Limited Self-Control and Longevity*

-- Discussion Paper Version --

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Abstract. This paper proposes a new framework to discuss self-control problems in the context of life-cycle health and longevity. Individual decisions are conceptualized as the partial control of impulsive desires of a short-run self (the limbic system) by a rationally forward-looking long-run self (the prefrontal cortex). The short-run self strives for immediate gratification through consumption of health-neutral and unhealthy goods. The long-run self reflects the long-term consequences of unhealthy behavior on health outcomes and longevity and invests time and money to improve current and future health. The model is calibrated with data from the U.S. and used to provide an assessment of the impact of imperfect self-control on unhealthy consumption, physical exercise, lifetime health, and the age at death.

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1. Introduction

Of all deaths in high income countries, about 18 percent have been attributed to smoking, 8.4 percent to overweight and obesity, and 7.7 percent to physical inactivity (WHO, 2009). For the U.S., one study attributes personal decision making to 46 percent of deaths due to heart disease and 66 percent of deaths due to cancer and concludes that "personal decisions are the leading cause of death" (Keeney, 2008). These facts raise doubt as to whether the conventional life cycle model based on fully rational individuals is the appropriate tool to analyze human health behavior and health outcomes. Several manifestations of bounded rationality have been suggested in order to better explain human health behavior (see Cawley and Ruhm, 2012, for an overview) but so far the problem of limited self-control has not been analyzed in the context of an economic life cycle model of endogenous health and longevity.[1]

This paper attempts to improve this state of affairs by integrating imperfect self-control into a life-cycle theory of gerontologically founded human aging. After carefully calibrating the model with data from the U.S., it is used for counterfactual computational experiments in order to assess the importance of self-control problems for health behavior and premature death. The benchmark case suggests that the average American could live 4 to 8 years longer if he had unlimited self-control, i.e. if he would not be afflicted by temptation and behave as the long-term planning agent assumed in conventional life-cycle models. This finding is scrutinized with extensive robustness checks and extensions of the basic model.

The integration of imperfect self-control into health economics is based on the dual-self model of Thaler and Shefrin (1981) and Fudenberg and Levine (2006). This approach formalizes the notion that humans are neither mere "cold" long-run planners nor mere "hot" affective persons by considering a dual-self consisting of a rational long-run self who partly controls the impulsive actions of a short-run self. Self-control, however, comes at a utility cost (in the present context, for example, pain from craving for an unhealthy good). The cost of self-control is increasing in the deviation of the constrained optimal solution from the optimal solution preferred by the short-run self. Structurally, the dual-self model is isomorph to the temptation utility model of Gul and Pesendorfer (2001, 2004). The conventional solution of the discounted utility model is included as a special case of perfect self-control.

[1] Outside the life cycle model, economic theory has addressed the impact of self-control on smoking and obesity (Gruber and Koszegi, 2001; Cutler et al., 2003; Ruhm, 2012).

The dual-self model provides a particular, psychological view on the role of impatience and present bias for human decision making. In economics, these phenomena are usually addressed by the modeling of a discount rate that individuals apply to utility experienced in the future. In health economics, several studies have found that individuals who discount the future heavily are more likely to be obese (e.g. Komlos et al., 2004), to smoke (e.g. Scharff and Viscusi, 2011), and to perform fewer health maintenance activities (Bradford, 2010); for surveys see Lawless et al. (2013) and Bradford et al. (2014). The conventional model of exponential discounting is a useful tool to analyze the impact of (rational) impatience for health behavior. It is, however, unsuitable for addressing present bias stemming from affective (irrational) behavior. For that purpose, it has been proposed to use hyperbolically declining discount rates.

While it is undisputed that individual decisions are subject to a strong present bias (for surveys see Frederick et al., 2002, and DellaVigna, 2009), it is less clear whether hyperbolic discounting is the best tool to describe affective behavior and self-control problems. According to conventional wisdom, hyperbolic discounting necessarily involves time-inconsistent decision making (see e.g. Angeletos et al., 2001., p.53; Cawley and Ruhm, 2012, p. 139). It is possible, however, to propose empirically plausible forms of hyperbolic discounting that support time-consistent decisions.[2] Strulik and Trimborn (2018) have recently integrated time-consistent hyperbolic discounting into a standard life cycle model. They showed that hyperbolically discounting individuals invest more in their health, spend less on unhealthy goods, and live longer than they would if they had a constant time preference rate. These considerations may be helpful for an assessment of the sometimes inconclusive studies on the impact of hyperbolic discounting on health behavior (e.g. Khwaja et al., 2007). Time-inconsistent hyperbolic discount also involves difficult conceptual problems. First it needs to address how individuals deal with their inconsistency problem (in naive or sophisticated way). Secondly, the problem arises whose welfare should be considered by policy interventions. It is thus useful to have an alternative modeling device of present-biased decision making, which models behavior that is time-consistent yet suboptimal from the perspective of a rational long-run planner.

