{\mathrm{D}}$ normalizes for a reference state of (best) health. The parameter $\epsilon$ controls by how much an additional health deficit affects the marginal utility from consumption. The age at death $T$ is endogenous and reached when $\bar{D}$ health deficits have been accumulated, $D(T) = \bar{D}$. Death is treated as a deterministic event since, in this context, the consideration of stochastic death adds little further insights (see e.g. Schuenemann et al., 2017b). The deterministic setup reduces complexity and helps to focus on the interesting issues of occupational choice. Individuals thus have three reasons to stay in good health: utility, productivity, and longevity.[2]

Individuals maximize lifetime utility by controlling consumption, savings, health investments, and the choice of occupation. The associated current-value Hamiltonian is given by

$$H = \left(\frac{\underline{\mathrm{D}}}{D}\right)^{\epsilon} \frac{(\tilde{c} + \alpha u)^{1-\sigma} - 1}{1 - \sigma} - \beta\ell + \lambda_D \mu \left(D - Ah^{\gamma} + Bu^{\omega} + Ez - a\right)$$
$$+ \lambda_k \left(rk + w\ell + w_R(1 - \ell) - \tilde{c} - qu - p\phi h\right),$$

with $w$ as in (1) and in which $\lambda_k$ and $\lambda_D$ are the shadow prices of wealth and health deficits. Notice that health deficits contribute negatively to welfare such that $\lambda_D < 0$. The first order conditions for $c$, $u$, and $h$ are:

$$(\tilde{c} + \alpha u)^{-\sigma} \left(\frac{\underline{\mathrm{D}}}{D}\right)^{\epsilon} = \lambda_k \tag{4}$$

$$\alpha \left(\tilde{c} + \alpha u\right)^{-\sigma} \left(\frac{\underline{\mathrm{D}}}{D}\right)^{\epsilon} = \lambda_k q + \lambda_D \mu B \omega u^{\omega - 1} \tag{5}$$

$$-\lambda_D \mu \gamma A h^{\gamma - 1} = \lambda_k \phi p. \tag{6}$$

The left-hand sides of the first order conditions show the marginal benefits and the right-hand sides the marginal costs. Equation (4) equates the marginal utility from consumption with the marginal cost from consumption, which is one unit of savings evaluated at the shadow price of wealth $\lambda_k$. Equation (5) equates the marginal utility from unhealthy consumption with the

[2]A fourth, here neglected motive arises if the disutility from work depends on the state of health, for example through (untreated) chronic pain. See Strulik (2021) for an introduction of pain and pain treatment into health economic theory. See Cutler et al. (2020) on the differential experience of pain by socioeconomic status.

marginal costs in terms of wealth and health. Equation (6) requires that the marginal benefit of health investments equals the marginal cost. The marginal cost consists of the monetary expenditure evaluated at the shadow price of wealth.

Since objective function and constraints are linear in $z$, optimal occupational choice has a bang-bang solution:

$$z = \begin{cases} 1 & \text{if } \lambda_k w_0 \left[\psi m_H(S,D,t) - m_L(S,D,t)\right] > -\lambda_D \mu E \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

The result is straightforward to interpret: Individuals supply labor in the health-demanding occupation if the net benefit (the left-hand side of (7)) exceeds the health toll $\mu E$, evaluated with the shadow price of health $\lambda_D$ (recall that the shadow price of health deficits is negative). By inserting (6) into (7) both shadow prices can be eliminated and we arrive at a quantitatively accessible solution for occupational choice:

$$z = \begin{cases} 1 & \text{if } w_0 \left[\psi m_H(S,D,t) - m_L(S,D,t)\right] > \frac{E}{\gamma A h^{\gamma-1}/(\phi p)} \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

Health-demanding work is chosen if the net payoff (on the left hand side) is larger than a measure of net costs (on the right hand side). Net costs are measured by additional health deficits accumulated by another increment of health demanding work ($E$) divided by the net marginal return of health investments, which is the marginal return of a unit of health investments ($\gamma \alpha h^{\gamma-1}$) divided by the cost of a unit of health investments ($\phi p$). Intuitively, individuals are, for given net payoff, more motivated to perform health-demanding work if the health damage from work is easily repaired, which is the case when the marginal return of health investment is high and/or health investments are not expensive.

The solution implies that at any given time increment (e.g., at the same day), individuals work in exactly one occupation which is either associated with a high health burden or a low health burden. If health-demanding work had a non-linear effect on health, the step function would be lost as a general feature of occupational choice. For plausible parameterizations of the model, individuals would then choose an interior value of $z$, i.e. they would be occupied simultaneously in health-demanding and non-health-demanding work and they would gradually adjust the $z$-level as they become older and more frail. In this case, it would be harder to associate $z$ with the choice of an occupation. Nevertheless, the results are qualitatively identical and quantitatively similar to those of the linear case discussed in the main text (see Appendix A.4).

Note that the linearity assumption and the implied step function (8) do not prevent individuals from changing their occupation continuously (e.g. hence and forth from one day to the next). In fact, however, it will turn out that the calibrated individuals prefer to change their occupation only occasionally and under a broad set of circumstances (model parameter values) individuals change their occupation never. This feature, which provides a plausible description of most lifetime careers, can be proven more generally under some additional assumptions.

PROPOSITION 1. *Suppose (i)* $\partial m_H/\partial t \leq \partial m_L/\partial t$, *(ii)* $\partial m_H/\partial D \leq \partial m_L/\partial D$, *(iii)* $m_j$ *concave in* $t$ *for* $j \in \{H, L\}$, *and (iv) there is a* $t = \bar{t}$ *with* $m_H(\bar{t}) = m_L(\bar{t}) = 0$. *Then, in any optimal life history, in which health deficits and health expenditure increased with increasing age, individuals had changed their occupation no more than twice.*

Condition (i) requires that the return to experience in health-demanding work is not larger than in non-health-demanding work, condition (ii) requires that negative impact of health deficits on productivity is not smaller in absolute terms in health-demanding work. Condition (iii) requires that the wage-for-age curves are either hump-shaped (namely when increasing experiences initially dominates the negative impact of physiological aging) or falling throughout the work life. Condition (iv) assumes that there is an age (which may be arbitrarily high) at which productivity in both occupations is zero. The proof of the proposition is in the Appendix A.1. The intuition for the result is that "life is smooth". Health deficits are continuously accumulated, which requires more health expenditure, experience grows continuously, and productivity is continuously harmed by physiological decline. In such a life, a discontinuity entailed by a change of occupations becomes desirable only occasionally and perhaps never. The same intuition can be applied to explain why actual life histories may be characterized by more frequent occupational changes: in these cases, life was not "smooth" and the experience of drastic shocks required the reoptimization of occupational choices.

A typical career of a low-skilled worker in the model begins in a health-demanding occupation (mining, construction). Advancing chronological age increases productivity through experience while physiological aging reduces productivity due to accumulated health deficits. When the negative health effects become too strong, the worker retires or switches to a less health-demanding occupation (driver, janitor).

As shown in Appendix A.2, the first order conditions and the associated co-state equations can be summarized as follows:

$$u = \max\left\{0,\ \left[\frac{(\alpha-q)\gamma A h^{\gamma-1}}{p\phi\omega B}\right]^{\frac{1}{\omega-1}}\right\} \tag{9}$$

$$\frac{\dot{c}}{c} = \frac{r-\rho-\epsilon\dot{D}/D}{\sigma} \tag{10}$$

$$\frac{\dot{h}}{h} = \frac{1}{1-\gamma}\left\{r-\mu+\frac{\mu\epsilon\gamma A h^{\gamma-1}c^{\sigma}}{\phi p D}\left(\frac{c^{1-\sigma}-1}{1-\sigma}-\beta\ell\right)+\frac{\mu\gamma A h^{\gamma-1}}{\phi p}\ell w_0\left[z\psi\frac{\partial m_H}{\partial D}+(1-z)\frac{\partial m_L}{\partial D}\right]\right\} \tag{11}$$

with $c \equiv \tilde{c}+\alpha u$. Equation (9) shows that unhealthy consumption requires that the preference for the unhealthy good is strong enough compared to the price $(\alpha - q > 0)$ and that unhealthy consumption declines in unhealthiness of the good $(B)$ and increases in the net marginal return of health investments $\gamma A h^{\gamma-1}/(p\phi)$. Equation (10) provides the standard consumption Euler equation (the Ramsey rule) and equation (11) is the health Euler equation obtained by Dalgaard and Strulik (2014) plus two extra terms. The original health Euler equation required the interest rate to be higher than the natural rate of health deficit accumulation, $r > \mu$ for health expenditure to rise over the life cycle. The first additional term captures the effect of health deficits on utility and the second extra term captures the effect of health deficits on the return to work, $\partial m_j/\partial D$. Since $\partial m_j/\partial D < 0$, the impact of health on the return to work leads a lower growth rate of $\dot{h}/h$ than in the standard model. The reason is that health investments are more effective when individuals are young and healthy. The second additional term matters only during the work life (for $\ell = 1$).

The full model consists of the system of equations (1)–(11), the initial values $D(0) = D_0$ and $k(0) = k_0$, the final values $D(T) = \bar{D}$ and $k(T) = \bar{k}$, and the transversality condition $H(T) = 0$, which together determine the unique solution for the lifetime trajectories of $c$ and $h$ and the age at death $T$. The transversality condition $H(T) = 0$ is the boundary condition that needs to hold for problems of free terminal time (here the age at death), see Hartl and Sethi (1983) for derivation and detailed discussion of the transversality condition.

## 3. Calibration

Because the model has no analytical solution, I solve it numerically with the relaxation method of Trimborn et al. (2008). The relaxation method solves the non-linearized dynamic system (1)–(11) with a user-defined error of approximation, which is set to $10^{-5}$. For the benchmark case, I set $k_0 = \bar{k} = 0$, i.e., the benchmark individual receives no inheritance and leaves no bequest. The model is calibrated for U.S. American men and women. We first consider the life cycle choices and health outcomes of men. The calibrated benchmark American starts life in the year 2010 at model-age 0 when he is 20 years old. He has a high school degree and some college education, summing up to $S = 14$ (which is slightly above the median years of education of 21-year-old Americans in the 1990s; Fischer and Hout, 2006).