[2]Formally, Strotz's (1956) fundamental theorem states that only exponential discounting leads to time-consistent decisions if the discount factor is a function of the algebraic distance between planning time and payoff time. The "if"-clause, however, seems to sometimes be forgotten in the following literature. In fact, any form of discounting that is separable in planning time and payoff time implies time-consistency, see Theorem 1 in Burness (1976) and Drouhin (2015).

Conceptually, the dual-self model is closer to the notion of multiple simultaneously-operating brain systems in psychology and neuroscience. It takes into account insights from neurology showing that different areas of the brain are occupied with short-run (impulsive) behavior and long-run (planned) behavior (McClure et al., 2004; Bechera, 2005; Hare et al., 2009). Affective states are triggered by the evolutionary older limbic system, which responds to stimuli without accounting for long-term consequences. Abstract thinking and long-term planning are located in the prefrontal cortex, the evolutionary newest area of the brain. The degree by which processes in the prefrontal cortex inhibit and override processes of the limbic system is called self-control or willpower and it is person-specific (i.e. brain-specific).

A series of empirical studies have provided evidence for imperfect self-control as a driver of impulsive consumption and low investment in general (Shiv and Fedorikhin, 1999; Baumeister, 2002; Ameriks et al., 2007) and as driver of unhealthy consumption like overeating (Crescioni et al., 2011; Stutzer and Meier, 2016), alcohol consumption (Lyvers, 2000), smoking (Kan, 2007; Fletcher et al., 2009; Daly et al., 2015), and physical exercise (Bogg and Roberts, 2004; Della Vigna and Malmendier, 2006; Cobb-Clark et al., 2014; Connell-Price and Jamison, 2015). Low self-control in childhood is a strong predictor of health and financial status in adulthood (Moffitt et al., 2011) where adolescents with low self-control develop more health deficits later in life (Miller et al., 2011) and individuals with low self-control tend to die earlier (Kern and Friedman, 2008).

Inferences about causality, however, are difficult to obtain from empirical studies because there exists no counterfactual or treatment group. Since experimental brain surgery is not an option, we cannot observe the same person twice, both with and without self-control problems, and aside from rare exceptions (Navqi et al., 2007) there remains an identification problem. This makes it hard to assess how much low self-control contributes to inferior health behavior and premature death. Here, I suggest addressing this problem with counterfactual computational experiments. I calibrate a dual-self life cycle model of health behavior for a Reference American with limited self-control and then perform the counterfactual exercise of removing the self-control problem.

It should be noted that the method of counterfactual experiments is not meant as a replacement of econometric analysis. It is a complementing, alternative method of inference that is particularly designed to avoid some problems like those originating from backward causality and omitted variables. In the present context, for example, one can easily imagine that self-control

influences also other variables than health behavior, like, for example, work effort, and has thus also an indirect impact on health and longevity through income. The perhaps most useful feature of computational experiments is that certain channels of influence can be shut down by design. In the example, by holding income constant, the computational experiment controls for the impact that self-control could have through income or other confounders on health behavior and health outcomes.

The model framework of health deficit accumulation is particularly suitable for the discussion of unhealthy behavior on the deterioration of bodily function and premature death. It is easy to see why the alternative paradigm, the health capital model (Grossman, 1972), is less suitable: It is based on the assumption that health capital depreciates at a given (potential age-specific) rate $d(t)$ such that individuals with health capital $H(t)$ lose health $d(t)H(t)$ through health depreciation. The health capital model thus assumes that for two persons of the same age t, the one in better health, i.e. with more health capital $H(t)$, loses more health in the next period.[3]

For quantitative explorations it is a problem that health capital is a latent variable, unknown to doctors and medical scientists, a fact that confounds a serious calibration of the model. The health deficit model developed by Dalgaard and Strulik (2014) avoids these shortcomings by using a health measure that has been established in gerontology, the health deficit index. The health deficit (or frailty) index measures the number of health deficits that a person has at a given age relative to the number of potential health deficits. It has been introduced by Mitnitski et al. (2002) and it has instigated a by now very large research program in the medical sciences. Due to its gerontological foundation, the health deficit model can be easily calibrated and used for numerical experiments. In the present context it will be used to assess the role of limited self-control on health behavior, aging, and longevity.[4] The model framework is sufficiently general to allow for a formal discussion of interesting health behavior, for example, the phenomenon of

[3]For a detailed comparison of the assumptions and predictions of the health capital model vs. the health deficit model see Section 2 in Dalgaard and Strulik (2014), Dalgaard and Strulik (2015), and Dalgaard et al. (2017). For a critique of the health capital model see also Case and Deaton, 2005; Wagstaff, 1986; Zweifel and Breyer, 1997; Almond and Currie, 2011.

[4]Earlier quantitative studies using the health deficit model were concerned with the Preston curve (Dalgaard and Strulik, 2014), the education gradient (Strulik, 2018), the long-term evolution of the age at retirement (Dalgaard and Strulik, 2017), and the gender gap in mortality (Schuenemann et al. 2017a).

quitting unhealthy consumption, varying socioeconomic gradients across behaviors like smoking and drinking, and exercising as a means to slow down bodily deterioration and postpone death.[5]

The remainder of the paper is organized as follows. The next section presents the basic model and introduces the key assumptions and mechanisms. In Section 3, the model is calibrated for a 20-year-old American man (called the Reference American) and smoking as the unhealthy good. Section 4 presents life cycle behavior and health outcomes for the Reference American and an otherwise identical person without self-control problems. This (artificial) person is predicted to consume about 45 percent less unhealthy goods and to invest about 16 percent more in his health such that he lives for about 4 years longer. In other words, the model predicts that the Reference American could live about 5 years longer if he had perfect self-control. A detailed sensitivity analysis shows that the predicted life years gained vary between 2 and 8, depending on model specification. The model is then used for a couple of out-of-sample predictions. For example, the model provides an explanation for why the poor are especially prone to self-control problems. In Section 5, the model is extended with respect to physical exercise as a means to improve health and the results from the basic model are corroborated with robustness checks. Section 6 concludes.

2. The Basic Model

Consider an individual who derives utility from consuming health-neutral goods c, as in any standard model, and from consuming unhealthy goods u. Let the utility function be given by

$$U(c,u) = \frac{\left[\beta c^{\psi} + (1-\beta)(u+\zeta)^{\psi}\right]^{\frac{1-\sigma}{\psi}} - 1}{1-\sigma}, \tag{1}$$

in which σ determines the elasticity of intertemporal substitution and ψ determines the elasticity of substitution between health neutral goods and unhealthy goods. The parameter β determines the general desirability of unhealthy consumption and the parameter ζ is a device to introduce abstention from unhealthy consumption, $\zeta \geq 0$. This is important because we would like to capture the fact that some people (of certain age, income group, or level of self-control) completely abstain from consuming the unhealthy good.

[5]The model is also more broadly related to studies that discuss life cycle health issues in a general equilibrium context, like Boehm et al. (2017) using the health deficit approach or Halliday et al. (2017) using the health capital approach. Bagchi and Feigenbaum (2014) discusses the general equilibrium outcomes of smoking on public finances and welfare of non-smokers, taking smoking behavior as given.

Following Fudenberg and Levine (2006), the individual is conceptualized as a dual self. The short-run self is driven by impulses and neglects the long-run consequences of consumption. Suppose the short-self has liquid funds $\tilde{w}$ at her disposal and maximizes (1) subject to the budget constraint $\tilde{w} = c + qu$, in which q is the relative price of unhealthy goods. Unhealthy consumption desired by the short-run self is then given by:

$$u = u_s \equiv \max\left\{0, \ \frac{\tilde{w} - \chi\zeta}{\chi + q}\right\}, \qquad \chi \equiv \left[\frac{1-\beta}{q\beta}\right]^{\frac{1}{\psi-1}} \tag{2}$$

and the desired health neutral consumption is $c = c_s \equiv \chi(u + \zeta)$. Unhealthy consumption preferred by the short-run self is increasing in liquid funds and declining in the price of unhealthy goods q, its desirability β, and the abstention parameter ζ. Notice that the short-run self would always desire a positive quantity of u if $\zeta = 0$. By inserting u_s and c_s into (1) we obtain the indirect utility (immediate gratification) desired by the short-run self, denoted by $U(c_s, u_s)$.