The calibration builds to a great extent on previous calibrations of the health deficit model. To calibrate the new element, occupational choice and its impact on health deficits, I parameterize equation (1) as

$$w = w_0 \left[ z\psi \mathrm{e}^{\theta_H S} \mathrm{e}^{g_H t} \mathrm{e}^{-\nu_H D} + (1-z) \mathrm{e}^{\theta_L S} \mathrm{e}^{g_L t} \mathrm{e}^{-\nu_L D} \right]. \tag{12}$$

The calibration of (12) is partly inspired by the Mincer (1972) equation. The parameter $\theta_j$ is the return to education in occupations with high and low health burden. In order to calibrate it, I conceptualize $H$–occupations as manual work with high physical health burden and low return to education whereas $L$–occupations are characterized by low physical health burden and a higher return to education. I then associate $H$–occupations with blue collar work and $L$–occupations with white collar work and use the estimates of Keane and Wolpin (1997) to calibrate $\theta_H = 0.024$ and $\theta_L = 0.070$. It should be noted, however, that the association of health burden and collar color works perfectly only when high-burden occupations are chosen by low-skilled individuals and low–burden occupations are chosen by high-skilled individuals. If low–burden occupations are chosen by low-skilled individuals the work could be manual with low health burden (e.g. driver, janitor) or non-manual with low health burden (sales person, office clerk). I will discuss the blue collar assignment extensively in Section 4.6. High-skilled workers, on the other hand, will never select into work with high physical health burden and low return to education. We could thus assume that the return to education in $H$–occupations applies only up to an upper limit of education (e.g. that there is no return beyond a high school diploma in woodcutting) without affecting the solution.

The age terms in Mincer-type regressions are typically associated with experience. Here, I allow them to encompass all age or time relevant influences, which include in particular the progression of labor-augmenting technological change during the work life. The wage equation is hump-shaped in age in the original Mincer-equations because "experience squared" enters negatively. This reduced-form modeling should be regarded as a large simplification since it is hard to imagine that workers have accumulated "too much experience", which reduces their productivity. The term "experience squared" is thought to capture deteriorating health that reduces productivity as workers age. Here, this feature is taken into account directly by modeling the impact of health deficits ($D$) on wages. This view is supported by Dalgaard et al. (2020) who show that, across countries, labor productivity increases monotonously in the share of elderly workers once health deficits are controlled for. The values of $g_L$ and $\nu_L$ are calibrated such that wages follow the age path implied by the estimates of the experience-terms in Keane and Wolpin (1997). This leads to $g_L = 0.046$ and $\nu_L = 40$.

Health-demanding occupations are characterized by a great variety of age-earning profiles. For example, there is little indication of declining wages in construction work while wages in coal mining decline mildly after 10 years and steeply after 20 years of employment (PayScale, 2020). I assume $g_H = g_L$ and $\nu_H = \nu_L$, which means that the only force that leads to an earlier decline of wages in health-demanding occupations is the entailed faster accumulation of health deficits. I adjust $\psi$ such that the benchmark American would earn as much in an occupation with high health burden as in an occupation with low health burden, which leads to the estimate $\psi = 1.9$. This calibration target is consistent with the fact that a construction worker earns about as much as an office clerk (DataUSA, 2020). It implies that the benchmark American selects an occupation with low health burden.

For the benchmark model with exogenous retirement, I set the retirement age to 65.5, corresponding with the current retirement age of American men (CRR, 2018). I set $w_0$ such that the mean labor income predicted for age 20 to age 30 equals the average labor income for single men in the year 2010 (BLS, 2011), i.e $ 27,928 (BLS, 2011). From age 65 onwards, individuals earn a pension of 40 percent of the wage previous to retirement, which implies for the benchmark worker a net replacement rate in terms of lifetime earnings of about 43 percent, which reflects the U.S. median replacement rate for social security benefits and retirement (Biggs and Springstead, 2008). Finally, I use from Abeliansky and Strulik (2021) the estimate that men who worked in occupations with high physical burden have accumulated at age 65 about 11 percent more health deficits than men in occupations with low burden. Targeting this value in the calibration leads to the estimate $E = 0.0012$.[3]

The remainder of the calibration follows closely the calibration in Dalgaard and Strulik (2014) and Schuenemann et al. (2017a). In the year 2010, the average life expectancy of a 20-year-old American male was 57.1 years, i.e the expected age at death was 77.1 (NVSS, 2014). I set $\mu = 0.043$, according to the estimate of the force of aging for Canadian men in Mitnitski et al. (2002a), and $r = 0.07$ as estimated by Jorda et al. (2017) for the long-run rate of return on equity and real estate. Health deficits are measured by the health deficit index (i.e. the share of potential health deficits exhibited by the individual). Initial health deficits are obtained as health deficits at age 20 from the estimate of Mitnitski et al. (2002), $D_0 = 0.027$ and final health deficits are obtained as health deficits at the time of death, i.e. $D(77.1) = 0.106$, according to Mitnitski et al. (2002a). I set $\underline{D}$ to 0.027. I set $\phi = 0.28$ according to the average out-of-pocket share at all ages (Machlin and Carper, 2014) and normalize the effective price of health care $\phi p$ to one. I set $\rho = 0.07$ such that consumption is almost constant over the life cycle (as observed for childless households, Browning and Ejrnæs, 2009). The calibration targets total health expenditure ($ph$) of American men in 2010 at the age of 30, 50, and 70 (MEPS, 2010). Unhealthy consumption $u$ is conceptualized as smoking. On average, single male Americans spent \$ 364 on cigarettes in the year 2010 (BLS, 2012). The smoking intensity declines with age by about factor 2 from age 25 to age 50 (Holford et al., 2014). Since many individuals quit smoking as they get older, smoking prevalence declines as well, by about factor 2.5 between age 25 and age 50. I try to capture the combined effect of declining intensity and declining prevalence for the calibrated average American whose smoking intensity thus declines by factor 5 (i.e. by 80%) from age 25 to age 50.

Summarizing, the parameter values of $A$, $a$, $B$, $\alpha$, $\gamma$, $\epsilon$, $\sigma$, and $\omega$, are jointly calibrated to fit the following stylized facts: (i) the model predicts the actual accumulation of health deficits over a lifetime (as estimated by Mitnitski et al., 2002a); (ii) death occurs at the moment when $\bar{D}$ health deficits have been accumulated at an age of 77.1 years (the expected age of death form 20 year old men in 2010); (iii-v) health expenditure matches health care expenditure of American

[3] The calibrated health damage should be interpreted with caution, as it is difficult to identify the causal impact of health-demanding work on health in empirical work. Empirical differences in health deficits by occupation may reflect not just the health toll of work, but also behavioral differences that are modelled separately in the theory.

men in 2010 at the age of 30, 50, and 70 (MEPS, 2010); (v-vi) average smoking expenditure of American men and the feature that expenditure declines by 80 percent between ages 25 and 50; (vii) a value of life of \$ 9 million, which corresponds with the empirical estimate of the statistical value of life used by the US Department of Transportation (2013).[4] This leads to the estimates $A = 0.000155$, $a = 0.0135$, $B = 10^{-7}$, $\alpha = 5.8$ $\gamma = 0.19$, $\epsilon = 0.02$, $\sigma = 1.12$, and $\omega = 1.20$.

While most of the calibrated parameters are latent, the estimated value of $\sigma$ accords well with studies suggesting that the intertemporal elasticity of substitution is close to unity (Chetty, 2006; Layard et al., 2008). The estimate of $\gamma$ coincides with the estimate in Dalgaard and Strulik (2014). The estimates for $B$ and $\omega$ imply that smoking shortens the length of life of the benchmark American by 2.2 years. To assess this prediction properly, notice that we calibrated an average American and not an average smoking American. The average American spends much less on cigarettes than the average smoking American. If a pack of cigarettes costs \$ 6 and contains 20 cigarettes, the average American smokes about 3 to 4 cigarettes per day. Among those who smoke daily in the year 2000, however, 39 percent smoked between 15 and 24 cigarettes and 16 percent smoked more than 24 cigarettes per day (American Lung Association, 2011). Empirical estimates consider the health costs of smoking for the average smoker. and estimate a range from 2.5 years (Preston et al., 2010) to 10 years (Jha et al., 2013) of life lost due to smoking. The health toll calibrated for the benchmark American's smoking intensity thus corresponds best to the estimates at the upper end of the empirical estimates. Most of the parameter estimates are similar to Schuenemann et al. (2017a). In particular, the health elasticity of marginal utility $\epsilon$ is estimated to be quite low for men. This means that, for men, the utility motive plays a minor role for health behavior compared to the longevity and productivity motive.

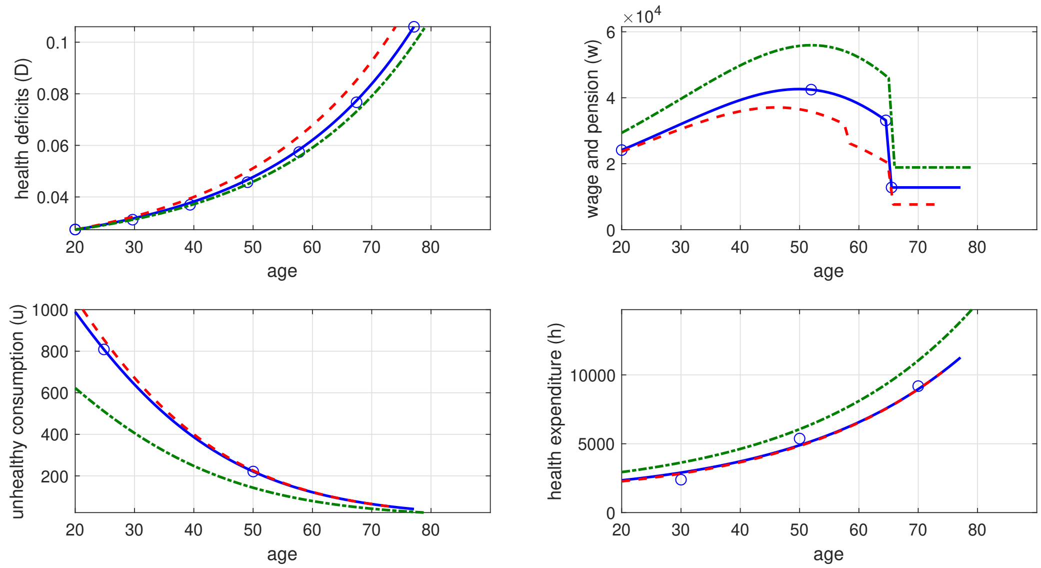
## 4. Results

4.1. **Baseline Results.** The predicted lifetime trajectories for health deficits, labor income, unhealthy consumption, and health care expenditure for the Reference American are shown by blue (solid) lines in Figure 1. Circles indicate targeted data points. Red (dashed) lines show the predicted behavior of an otherwise identical individual with 20 percent lower level of education

[4]The value of life is obtained by applying the methodology of Murphy and Topel (2006), i.e. I compute expected life time utility evaluated at the initial marginal utility from consumption, $\int_0^T \mathrm{e}^{-\rho\tau} u[c(\tau), D(\tau), R(\tau)]\mathrm{d}\tau)/u_c[c(0), D(0), R(0)]$.

(i.e. $S = 11.2$). While the benchmark individual has been calibrated to choose a non-health-demanding occupation, the less educated individual turns out to prefer health-demanding work in young and middle age. Due to the lower education, the net payoff of health demanding work is larger than the health costs; the left hand side in (7) is larger than the right hand side. At about age 58, health and productivity have eroded so much that the individual optimally changes to a non-health-demanding occupation, which he keeps until retirement at age 65.

Figure 1: Occupational Choice, Health Behavior, and Health Outcomes: Men




Blue (solid) lines: Reference American ($z = 0$). Red (dashed lines): 20% lower level of education. Green (dash-dotted) lines: 20% level of education. Circles: targeted data points, see text for details.

The two bottom panels in Figure 1 show health behavior. They reveal that health behavior of the benchmark individual and the individual in health-demanding occupation virtually coincide (the red dotted curve lies above the blue solid curve). This feature is the outcome of two countervailing effects. On the one hand, the individual is poorer than the benchmark individual and thus a long life is less desirable compared to pressing instantaneous consumption needs. This feature has been explored in detail in Hall and Jones (2007) and, in the context of the health deficit model, in Dalgaard and Strulik (2014). It is built on the fact that marginal utility from instantaneous consumption is declining in the level of consumption while lifetime utility is linear in life years of consumption. This means that richer individuals find it less attractive to further increase instantaneous consumption compared to investments in a long life. In turn, poorer individuals are predicted to spend less on health care and more on unhealthy consumption. On the other hand, individuals in health-demanding occupations have an additional incentive for

Table 1: Comparative Dynamics and Sensitivity Analysis: Men

| case | parameter change | remark | $\Delta u/u$ | $\Delta h/h$ | $\Delta T$ | $\Delta V/V$ | mean($z$) |
|---|---|---|---|---|---|---|---|
| 1 | $\Delta S = -20\%$ | lower level of education | 0.09 | -0.07 | -3.11 | -0.08 | 0.82 |
| 2 | $\Delta S = +20\%$ | higher level of education | -0.38 | 0.28 | 1.91 | 0.24 | 0.00 |
| 3 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | -0.20 | 0.17 | 7.08 | 0.20 | 1.00 |
| 4 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 0.47 | -0.23 | -10.2 | -0.27 | 0.64 |
| 5 | case 1 and $k_0 = \$0.2$ mill. | wealthier individual | -0.59 | 0.51 | 0.06 | 0.39 | 0.75 |
| 6 | case 1 and $k_0 = \$1.0$ mill. | much wealthier individual | -0.94 | 3.21 | 9.48 | 2.39 | 0.00 |
| 7 | $\phi = 1$ | no health insurance | 0.00 | -0.80 | -4.42 | -0.05 | 0.00 |
| 8 | $\phi = 1$ and case 1 | no health insurance and low edu | 0.11 | -0.81 | -6.87 | -0.12 | 0.72 |
| 9 | $\phi = 1$ and case 2 | no health insurance and high edu | -0.38 | -0.74 | -3.14 | 0.17 | 0.00 |
| 10 | $\alpha = 13$ | heavy smoker | 2.45 | 0.85 | -5.13 | 0.55 | 0.00 |
| 11 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 2.91 | 0.73 | -6.59 | 0.45 | 0.00 |
| 12 | $\alpha = 13$ and case 2 | heavy smoker and high edu. | 1.85 | 1.13 | -2.96 | 0.77 | 0.00 |
| 13 | $\Delta w_0 = +20\%$ | higher income level | -0.36 | 0.26 | 1.80 | 0.22 | 0.00 |
| 14 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | -0.30 | 0.17 | -1.60 | 0.12 | 0.88 |
| 15 | $\Delta w_0 = +20\%$ and case 2 | higher income level and high edu. | -0.62 | 0.65 | 3.55 | 0.54 | 0.00 |
| 16 | $\Delta A = +20\%$ | medical progress | 0.00 | 0.31 | 5.59 | 0.07 | 0.00 |
| 17 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 0.08 | 0.22 | 1.50 | -0.02 | 0.96 |
| 18 | $\Delta A = +20\%$ and case 2 | medical progress and high edu. | -0.38 | 0.70 | 8.53 | 0.34 | 0.00 |

The table shows the predicted deviation of health behavior and health outcomes from the calibrated benchmark individual. $\Delta T$ is measured in years, $\Delta u/u$, $\Delta h/h$, and $\Delta V/V$ are relative deviations; $\Delta V/V$ can be read, alternatively, as relative change in lifetime utility or relative change in the value of life. The mean($z$)–column shows the fraction of the total work life spent in health-demanding occupation.

healthy behavior. Health investments and a low level of unhealthy consumption help to sustain a healthy body and to delay the move to a lower paid occupation in less-health demanding work. This mechanism is perhaps most obvious for professional athletes. The model predicts that the two countervailing forces almost balance each other in their impact on health behavior. This means that almost all differences in health outcomes can be attributed to the direct health effects from physically demanding work.

Green (dash-dotted) lines in Figure 1 show health behavior and health outcomes for an individual with 20 percent higher level of education. Since both the better educated individual and the benchmark American work in less health-demanding occupations, the health-preserving incentive for occupational purpose is missing for both and only the longevity incentive is present. Consequently, the better educated and richer individual is predicted to invest more in health and to abstain more from unhealthy consumption.

In order to facilitate the subsequent analysis of comparative dynamics, I summarize lifetime health behavior and health outcomes in 5 simple aggregates, as shown in Table 1. I report averages of lifetime unhealthy consumption and health investment and express them in terms of relative deviation from the benchmark American ($\Delta u/u$, $\Delta h/h$). I report the deviation in age of death from benchmark $\Delta T$ and the implied relative deviation in lifetime utility or the value of life ($\Delta V/V$). Finally, I report the fraction of work years spent in health-demanding work. Case 1 in Table 1 provides these aggregates for the individual with 20% less education than the benchmark individual. This individual is predicted to spend 9 percent more on unhealthy consumption and 7 percent less on health care than the Reference American. The individual is predicted to spend 82 percent of his work life in a health-demanding occupation, to experience 8 percent less lifetime utility, and to die 3 years earlier than the Reference American. Given the small deviation in health behavior, the deviation in longevity can be explained almost entirely by the physical demands of the occupation.

Case 2 shows the lifetime aggregates for the individual with 20 percent more education than the benchmark individual. This individual consumes 38 percent less unhealthy goods, invests 28 percent more in health, lives about 2 years longer, and enjoys 24 percent higher lifetime utility. Since the individual does not differ in occupational choice from the Reference American, the gain in longevity is entirely explained by health behavior.

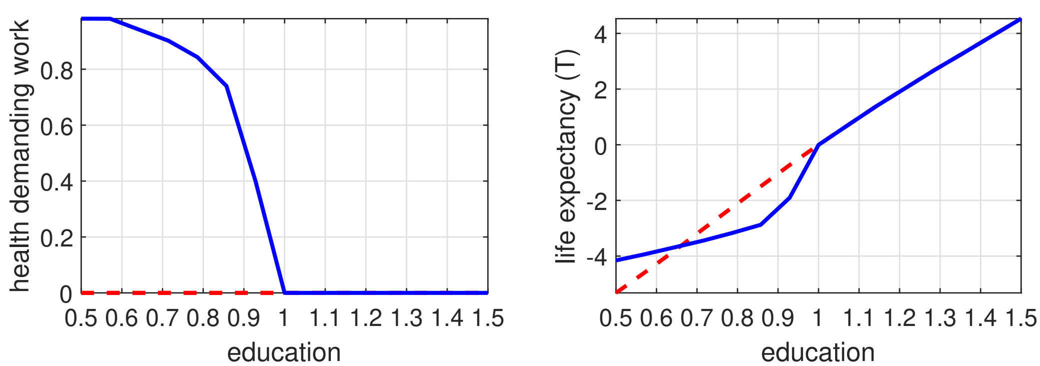
4.2. **Divergence of Health Deficits.** The health deficit model predicts that health deficits by age across occupations diverge before *and* after retirement (see the upper left panel of Figure 1). The reason is that individuals in health-demanding occupations have developed more health deficits at the age of retirement. After retirement, the negative impact of work on deficit accumulation is gone but the self-productive nature of health-deficit accumulation persists. Controlling for behavior, individuals accumulate $\mu D(t)$ new health deficits at each time increment such that there is divergence: individuals who were unhealthier at age of retirement age faster in physiological terms after retirement. This general feature has been formally scrutinized by Dragone and Vanin (2021) who identified health capital accumulation as self-depleting process and health deficit accumulation as self-productive process. The prediction of the model is in line with results from Abeliansky and Strulik (2021) who show for a panel of European countries that low-skilled workers and workers in occupations with high physical job burden accumulate health deficits faster before and after retirement.[5]

[5]Almond and Currie (2011) and Dalgaard et al. (2021) analyze self-depletion and self-production in the context of early-life health shocks. The self-depleting health capital model predicts that initial shocks are depreciated away as individuals grow older while the self-productive health deficit model predicts that initial shocks are amplified such that small shocks in childhood can have severe impact on late life health. See Abeliansky and Strulik (2018b, 2020) for an empirical test of the health deficit model in the context of early life origins of late life health.

4.3. **Controlling for Selection.** By holding preferences, prices, and technologies constant, the computational experiments already control for most of the confounders in empirical studies on occupational health effects. However, individuals differ by design in education which causes a selection problem. An ideal experiment would control for selection and would observe the same individual twice, in health-demanding and in non health-demanding occupation. While this counterfactual performance cannot be observed in empirical experiments, it can be easily explored with computational experiments. For that purpose, I run the life cycle problem twice, once when individuals select to enter health-demanding work and once when selection is disabled and the same individual has to perform non-health demanding work.

The result of this experiment is presented in Figure 2. Blue (solid) lines show, for alternative levels of education, the fraction of work years spent in health-demanding work (left panel) and, as one aggregate of life time health behavior, the age at death (right panel); education is reported relative to the education of the calibrated Reference American. Individuals with half of benchmark education are predicted to spend their whole work life in health-demanding work. With increasing education, aging individuals move earlier to non-health demanding work. From a level of 92% of benchmark education onwards, individuals spend their entire work life in non-health demanding work. The education gradient is then basically linear. Individuals with 50% more than benchmark education are predicted to live about 4 years longer.

Figure 2: Education, Occupation and Longevity (with and without Selection)




The blue line shows for alternative levels of education ($\theta S$), the fraction of the work life spent in health demanding occupations and the predicted age at death; all other parameters as in benchmark calibration. The red line shows the predicted age at death when selection into health demanding work is shut off. Education is measured relative to benchmark.