The long-run self faces the same instantaneous utility function (1), plans life cycle decisions from now until death, and takes the impact of unhealthy consumption on health into account. Moreover, the long-run self spends some income on health care and saves some income for later use, particularly for remedying health deficits in old age. This means that the long-run self faces the budget constraint

$$\dot{k} = w + rk - c - qu - ph, \tag{3}$$

in which k is financial wealth, r is the interest rate, w is non-financial income, h is health expenditure, and p is the relative price of health.

As they age, individuals accumulate health deficits D at a natural rate μ (Mitnitski et al., 2002). Health investments slow down the rate of health deficit accumulation (as in Dalgaard and Strulik, 2014) and unhealthy consumption speeds up health deficit accumulation. The health deficit index measures the number of health deficits that a person has at a given age relative to the number of potential health deficits. Summarizing the evolution of health deficits is given by

$$\dot{D} = \mu\left[D - Ah^{\gamma} + Bu - a\right]. \tag{4}$$

The parameters A and γ determine the available medical technology, as explained in detail in Dalgaard and Strulik (2014). The parameter B determines the unhealthiness of u-consumption.

Since little is known about the involved "technology" we assume a linear impact of unhealthy good consumption on health deficit accumulation in order to obtain a closed-form solution.

Following Fudenberg and Levine (2006), the long-run self maximizes lifetime utility

$$V = \int_0^T \mathrm{e}^{-\rho t} \left\{ U(c,u) - \omega \left[U(c_s,u_s) - U(c,u) \right] \right\} \mathrm{d}t. \tag{5}$$

We consider adults and the initial age 0 will be associated with age 20 in the numerical calibration. The term in square brackets in (5) reflects the difference between the utility desired by the short-run self $U(c_s, u_s)$ and the utility actually experienced $U(c_s, u_s)$. The parameter ω measures the cost of self-control, i.e. the expression $\omega \left[U(c_s,u_s) - U(c,u) \right]$ measures the "pain" that the individual experiences when he does not concede to the desires of the impulsive short-run self. For $\omega = 0$, we would have perfect self-control (or willpower) and the model is reduced to a standard life cycle model of health deficit accumulation. The main aim of the calibrated model will be to estimate ω and then to run the counterfactual experiment by setting $\omega = 0$ and to discover how individuals would behave and how long they would live if there were no self-control problems.

The current value Hamiltonian associated with problem (1)–(5) is given by

$$H = (1+\omega)U(c,u) - \omega U(c_s,u_s) + \lambda_k \left[w + rk - c - qu - ph \right] + \lambda_D \mu \left[D - Ah^\gamma + Bu - a \right]. \tag{6}$$

The first order conditions with respect to consumption c, unhealthy consumption u, and health investments h are

$$0 = \frac{\partial U}{\partial c} - \frac{\lambda_k}{1+\omega} \tag{7}$$

$$0 = u \left[\frac{\partial U}{\partial h} - \frac{\lambda_k q - \lambda_D \mu B}{1+\omega} \right] \tag{8}$$

$$0 = \lambda_k p + \lambda_D \mu \gamma A h^{\gamma-1}. \tag{9}$$

The first term on the right-hand side of condition (7) is the marginal utility experienced from consuming one unit of health neutral goods. If ω were zero, the right-hand side of (7) would be equal to the marginal cost of consuming one unit, consisting of foregone saving multiplied by the shadow price of capital λ_k, as in the standard life cycle model. With limited self-control, $\omega > 0$ and the right-hand side is smaller than the marginal cost of consumption. This means that the left-hand side is also smaller than in the corresponding standard model such that individuals,

ceteris paribus, consume more and save less since marginal utility is declining with increasing consumption.