Results from the counterfactual experiment are represented by red (dashed) lines. The panel on the right-hand side shows that when individuals with low education are forced to perform less health-demanding work, they are unhealthier and die earlier than in health-demanding work.

This perhaps surprising result is straightforwardly explained. Two countervailing mechanisms are present: (i) Individuals with lower education earn less income, which, taken for itself, induces less healthy behavior (longevity effect). (ii) Individuals with lower education lose relatively more income when they move to occupation with low health burden. They prefer to stay a longer part of their life in health-demanding work and, taken for itself, have the incentive to invest more in their health (investment effect). Figure 2 shows that at low levels of education, the income loss from leaving health demanding occupations is so strong that individuals live longer in their self-selected health demanding occupation than if they were forced into a less paid, less health-demanding occupation. From a level of about 70 percent of average education this outcome is reversed and individuals would live longer in an enforced healthier occupation with lower wage. With increasing education, the relative importance of the hazard payment for wages declines and individuals prefer to stay shorter in health-demanding work, which means that longevity effect becomes the dominating driver of health behavior.

Summarizing, the model suggests that the health gradient of education is lower in manual health-demanding work than in occupations without health burden once the level of education is taken into account. Thus, controlling for selection, the model does not support the view that health-demanding work causes unhealthy behavior. It suggests that observed associations of unhealthy behavior and manual, health-demanding work run through the channels of low education and low income.

4.4. **Health and Wealth Effects on Occupational Choice.** In this subsection we focus on the individual with 20% less than benchmark education and investigate how different initial endowments with health and wealth influences occupational choice. All other parameters are as in the benchmark case. Case 3 considers an individual who is 10% healthier initially. This individual is predicted to stay his whole work life in health-demanding work because health erodes later in life. Compared to the case-1 individual he has a greater incentive for healthy behavior due to both the longevity effect and the productivity effect. Consequently, he invests 17% more in health and consumes 20% less unhealthy goods. Health behavior amplifies the impact of the anyway good natural endowment on longevity and the individual is predicted to live 7 years longer than the benchmark (death at age 84).

Case 4 considers an individual who starts the work life with 10% more health deficits. This individual earns less in health demanding work and due to further deteriorating health he moves earlier out of health-demanding work and earns less lifetime income. The incentive for healthy behavior is lower due to the smaller longevity effect and consequently the individual behaves less healthy such that the anyway inferior state of health deteriorates faster and death occurs 10 years earlier (age 67). Summarizing, the model supports the observation that less-healthy workers are selected out of health-demanding work (Case and Deaton, 2005).

Case 5 and 6 investigate wealth effects by endowing the case-1 individual with inheritances of 0.2 million $ or 1.0 million $. Individuals respond by performing less health-demanding work but only the large inheritance is sufficient to prevent all health-demanding work. While the productivity effect is less pronounced or entirely absent, the longevity effect is larger for richer individuals. In particular, the large inheritance induces a drastic reduction of unhealthy behavior and an enormous increase in health investments, which both improve longevity. Summarizing the model supports the observation that not only education but also wealth protects from health-demanding work (Case and Deaton, 2005).

4.5. **Health Insurance and Unhealthy Preferences.** We next consider health behavior and outcomes for the Reference American as well as of the two individuals with less and more education (case 1 and case 2) under different micro or macro assumptions. We begin with the effects of health insurance by setting the out-of-pocket ratio to $\phi = 1$, i.e. by eliminating health insurance. Case 7 in Table 1 shows that the benchmark individual reduces health investments drastically (by 80 percent) and dies 4.4 years earlier. The less well-educated individual shows the same response of health investments and since health and productivity deteriorates faster he now moves earlier out of health-demanding work than the case-1 individual. The faster erosion of health through work further reduces longevity and the individual dies 6.8 years earlier than benchmark (2.4 years earlier than the benchmark individual without health insurance). The individual with a high level of education (case 8) reduces health expenditure as well and additionally responds with reducing unhealthy behavior such that the health toll of absent insurance is less severe. Summarizing, less well educated individuals in health-demanding work suffer the most from unavailable (employer-provided) health insurance.

We next investigate the taste for unhealthy consumption. Setting $\alpha = 13$ increases unhealthy behavior (smoking) of the Reference American by about 250%. This scenario better conceptualizes smoking behavior of an average smoker (rather than that of an average American). The heavily smoking Reference American is predicted to invest more in health but nevertheless to die 5 years earlier (case 10 in Table 1). If the less well educated individual is a heavy smoker, we additionally observe that he avoids health-demanding work due to faster deteriorating health. This leads to a reduction of income, a lower level of consumption, and higher marginal utility from consumption, which in turn induces more smoking and less health care expenditure. The same change in taste causes a milder increase in smoking of the high-skilled individual, who also responds most strongly with health investments and thus experiences the smallest health repercussions from the increased taste for tobacco (case 12).

4.6. **Blue Collar Work and Health Behavior.** Studies of occupational health effects often classify occupations as manual vs. non-manual or by collar color and find detrimental health effects for (manual) blue collar occupations (e.g. Case and Deaton, 2005; Ravesteijn et al., 2018). The predictions of the model are consistent with these observations. If individuals select into health-demanding blue collar work, the detrimental health effects stem to a large extent from occupational health hazards (Section 4.1). As discussed above, the assignment of color collar is ambiguous when low-skilled individuals perform less health-demanding work, which could be manual or non-manual. Compared to high-skilled occupations, however, these occupations are associated with less healthy behavior because of lower income and the longevity effect. In both cases, blue color work will be associated with low levels of health during the work life and due to the self-productive nature of health deficits, occupational health effects prevail (and increase further) after retirement. The predictions thus support the finding that blue collar workers accumulate more health deficits before and after retirement (Abeliansky and Strulik, 2021).

The model is also useful to explain why there exists only very limited evidence for a *causal* effect of blue color work on health behavior. A rare study that claims to investigate causal effects of occupation on health behavior is Kelly et al. (2011). It is shown that most of the association between blue collar occupation and health behavior is explained by selection and that the remaining association can be easily wiped out by additional selection on "unobserved factors". The model rationalizes these observations by two counterbalancing effects (see Case 1 and Section 4.3): Individuals in blue collar work earn less income than the better educated benchmark individual, a feature which in itself reduces the incentive to behave healthily. However, income at this level of education is higher in health-demanding work, which is abandoned only because health deteriorates too much. This feature in itself increases the incentive for healthy behavior in order to preserve health and to stay longer in the better paid occupation. Taken selection into account, the model predicts at best only a weak causal effect of blue color work on health behavior.

These predictions are consistent with the observation that blue collar workers, on average, engage more in unhealthy behavior. The model predicts that better educated and richer individuals invest more in their health and spend less on unhealthy consumption (Table 1). Since blue collar workers are on average less educated and poorer they engage *for this reason* more in unhealthy behavior. The association with occupation, however, is not causal but captures the well-established association of socio-economic status and risky health behavior (Cawley and Ruhm, 2011).

Extensions of the model with elements of bounded rationality could be used to make more of the "unobserved factors" visible. For example, it has been shown that individuals who suffer from low self-control or time-inconsistent decision making invest less in their health and spend more on unhealthy consumption (Strulik, 2019a,b; Strulik and Werner, 2021). If, for the same reason, these individuals obtain less education, they will be more likely to chose blue collar occupations. Finally, there may be detrimental effects of blue collar work on health behavior that operate outside the life cycle model of health-deficit accumulation. For example, it has been argued that a "drinking culture" is prevalent in some blue collar occupations (Applebaum, 1981). Recently, Case and Deaton (2017) argued that individuals who aspired to traditional middle class occupations but ended up in low paid blue collar work may be motivated to engage in risky health behavior such as opioid use (see Grossmann and Strulik, 2021, for an analytical discussion of health effects from loss of middle class status). In all cases, however, it would not be the health-demanding nature of blue collar work that causes unhealthy behavior.

4.7. **Income Growth and Medical Progress.** We next consider an increase of the general level of income by assuming that $w_0$ is 20% higher. This scenario could be imagined as a look into the future of a later-born generation; an otherwise identical individual who starts work life 20 years after the Reference American, 20 years in which wages grew unbiasedly by about 1 percent per year. All three types of individuals respond to increasing income with less unhealthy consumption and more health investment and greater longevity. These responses are most strongly observed for the high-skilled individual (case 15). The low-skilled individual additionally responds by spending somewhat more time in health-demanding work.

Finally, we investigate effects from a 20% higher level of medical technology, which could be conceptualized as a generation (or 20 years) of medical technological progress advancing at 1 percent per year.[6] All three types of individuals respond to increasing medical efficacy by spending more on health and the high-skilled individual additionally responds by reducing unhealthy behavior. The low-skilled individual responds additionally by spending almost the entire working life in health-demanding work because health deficits can now be remedied more easily (see condition (8)). Overall, low-skilled individuals benefit less from medical technological progress and income growth, implying that these processes further increase the education gradient.

## 5. Endogenous Retirement

The first order condition for optimal retirement requires that at the age of retirement $R$, $\beta = \lambda_k(R)(w(R) - w_R(R))$, i.e. that the disutility of work equals the utility gain from work, which consists of the difference between wage income and pension, $w - w_R$, evaluated with the marginal utility from consumption $\lambda_k$. After inserting (4) and (12), the optimal age at retirement $R$ is obtained as the solution of equation (13):

$$\beta = \left(\frac{\underline{\mathrm{D}}}{D(R)}\right)^{\epsilon} c(R)^{-\sigma}\left[1 - \xi(R)\right] w_0 \left[z\psi \mathrm{e}^{\theta_H S} \mathrm{e}^{g_H R} \mathrm{e}^{-\nu_H D(R)} + (1-z)\mathrm{e}^{\theta_L S}\mathrm{e}^{g_L R}\mathrm{e}^{-\nu_L D(R)}\right], \quad (13)$$

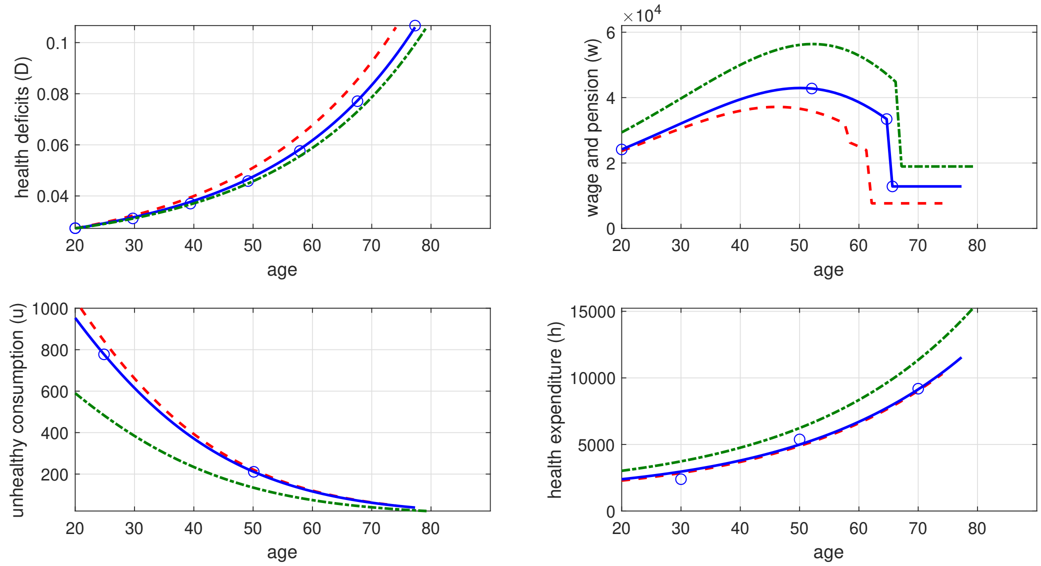
in which $\xi(R)$ is the replacement rate. We see that a more generous replacement rate $\xi(R)$ induces earlier retirement and that, ceteris paribus, individuals with many health deficits retire earlier since any value of $D(R)$ is reached at lower age $R$. Moreover, wealthy persons, who enjoy a high level of consumption and thus low marginal utility from consumption, are predicted to retire earlier. Inspection of (13) also suggests that highly educated individuals (with large $\theta_L S$) retire later since, ceteris paribus, wages in old age are higher and decline more slowly. In order to assess these and other effects quantitatively we turn to the calibrated model.

I set the replacement rate at the normal age of retirement to 0.4, as in the previous section. In order to capture income effects from early and late retirement, the model is refined in the following way. The normal retirement age is set to 67. For each month that the individual retires before the normal retirement age, benefits are reduced by 5/9 of one percent, up to 36 months (retirement at 64). If early retirement exceeds 36 months, benefits are further reduced by 5/12 of one percent per month, up to 24 months (retirement at 62). Individuals who leave

[6] Abeliansky et al. (2020) compute the frailty index for a panel of US American individuals and estimate that average health deficits at any age are by about one percent lower for every year of later birth.

the workforce before age 62 receive no benefits up to age 62. Individuals who retire beyond the normal retirement age receive a credit of 8 percent per year for each year of later retirement up to age 70 (Social Security Online, 2020). I calibrate $\beta$ such that the Reference American prefers to retire at age 65.5, i.e. at the exogenously imposed age from the previous section. This treatment has the advantage that benchmark results are kept from the previous section and observed changes in predicted retirement age in the comparative dynamic experiments can be attributed to education and occupational choice. This leads to the estimate $\beta = 0.18$. All other parameters are kept from the benchmark calibration.

Figure 3: Occupational Choice and Health with Endogenous Retirement: Men




Blue (solid) lines: Reference American ($z = 0$). Red (dashed lines): 20% lower level of education. Green (dash-dotted) lines: 20% higher level of education.

Blue (solid) lines in Figure 3 show the predicted life cycle trajectories for the Reference American. Circles indicate targeted data points. By design, life cycles choices are indistinguishable from those under exogenous retirement for the calibrated benchmark American. Red (dashed) lines show predicted behavior for an otherwise identical individual with 20 percent less education. This individual spends most of his work life in health-demanding work such that health deteriorates faster and retirement is entered earlier, at about age 62. Life cycle health behavior and health outcomes are again summarized in 5 aggregates and shown, together with the age at retirement, in Table 2. Comparing case 1 of Table 1 and 2, we see that the behavioral changes induced by endogenous retirement are not large: The lower lifetime income due to early retirement motivates somewhat more unhealthy consumption and somewhat less health care with a small reduction in longevity. In relative terms, due to earlier retirement, a larger part of working life is spent in health-demanding work.

Green (dash-dotted) lines in Figure 3 show trajectories for an individual with 20 percent more education. Again, health behavior and health outcomes are very similar to those under exogenous retirement and the most remarkable feature is that of later retirement, at age 67.6 (case 2 in Table 2).

Table 2: Comparative Dynamics and Sensitivity Analysis: Endogenous Retirement

| case | parameter change | remark | $\Delta u/u$ | $\Delta h/h$ | $\Delta T$ | $\Delta V/V$ | mean($z$) | $R$ |
|---|---|---|---|---|---|---|---|---|
| 1 | $\Delta S = -20\%$ | lower level of education | 0.12 | -0.08 | -3.23 | -0.09 | 0.89 | 62.1 |
| 2 | $\Delta S = +20\%$ | higher level of education | -0.39 | 0.29 | 1.93 | 0.25 | 0.00 | 67.1 |
| 3 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | -0.22 | 0.19 | 7.14 | 0.23 | 0.98 | 72.4 |
| 4 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 0.60 | -0.27 | -10.53 | -0.29 | 0.80 | 55.6 |
| 5 | case 1 and $k_0 =$ \$0.2 mill. | wealthier individual | -0.55 | 0.48 | -0.12 | 0.38 | 0.95 | 55.9 |
| 6 | case 1 and $k_0 =$ \$1.0 mill. | much wealthier individual | -0.93 | 2.92 | 8.95 | 2.25 | 0.00 | 55.9 |
| 7 | $\phi = 1$ | no health insurance | 0.03 | -0.80 | -4.55 | -0.06 | 0.00 | 61.1 |
| 8 | $\phi = 1$ and case 1 | no health insurance and low edu | 0.16 | -0.82 | -7.08 | -0.14 | 0.87 | 57.5 |
| 9 | $\phi = 1$ and case 2 | no health insurance and high edu | -0.37 | -0.74 | -3.25 | 0.16 | 0.00 | 63.1 |
| 10 | $\alpha = 13$ and case 1 | heavy smoker | 2.80 | 0.76 | -5.92 | 0.49 | 0.00 | 55.7 |
| 11 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 3.23 | 0.65 | -7.21 | 0.40 | 0.16 | 55.7 |
| 12 | $\alpha = 13$ and case 2 | heavy smoker and high edu. | 2.30 | 0.91 | -4.31 | 0.62 | 0.00 | 55.0 |
| 13 | $\Delta w_0 = +20\%$ | higher income level | -0.37 | 0.27 | 1.81 | 0.23 | 0.00 | 67.1 |
| 14 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | -0.29 | 0.16 | -1.69 | 0.12 | 0.91 | 63.3 |
| 15 | $\Delta w_0 = +20\%$ and case 2 | higher income level and high edu. | -0.63 | 0.67 | 3.59 | 0.55 | 0.00 | 69.5 |
| 16 | $\Delta A = +20\%$ | medical progress | -0.03 | 0.33 | 5.87 | 0.08 | 0.00 | 71.4 |
| 17 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 0.08 | 0.22 | 1.54 | -0.02 | 0.94 | 66.9 |
| 18 | $\Delta A = +20\%$ and case 2 | medical progress and high edu. | -0.41 | 0.75 | 8.92 | 0.38 | 0.00 | 76.1 |

The table shows the predicted deviation of health behavior and health outcomes from the calibrated benchmark individual. $\Delta T$ is measured in years, $\Delta u/u$, $\Delta h/h$, and $\Delta V/V$ are relative deviations; $\Delta V/V$ can be read, alternatively, as relative change in lifetime utility or relative change in the value of life. The mean($z$)–column shows the fraction of the total work life spent in health-demanding occupation.

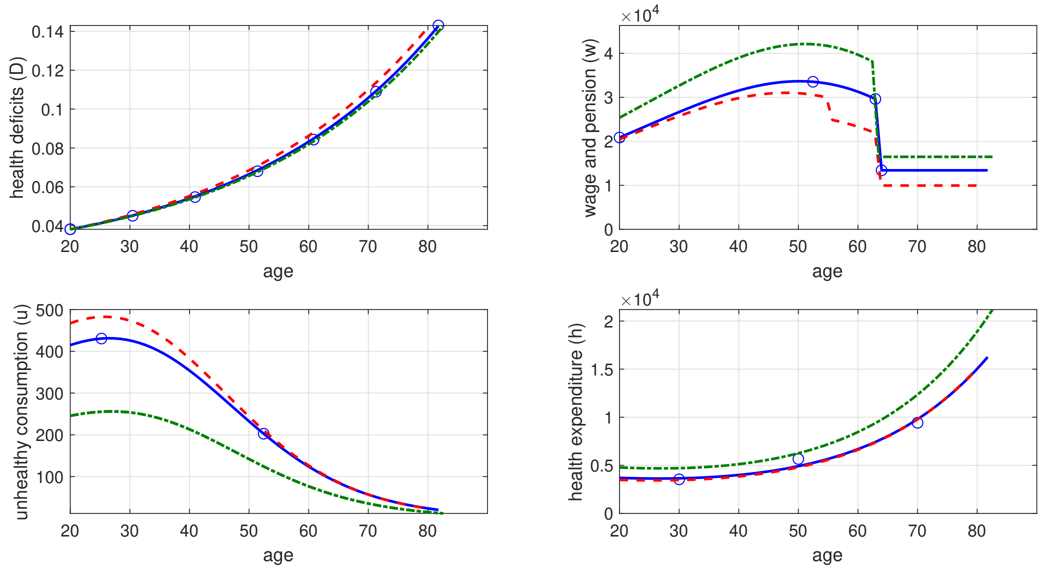
Cases 3 to 18 in Table 2 reiterate the comparative dynamics of Table 1 for endogenous retirement. The overarching conclusion is that the predicted occupational choice, health behavior, and health outcomes are very similar to the case of exogenous retirement. Instead of going through the results one-by-one, we only briefly consider some selected results. As expected, less healthy individuals retire (much) earlier and healthy individuals retire later when retirement is a choice variable (cases 3 and 4). Wealthy individuals are predicted to retire much earlier but do not change much their prefered occupation when retirement are becomes a choice variable (cases 5 and 6). Likewise, missing health insurance induces earlier retirement at all skill-levels but does not much affect occupational choice (cases 7 to 9). The option of earlier retirement induces heavy smokers to smoke more, spend somewhat less on health, and to die earlier. Apparently, individuals prefer to shift more experience of utility towards young age at the expense of old age utility (cases 10 to 12). Higher income induces later retirement at all skill levels and the effect is mildly larger for low-skilled workers who are also induced to stay a bit longer in health-demanding work (cases 13 to 15). Likewise, medical advances induce later retirement at all skill levels, with a mildly larger effect for high-skilled workers who benefit most from medical advances. Overall, the conclusion is that endogenous retirement has a pronounced effect on retirement but small effects on occupational choice, health behavior, and health outcomes. In other words, the results from the benchmark model are robust against the introduction of endogenous retirement.