Likewise, if the individual consumes the unhealthy good, the first term in parentheses of condition (8) shows the marginal utility experienced from consuming one unit of the unhealthy good. If ω were zero, the second term in parentheses would be the marginal cost of consuming the unhealthy good, which accrues because of lower savings (marginal effect captured by $\lambda_k q$) and because of the quicker accumulation of health deficits (marginal effect captured by $\lambda_D \mu B$). Note that health deficits are "bad" such that the associated shadow price λ_D is negative. With limited self-control, $\omega > 0$ and individuals devalue the costs of unhealthy consumption. This means that they consume more unhealthy goods and experience lower marginal utility from consumption. Ceteris paribus, the consumption of unhealthy and health neutral goods is increasing in ω (declining in willpower).

Condition (9) requires that the marginal cost of health expenditure, given by λp, is equal to the marginal benefit of health expenditure. The marginal benefit consists of the marginal impact on health deficit accumulation $\mu\gamma A^{\gamma-1}$ (i.e. the marginal productivity of the health technology) multiplied by the contribution to the objective function of having one health deficit less ($-\lambda_D$).

The costate equations for problem (1)–(5) are:

$$r\lambda_k = \rho\lambda_k - \dot{\lambda}_k \tag{10}$$

$$\mu\lambda_D = \rho\lambda_D - \dot{\lambda}_D. \tag{11}$$

The system (7)–(11) can be simplified by eliminating the co-state variables. This leads to the following solution:

$$\frac{\dot{h}}{h} = \frac{r-\mu}{1-\gamma}. \tag{12}$$

$$\text{If} \quad \left(q + \frac{pB}{\gamma A h^{\gamma-1}}\right)\frac{\beta}{1-\beta} \geq \left(\frac{c}{\zeta}\right)^{\frac{1}{1-\psi}}, \text{ then } \quad u = 0, \quad \frac{\dot{c}}{c} = \frac{r-\rho}{\sigma + \frac{(1-\sigma-\psi)(1-\beta)(c/\zeta)^{-\psi}}{\beta+(1-\beta)(c/\zeta)^{-\psi}}}. \tag{13}$$

Otherwise:

$$u = c\left\{\left[\frac{pB}{\gamma A h^{\gamma-1}} + q\right]\frac{\beta}{1-\beta}\right\}^{\frac{1}{\psi-1}} - \zeta \tag{14}$$

$$\frac{\dot{c}}{c} = \frac{1}{\sigma}\left\{r - \rho - (1-\sigma-\psi)\frac{(1-\beta)x^{\psi}}{\beta+(1-\beta)x^{\psi}} \cdot \frac{r-\mu}{(1-\gamma)(\psi-1)\left(1+\frac{q\gamma A h^{\gamma-1}}{pB}\right)}\right\} \tag{15}$$

with $x \equiv (u+\zeta)/c$. Equation (12) is the "Health Euler" for the lifetime trajectory of health expenditure, as derived and explained in Dalgaard and Strulik (2014). The condition in (13) determines whether individuals consume the unhealthy good. The unhealthy good is not consumed if it is sufficiently expensive (q is sufficiently high), or sufficiently harmful (B is sufficiently high), or if it is sufficiently little desired ($\beta/(1-\beta)$ is sufficiently high). Ceteris paribus, the unhealthy good is more likely to be consumed if health neutral consumption is high (because the two goods are not perfect substitutes), if the price of health care p is low, and if health investment is low such that marginal return of health expenditure, $\gamma A h^{\gamma-1}$, is high. In this case, damages from unhealthy consumption are relatively cheaply repaired, which provides an incentive to make unhealthy consumption choices. Notice that these partial effects introduce an a priori ambiguous income effect on unhealthy consumption since richer individuals are likely to spend not only more on health neutral consumption (thereby increasing the incentive for unhealthy behavior) but also more on health (thereby reducing the incentive for unhealthy behavior). Which effect dominates is an interesting question that will be answered with the calibrated model in Section 3. At a more general level, notice that the long-run self takes into account how unhealthy consumption damages the body and how easily the damage could be repaired while the short-run self cares only about short-run costs and pleasures, cf. equation (2).

Inspection of (14) shows that if the unhealthy good is consumed, higher q, p, B, and h lead to lower consumption while higher c induces more consumption, with the same intuition as provided with respect to the extensive margin. Equations (13) and (15) are the Euler equations for health neutral consumption. The standard Euler equation is augmented to take the effect from (potential) unhealthy consumption into account. For the special case of $\beta = 1$, there is never an incentive for unhealthy consumption and (13) is reduced to the standard Ramsey rule $\dot{c}/c = (r-\rho)/\sigma$.