## 6. Occupational Choice, Aging, and Longevity of Women

In this section we investigate a recalibration of the model for a reference American woman, a single woman of age 20 in the year 2010. The most distinctive features in this context are that, on average, women (compared to men) display more health deficits at any given age but develop new health deficits more slowly and that death occurs later when more health deficits have been accumulated (Mitnitski et al., 2002a,b; Abeliansky and Strulik, 2018a,b). A health-economic theory and detailed discussion of this morbidity-mortality paradox is provided in Schuenemann et al., 2017a, 2020). Here I take up the discussion with a new focus on occupational choice. Specifically, I follow Mitnitski et al. (2002) and Schuenemann et al. (2017a) and set $\mu = 0.031$ and $D_0 = 0.0381$, as the initial value of deficits of a 20-year-old woman. I set $\bar{D} = 0.1429$ as average health deficits accumulated by women at age 81.7 since the life expectancy of women at age 20 was 61.7 in 2010 (NVSS, 2014). I adjust $w_0$ such that the reference woman earns 18.8% less labor income than the Reference American, in correspondence with the OECD's (2016) estimate of difference between median labor income of males and females in the US. Following the discussion for men, I first consider exogenous retirement and set the retirement age to 63 (CRR, 2018). I adjust $\nu_L$ and $\nu_H$ such that the age-earnings profile for the reference woman follows that of the reference man (peaking at about age 50) since age-earnings profiles for single men and single women are very similar (Vandenbroucke, 2018).

In order to control the experiment and to facilitate comparison with male occupational choice, I assume that women face the same health technology (the same $A$ and $\gamma$) the same health

Figure 4: Occupational Choice, Health Behavior, and Health Outcomes: Women




Blue (solid) lines: Reference American Women ($z = 0$). Red (dashed lines): 20% lower level of education. Green (dash-dotted) lines: 20% higher level of education. Circles: data points, see text for details.

damage from unhealthy behavior and unhealthy occupation (the same $B$, $E$, and $\omega$), the same return to experience and the same return to education as men. I then determine the remaining parameters, $\alpha$, $\epsilon$, $\sigma$, and $a$ by targeting the observed health expenditure at age 30 and 70 (MEPS, 2010), average life expectancy at 20, and average yearly expenditure for smoking (BLS, 2012). Women are predicted to spend about 25% more on health and about half as much on cigarettes than men. These targets leads to the calibration $\alpha = 5.45$; $\epsilon = 0.11$, $\sigma = 1.28$, and $a = 0.0129$. These estimates replicate the findings of Schuenemann et al. (2017a) that women, compared to men, put more utility weight on health (higher $\epsilon$) and display a lower elasticity of intertemporal substitution (lower value of $1/\sigma$). This means that women, compared to men, put more utility weight on a long life and less weight on satisfaction from instantaneous consumption of unhealthy and health neutral goods.

Figure 4 shows the predicted life cycle trajectories for health behavior and health outcomes. Table 3 summarizes aggregates of behavior and outcomes as well as occupational choice. Values are now expressed relative to the calibrated reference woman who received 14 years of education and prefers not to work in health-demanding occupation. The structure of the table and its entries follows exactly the one for men (Table 1). Case 1 shows life cycle behavior of a woman with 20 percent less education. As her male counterpart, the low-skilled woman prefers to start work life in health-demanding occupation. However, she moves earlier out of health-demanding work at an earlier age, at about age 52 (but due to earlier retirement she stays about the same fraction of the work life in health-demanding work). Low-skilled women, compared to men, are predicted to lose about half as much in terms of life expectancy due to health-demanding work, about 1.5 years compared to 3 years in Table 1. As for men, low-skilled women behave somewhat unhealthier and high-skilled women behave much healthier than benchmark women. Women achieve somewhat less life extension from healthy behavior, which reflects decreasing returns of health expenditure together with the fact that women spend more on health already at benchmark level.

Table 3: Comparative Dynamics and Sensitivity Analysis: Women

| case | parameter change | remark | $\Delta u/u$ | $\Delta h/h$ | $\Delta T$ | $\Delta V/V$ | $z=1$ |
|---|---|---|---|---|---|---|---|
| 1 | $\Delta S = -20\%$ | lower level of education | 0.11 | -0.05 | -1.56 | -0.05 | 0.81 |
| 2 | $\Delta S = +20\%$ | higher level of education | -0.40 | 0.29 | 0.81 | 0.24 | 0.00 |
| 3 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | -0.25 | 0.15 | 6.42 | 0.17 | 0.95 |
| 4 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 0.60 | -0.21 | -7.80 | -0.23 | 0.63 |
| 5 | case 1 and $k_0 =$ \$0.2 mill. | wealthier individual | -0.56 | 0.51 | 1.20 | 0.40 | 0.63 |
| 6 | case 1 and $k_0 =$ \$1.0 mill. | much wealthier individual | -0.97 | 4.65 | 5.16 | 3.16 | 0.00 |
| 7 | $\phi = 1$ | no health insurance | -0.05 | -0.79 | -2.60 | -0.01 | 0.00 |
| 8 | $\phi = 1$ and case 1 | no health insurance and low edu | 0.07 | -0.08 | -3.93 | -0.05 | 0.73 |
| 9 | $\phi = 1$ and case 2 | no health insurance and high edu | -0.43 | -0.73 | -2.02 | 0.24 | 0.00 |
| 10 | $\alpha = 13$ | heavy smoker | 2.62 | 0.83 | -1.64 | 0.01 | 0.00 |
| 11 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 3.21 | 0.70 | -1.94 | 0.51 | 0.00 |
| 12 | $\alpha = 13$ and case 2 | heavy smoker and high edu. | 1.98 | 1.02 | -0.23 | 0.76 | 0.00 |
| 13 | $\Delta w_0 = +20\%$ | higher income level | -0.38 | 0.27 | 0.74 | 0.22 | 0.00 |
| 14 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | -0.31 | 0.20 | -0.87 | 0.15 | 0.84 |
| 15 | $\Delta w_0 = +20\%$ and case 2 | higher income level and high edu. | -0.64 | 0.67 | 1.52 | 0.52 | 0.00 |
| 16 | $\Delta A = +20\%$ | medical progress | 0.04 | 0.24 | 2.90 | 0.01 | 0.00 |
| 17 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 0.14 | 0.18 | 1.06 | -0.04 | 0.93 |
| 18 | $\Delta A = +20\%$ and case 2 | medical progress and high edu. | -0.38 | 0.61 | 3.98 | 0.24 | 0.00 |

The table shows the predicted deviation of health behavior and health outcomes from the calibrated benchmark individual. $\Delta T$ is measured in years, $\Delta u/u$, $\Delta h/h$, and $\Delta V/V$ are relative deviations; $\Delta V/V$ can be read, alternatively, as relative change in lifetime utility or relative change in the value of life. The $z = 1$–columns shows the fraction of the total work life spent in health-demanding occupations.

Most of the results of comparative dynamics for women are very similar to those obtained for men. Women, compared to men, are predicted to gain somewhat less longevity from a 20% income increase and to gain much less longevity from medical technological progress. Again, these outcomes are explained by decreasing returns to health expenditure and the fact that women spend more on health care at benchmark level. Finally, we consider endogenous retirement and determine $\beta$ such that the Reference Women prefers to retire at the previously exogenous age (of 63). This leads to the estimate $\beta = 0.033$. Table A.1 in the Appendix summarized the results of the comparative dynamic analysis, which can be compared in two directions, with respect to exogenously retired women (Table 3) and with respect to endogenously retired men (Table 2).

## 7. Conclusion

In this paper, I proposed a life cycle model of occupational choice with endogenous health behavior, aging, and longevity. The model is embedded in the gerontologically founded health deficit model of Dalgaard and Strulik (2014) and predicts that the health gradient between workers in health-demanding occupations and those in less health-demanding occupations widens with age of workers as observed by Case and Deaton (2005) and several other studies. Moreover, the model predicts that the health gradient continues to widen in retirement, after the direct health impact of work is gone. The reason lies in the self-productive nature of health deficit accumulation: workers in health-demanding occupations enter retirement with more health deficits, which are then conducive to the faster development of new health deficits. Abeliansky and Strulik (2021) provide corroborating evidence for a widening occupational health gradient, before and after retirement.

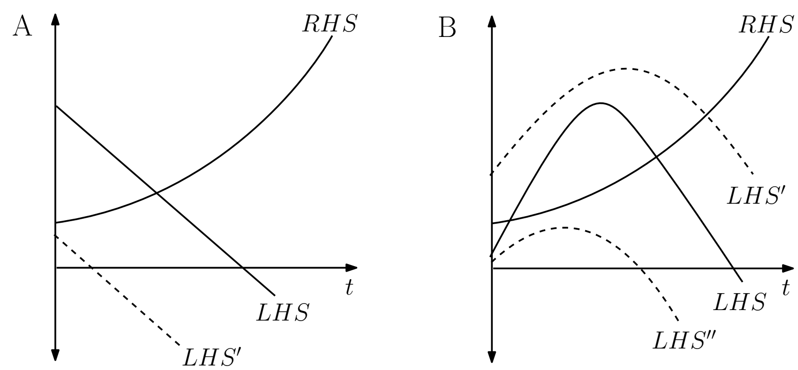
The health deficit model eliminates some inconsistencies of the health capital model (based on Grossman, 1972) that were emphasized by Case and Deaton (2005) and several other authors. The model explains why health-demanding work is ceteris paribus preferred by male, young, and healthy individuals with a relatively low level of education and leads to some non-obvious and perhaps surprising conclusions. For example, it has been shown that, at low and intermediate levels of education, occupational choice has an negligible effect on health behavior and health outcomes when occupations are optimally chosen because income and health investment effects largely offset each other. The model motivates a widening socioeconomic gradient of health caused by medical progress. The reason is that better medical technology induces low-skilled individuals to spend a greater part of their life in health-demanding work, which partly offset the decelerating effect of better medical provisions on health deficit accumulation.

This is the first attempt to account for occupational choice in a model of endogenous accumulation of health deficits and, naturally, there are many possibilities to extend the model and to apply it to specific research questions. For example, job characteristics were captured by simple parameters. A more complicated model could take into account that workers may invest in workplace safety (Guardado and Ziebarth, 2019). The model could also be combined with several other application of the health deficit model. For example, it could be taken into account that pain does not only reduce utility (as in Strulik, 2021) but also limits occupational choice. Other unhealthy behavior such as eating and its effects on obesity and health (as in Strulik 2020) could be investigated in the context of occupational choice and discrimination at the workplace. An integration with Schuenemann et al. (2020) would facilitate an exploration of the occupational choices and health behaviors of couples.

## Appendix

**A.1. Proof of Proposition 1.** Since health deficits increase with age and education is a given constant both $m_j(S,D,t)$ can be represented as a (unit-) wage-for-age-curve with slope $\mathrm{d}m_j/\mathrm{d}t = \partial m_j/\partial t + (\partial m_j/\partial D)\,(\partial D/\partial t)$ and the (unit-) wage differential $\psi m_H - m_L$ is a unique function of age. Conditions (i) and (ii) ensure that $\psi m_H > m_L$ holds true either initially or never. If $\psi m_H$ is never larger than $m_L$, an occupation with high health burden is never worthwhile. We henceforth focus on $\psi m_H(0) - m_L(0) > 0$.

Figure A.1: Occupational Choice by Age




The Figure shows the left-hand side and right hand side of condition (8). Dashed trajectories indicate alternative age patterns. Individuals select health-demanding work iff $LHS > RHS$ (for ages $t$ before retirement).

Since the wage-for-age curves are both concave, falling for large $t$, and zero at age $\bar{t}$, they intersect either once or never before $\bar{t}$ and the wage differential $\psi m_H - m_L$ is either monotonically decreasing or first increasing and then decreasing in age. Thus, the left-hand side of condition (8), here denoted by LHS, is either monotonically decreasing or first increasing and then decreasing in age. These cases are shown in panel A and B of Figure A.1. The right-hand side of condition (8) (denoted by RHS) is increasing in health expenditure and since health expenditure is non-negative and increasing in age, the RHS is non-negative and strictly increasing in age. Thus, there is at most one intersection of LHS and RHS in panel A and at most two intersections in panel B. In both panels the solid RHS line shows the case with the most intersections and dashed lines show alternative life histories with less intersections. If the age at an intersection is smaller than the retirement age, individuals change their occupation at that age. In panel A, individuals change their occupation at most once (from health-demanding to non health-demanding). In panel B, individuals change their occupation at most twice (from non-health demanding to health-demanding and back).

**A.2. Derivation of equations (9)–(11).** The costate equations that characterize the optimal solution are obtained as

$$\lambda_k r = \lambda_k \rho - \dot{\lambda}_k \tag{A.1}$$

$$-\frac{\epsilon}{D}\left(\frac{\bar{D}}{D}\right)^{\epsilon}\left(\frac{c^{1-\sigma}-1}{1-\sigma} - \beta\ell\right) + \lambda_D \mu - \lambda_k w_0 \ell\left[z\psi\frac{\partial m_H}{\partial D} + (1-z)\frac{\partial m_L}{\partial D}\right] = \lambda_D \rho - \dot{\lambda}_D \tag{A.2}$$

Using $c \equiv \tilde{c} + \alpha u$, it follows from (4):

$$c^{-\sigma}\left(\frac{\underline{\mathrm{D}}}{D}\right)^{\epsilon} = \lambda_k \qquad \Rightarrow \qquad -\epsilon\frac{\dot{D}}{D} - \sigma\frac{\dot{c}}{c} = \frac{\dot{\lambda}_k}{\lambda_k}. \tag{A.3}$$

Substituting $\dot{\lambda}_k/\lambda_k$ from (A.1) provides (10) in the main text. Using (4) and (6) to eliminate $\lambda_k$ and $\lambda_D$ from (5), we obtain:

$$\alpha - q - \frac{p\phi\omega B u^{\omega-1}}{\gamma A h^{\gamma-1}} = 0. \tag{A.4}$$

Solving for $u$ provides (9) in the text. Log-differentiating (6) with respect to age, we obtain

$$\frac{\dot{h}}{h} = \frac{1}{1-\gamma}\left(\frac{\dot{\lambda}_D}{\lambda_D} - \frac{\dot{\lambda}_k}{\lambda_k}\right) \tag{A.5}$$

Inserting (6) into (A.2) provides:

$$\frac{\dot{\lambda}_D}{\lambda_D} = \rho - \mu - \frac{\mu\gamma A h^{\gamma}}{\phi p} w_0 \ell \left[z\psi\frac{\partial m_H}{\partial D} + (1-z)\frac{\partial m_L}{\partial D}\right] + \frac{\epsilon}{\lambda_D D}\left(\frac{\underline{\mathrm{D}}}{D}\right)^{\epsilon}\left(\frac{c^{1-\sigma}-1}{1-\sigma} - \beta\ell\right) \tag{A.6}$$

Substituting $\lambda_D$ from (6) and then $\lambda_k$ from (4), we obtain:

$$\frac{\dot{\lambda}_D}{\lambda_D} = \rho - \mu - \frac{\mu\gamma A h^{\gamma}}{\phi p} w_0 \ell \left[z\psi\frac{\partial m_H}{\partial D} + (1-z)\frac{\partial m_L}{\partial D}\right] - \frac{\epsilon\mu\gamma A h^{\gamma-1} c^{\sigma}}{\phi p D}\left(\frac{c^{1-\sigma}-1}{1-\sigma} - \beta\ell\right) \tag{A.7}$$

Finally, substituting (A.7) and $\dot{\lambda}_k/\lambda_k$ from (A.1) into (A.5) provides (11) in the text.

7.1. **A.3. Results for Women when Retirement is Endogenous.** They are shown in Table A.1

7.2. **A.4. Nonlinear Health Effects from Occupation.** In this section, I check the robustness of results to nonlinear health effects from occupation. To this end, I replace the health damage $Ez$ with $Ez^{\zeta}$, $\zeta > 0$. This leads to the optimal occupational choice:

$$z = \max\left\{0,\ \min\left\{1,\ \left[w_0(\psi m_H - m_L)\frac{\gamma A h^{\gamma-1}}{\zeta\phi p E}\right]^{1/(\zeta-1)}\right\}\right\}, \tag{A.8}$$

which replaces (8) in the paper. Additionally to the corner solutions, the possibility of an interior solution emerges. Any plausible calibration will produce the results that health expenditure is increasing with age. For $\zeta < 1$ and an interior solution, the model would then predict that individuals work more in occupations of high health burden when they get older. This implausible behavior is excluded by focussing on cases where $\zeta > 1$. This means that the marginal health damage increases with exposure to health damaging work.

The solution of the refined model has the convenient feature that it preserves the optimal choice of the calibrated benchmark individual (since, in this case, $\psi m_H - m_L = 0$). As a first robustness check, I consider case 1 of Table 1 for alternative $\zeta$. For $\zeta = 1$ this worker stayed 82 percent of his work life in an occupation of high health burden and then switched to an occupation of low health burden. The panel on the left-hand side of Figure A.2 shows the optimal $z$ predicted for alternative $\zeta$. For $\zeta = 1.05$, the solution preserves almost the step function with a very quick transition from $z = 1$ to a $z$-value close to (but not exactly) zero. As

Table A.1: Comparative Dynamics and Sensitivity Analysis: Endogenous Retirement: Women

| case | parameter change | remark | $\Delta u/u$ | $\Delta h/h$ | $\Delta T$ | $\Delta V/V$ | $z=1$ | $R$ |
|---|---|---|---|---|---|---|---|---|
| 1 | $\Delta S = -20\%$ | lower level of education | 0.07 | -0.04 | -1.51 | -0.04 | 0.92 | 57.8 |
| 2 | $\Delta S = +20\%$ | higher level of education | -0.44 | 0.33 | 0.89 | 0.26 | 0.00 | 63.6 |
| 3 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | -0.30 | 0.18 | 6.53 | 0.20 | 0.90 | 67.4 |
| 4 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 0.59 | -0.21 | -7.80 | -0.24 | 0.75 | 55.7 |
| 5 | case 1 and $k_0 = \$0.2$ mill. | wealthier individual | -0.48 | 0.39 | 1.04 | 0.30 | 0.53 | 55.2 |
| 6 | case 1 and $k_0 = \$1.0$ mill. | much wealthier individual | -0.97 | 4.47 | 5.08 | 3.05 | 0.00 | 55.1 |
| 7 | $\phi = 1$ | no health insurance | -0.08 | -0.78 | -2.56 | 0.01 | 0.00 | 60.1 |
| 8 | $\phi = 1$ and case 1 | no health insurance and low edu | 0.05 | -0.80 | -3.90 | -0.05 | 0.86 | 55.3 |
| 9 | $\phi = 1$ and case 2 | no health insurance and high edu | -0.46 | -0.72 | -1.98 | 0.25 | 0.00 | 59.5 |
| 10 | $\alpha = 13$ | heavy smoker | 2.69 | -0.62 | -4.02 | 0.56 | 0.00 | 55.2 |
| 11 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 3.23 | -0.65 | -4.64 | 0.47 | 0.00 | 55.8 |
| 12 | $\alpha = 13$ and case 2 | heavy smoker and high edu. | 2.11 | -0.59 | -3.35 | 0.68 | 0.00 | 55.6 |
| 13 | $\Delta w_0 = +20\%$ | higher income level | 2.15 | -0.59 | -3.40 | 0.67 | 0.00 | 55.6 |
| 14 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | 2.73 | -0.63 | -4.06 | 0.56 | 0.00 | 55.2 |
| 15 | $\Delta w_0 = +20\%$ and case 2 | higher income level and high edu. | -0.70 | 0.81 | 1.68 | 0.63 | 0.00 | 64.0 |
| 16 | $\Delta A = +20\%$ | medical progress | -0.06 | -0.73 | -0.60 | 0.01 | 0.00 | 61.4 |
| 16 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 0.07 | -0.75 | -2.13 | -0.05 | 0.87 | 58.4 |
| 16 | $\Delta A = +20\%$ and case 2 | medical progress and high edu. | -0.44 | -0.65 | 0.14 | 0.26 | 0.00 | 63.0 |

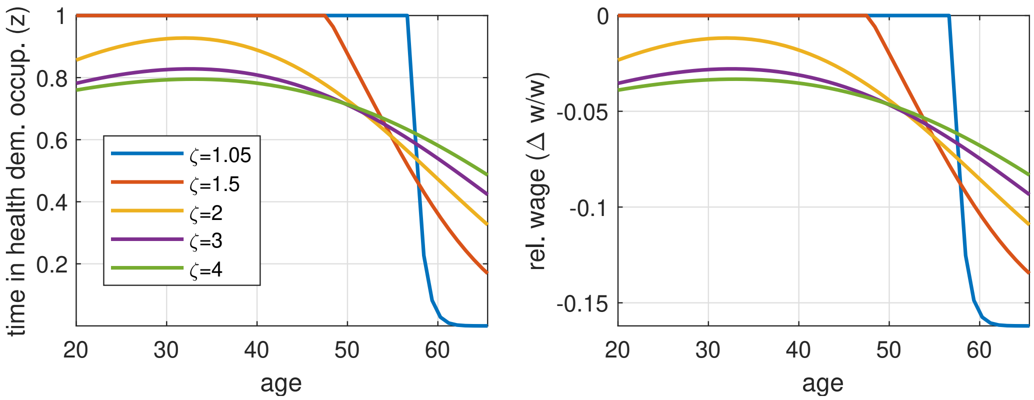
The table shows the predicted deviation of health behavior and health outcomes from the calibrated benchmark individual. $\Delta T$ is measured in years, $\Delta u/u$, $\Delta h/h$, and $\Delta V/V$ are relative deviations; $\Delta V/V$ can be read, alternatively, as relative change in lifetime utility or relative change in the value of life. The $z = 1$–columns shows the fraction of the total work life spent in health-demanding occupations.

$\zeta$ gets larger, the transition becomes more gradual. Up to $\zeta$ values around 1.5, the individuals prefer to spend most of the work life fulltime in health demanding work.

For higher values of $\zeta$ the feature of a corner solution is lost. However, even then, the deviation from the corner solution is not large for most of the worker's life. For $\zeta = 3$, young and middle aged workers prefer to spend around 80 % (instead of 100%) in health demanding work. In order to assess the economic consequences, I show in the panel on the right-hand side of Figure A.2 the relative loss in wages compared to fulltime health-demanding work. Recall that individuals with less than benchmark years of education earn more in health-demanding work. If they forego health-demanding work, this is solely motivated by health concerns. The figure shows the relative wage that individuals are willing to give up for a less than 100% exposure to health demanding work. In other words, the figure shows the minimum costs of having two occupation within the same time increment (at the same day) that would prevent two simultaneous occupations. These costs would comprise, for example, the monetary value of the leisure time lost due to daily commuting from one part-time occupation to the other. Since these costs are not large, it is plausible that a corner solution would prevail in a more complex model that allows for an interior solution and imposes a job switching (commuting) cost.

Figure A.2 reveals another interesting feature: for $\zeta \neq 1$, the individual never completely abandons the unhealthy occupation. Even for $\zeta$ close to 1, individuals prefer to stay a bit of their (daily) time in the occupation with high health burden. This feature can also be read

Figure A.2: Sensitivity Analysis for Non-linear Health Damage from Work (Alternative $\zeta$s)




Calibration as for benchmark model in the paper. Predictions for Case 1 from Table 1 for alternative values of $\zeta$.

off from equation (A.8): $z$ stays positive as long as $\psi m_H > m_L$. The replacement of $\zeta = 1$ in the main text by $\zeta > 1$ thus entails the implausible feature that individuals perform healthy and unhealthy work within the same time increment and eliminates the plausible feature that individuals abandon unhealthy work completely when they become older and more frail.

I next report in Table A.2 the results of a detailed sensitivity analysis in which I computed the comparative dynamics for all cases from Table 1 and $\zeta = 1.5$, $\zeta = 2$, and $\zeta = 3$. For some cases, the individual was found to prefer fulltime employment in work with low health burden over the whole work life irrespective of the value of $\zeta$, which is indicated by "all" in Table A.2 (since results are the same for all values of $\zeta$). Cases 1 to 3 consider the individual with lower education from case 1 of Table 1. For $\zeta = 1.5$, results deviate only marginally from Case 1 of Table 1, even the share of the work life spent in health-demanding work is very similar, although results differ qualitatively in the sense that, in the linear model, individuals work in occupations with low health-demand fulltime after their career in health-demanding work whereas, in the non-linear model, they work simultaneously in jobs with low and high health demands. For higher values of $\zeta$, the deviation from the linear case becomes somewhat larger. For $\zeta = 3$, lifetime work in health-demanding occupations declines to 72 percent, instead of 82 percent and the individual consumes more unhealthy goods, since it became somewhat less important to maintain good health for the health-demanding job. As a result, his stay in blue collar work reduces lifetime by 2 years, instead of 3 years.

Similar conclusions can be drawn for almost all the other cases. Only the "heavy smoker" case provides result that individuals stay somewhat longer in health-demanding work when health-demanding work becomes unhealthier. Inspection of the lifetime trajectories shows that the result is a compositional effect. For low value of $\zeta$, the heavy smoker spends most of his time in health-demanding work when young and then withdraws quickly while for high values of $\zeta$ he prefers to spend less time initially and to withdraw more reluctantly. Of course, such a result would be impossible when individuals are fulltime employed in their occupations, as in the linear model from the main text. But even for the heavy smoker, the conclusions from the main text would be preserved: ceteris paribus, individuals with a taste for unhealthy consumption spend a smaller part of their work life in health-demanding work.

The main takeaway from Table A.2 is that that for the predicted changes in occupational choice, health behavior, and health outcomes vary only marginally from the predictions from the linear case Table 1 for $\zeta$ values up to 1.5. Even when the deviations are somewhat larger for greater values of $\zeta$, the *direction* of the change is always the same as for the linear model. All qualitative conclusions from the main text are robust to the consideration of increasing marginal health costs in health-demanding occupations.

Table A.2: Robustness Checks: Non-linear Health Effects of Occupational Choice

| case | parameter change | remark | $\zeta$ | $\Delta u/u$ | $\Delta h/h$ | $\Delta T$ | $\Delta V/V$ | mean($z$) |
|---|---|---|---|---|---|---|---|---|
| 1 | $\Delta S = -20\%$ | lower level of education | 1.5 | 0.10 | -0.07 | -3.05 | -0.09 | 0.81 |
| 2 | $\Delta S = -20\%$ | lower level of education | 2.0 | 0.13 | -0.08 | -2.66 | -0.09 | 0.76 |
| 3 | $\Delta S = -20\%$ | lower level of education | 3.0 | 0.16 | -0.08 | -1.96 | -0.09 | 0.72 |
| 4 | $\Delta S = +20\%$ | higher level of education | all | -0.38 | 0.28 | 1.90 | 0.24 | 0.00 |
| 5 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | 1.5 | -0.20 | 0.17 | 7.09 | 0.20 | 0.99 |
| 6 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | 2.0 | -0.19 | 0.17 | 7.35 | 0.20 | 0.95 |
| 7 | case 1 and $\Delta D_0 = -10\%$ | healthier individual | 3.0 | -0.16 | 0.15 | 8.63 | 0.20 | 0.83 |
| 8 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 1.5 | 0.48 | -0.24 | -10.09 | -0.28 | 0.63 |
| 9 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 2.0 | 0.53 | -0.25 | -9.75 | -0.28 | 0.60 |
| 10 | case 1 and $\Delta D_0 = +10\%$ | less healthy individual | 3.0 | 0.54 | -0.25 | -9.36 | -0.28 | 0.63 |
| 11 | case 1 and $k_0 = \$0.2$ mill. | wealthier individual | 1.5 | -0.54 | 0.48 | 0.77 | 0.37 | 0.65 |
| 12 | case 1 and $k_0 = \$0.2$ mill. | wealthier individual | 2.0 | -0.53 | 0.47 | 1.37 | 0.37 | 0.61 |
| 13 | case 1 and $k_0 = \$0.2$ mill. | wealthier individual | 3.0 | -0.53 | 0.48 | 1.85 | 0.38 | 0.64 |
| 14 | $\phi = 1$ | no health insurance | all | 0.00 | -0.80 | -4.42 | -0.06 | 0.00 |
| 15 | $\phi = 1$ and case 1 | no health insurance and low edu | 1.5 | 0.12 | -0.81 | -6.79 | -0.13 | 0.72 |
| 16 | $\phi = 1$ and case 1 | no health insurance and low edu | 2.0 | 0.15 | -0.81 | -6.39 | -0.14 | 0.68 |
| 17 | $\phi = 1$ and case 1 | no health insurance and low edu | 3.0 | 0.17 | -0.82 | -5.88 | -0.13 | 0.67 |
| 18 | $\phi = 1$ and case 4 | no health insurance and high edu | all | -0.38 | -0.74 | -3.14 | 0.16 | 0.00 |
| 19 | $\alpha = 13$ | heavy smoker | all | 2.45 | 0.85 | -5.13 | 0.55 | 0.00 |
| 20 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 1.5 | 2.77 | 0.76 | -6.59 | 0.46 | 0.26 |
| 21 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 2.0 | 2.73 | 0.77 | -6.44 | 0.47 | 0.36 |
| 22 | $\alpha = 13$ and case 1 | heavy smoker and low edu. | 3.0 | 2.69 | 0.78 | -6.24 | 0.48 | 0.48 |
| 23 | $\alpha = 13$ and case 4 | heavy smoker and high edu. | all | 1.93 | 1.04 | -3.30 | 0.70 | 0.00 |
| 24 | $\Delta w_0 = +20\%$ | higher income level | all | -0.36 | 0.26 | 1.80 | 0.22 | 0.00 |
| 25 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | 1.5 | -0.29 | 0.17 | -1.54 | 0.11 | 0.86 |
| 26 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | 2.0 -0.27 | 0.16 | -1.16 | 0.11 | 0.80 | |
| 27 | $\Delta w_0 = +20\%$ and case 1 | higher income level and low edu. | 3.0 | -0.25 | 0.15 | -0.33 | 0.11 | 0.74 |
| 28 | $\Delta w_0 = +20\%$ and case 4 | higher income level and high edu. | all | -0.62 | 0.65 | 3.55 | 0.53 | 0.00 |
| 29 | $\Delta A = +20\%$ | medical progress | all | 0.00 | 0.31 | 5.59 | 0.07 | 0.00 |
| 30 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 1.5 | 0.09 | 0.22 | 1.56 | -0.03 | 0.92 |
| 31 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 2.0 | 0.11 | 0.21 | 1.88 | -0.03 | 0.86 |
| 32 | $\Delta A = +20\%$ and case 1 | medical progress and low edu. | 3.0 | 0.14 | 0.20 | 2.84 | -0.03 | 0.77 |
| 33 | $\Delta A = +20\%$ and case 4 | medical progress and high edu. | all | -0.38 | 0.70 | 8.53 | 0.34 | 0.00 |

The table shows the predicted deviation of health behavior and health outcomes from the calibrated benchmark individual. $\Delta T$ is measured in years, $\Delta u/u$, $\Delta h/h$, and $\Delta V/V$ are relative deviations; $\Delta V/V$ can be read, alternatively, as relative change in lifetime utility or relative change in the value of life. The $z = 1$–columns shows the fraction of the total work life spent in health-demanding occupations; "all" indicates that results are the same, irrespective of the value of $\zeta$.

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