An interesting feature of the reduced-form dynamic system (12)–(15) is that it is independent from ω. This does, of course, not mean that the solution is independent from willpower. Willpower enters through the terminal condition, which requires that the Hamiltonian at the time of death is zero, which can be equivalently written as in (16):

$$0 = \bar{H} \equiv \frac{H(T)}{1+\omega} = U(c(T), u(T)) - \frac{\omega}{1+\omega} U(c_s, u_s) \tag{16}$$
$$+ \frac{\lambda_k(T)}{1+\omega}\left[w(T) + rk(T) - c(T) - qu(T) - ph(T)\right] + \frac{\lambda_D(T)}{1+\omega}\mu\left[D - Ah(T)^{\gamma} + Bu(T) - a\right].$$

Notice that lower willpower, i.e. higher ω, amplifies the negative impact of short-run desires $U(c_s, u_s)$ on $\bar{H}$ and that it reduces the positive impact of savings and health deficit accumulation. From this, we expect that it leads to life cycle decisions resulting in a shorter life. Willpower thus affects the level of expenditure allocated to the two goods and savings and health expenditure but it does not affect the slope of life cycle trajectories, which are obtained from the Euler equations. Intuitively, it makes sense that the slope of life cycle trajectories is determined by intertemporal trade-offs faced by the long-run self, based on r, ρ, and other prices, while short-run desires impact on the "within period" allocation, i.e. on the level of the expenditure paths. How exactly life cycle plans are affected by willpower can only be determined by numerical analysis. The other boundary conditions are that the optimal life cycle trajectory has to fulfil are $k(0) = k_0$, $D(0) = D_0$, $k(T) = \bar{k}$, and $D(T) = \bar{D}$, implying that the individual dies when $\bar{D}$ health deficits have been accumulated.

3. Calibration

The model is calibrated to match initial deficits D_0, final deficits $\bar{D}$, longevity T, and life-cycle health investments $h(t)$ for 20-year-old U.S. American men in the year 2010. From Mitnitski et al. (2002), I take the estimate for the rate of aging, $\mu = 0.043$. I set r to 0.07 according to the long-run real interest rate (Jorda et al., 2017) and $\rho = r$ as in Dalgaard and Strulik (2014). 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). From Mitnitski et al. (2002), I infer terminal health deficits $\bar{D} = D(75.6) = 0.106$ and initial health deficits $D(0) = D(20) = 0.0273$.[6] In order to get an estimate of a, I assume that before the 20th century, the impact of medical technology on adult mortality was virtually zero. In the year 1900, the life expectancy of a 20-year-old American was 42 years (death at 62; Fries, 1980), implying that a 20-year-old expected to live for 46 additional years. I set a such that a person who abstains from unhealthy consumption and has no access to life prolonging medical technology expects $T = 46$. From this value, I get the estimate $a = 0.0135$.

When the individual is between 20 and 65 years old, I set $w = 27,928$, which is the average labor income for single men in the year 2010 (BLS, 2012). For older individuals, I set $w =$

[6] Mitnitski et al. estimate health deficit accumulation for Canadian men. Deficit accumulation within the USA and Canada appears to be similar enough to justify it as a good approximation for the U.S. (Rockwood and Mitnitski, 2007).

$0.45 \cdot 27,928$ using an average replacement rate of 0.45 from the OECD (2016). In order to assure that the savings motive is confined to that of health and consumption expenditure, I assume that the initial and final capital stock are zero. I assume that all labor income and pension payments are liquid but that capital income is illiquid, i.e. for the benchmark case $\tilde{w} = w$. Furthermore, I normalize the price of health and the unhealthy good to unity, $p = q = 1$. This is an interesting benchmark case because it eliminates any price channel through which poor individuals may have an incentive to consume more unhealthy goods or spend less on health. We later investigate the sensitivity of results with respect to alternative prices.

While the model is applicable for unhealthy consumption in general, we need to specify the unhealthy good for quantitative analysis. Since most of the available empirical literature on consumption of unhealthy goods is on cigarettes and tobacco, I begin with a calibration that tries to capture characteristics of cigarette consumption and investigate alternative assumptions with a sensitivity analysis.[7] On average, single male Americans spent \$ 364 on cigarettes in the year 2010 (BLS, 2012). Doll et al. (2004) estimate that for men born between 1900 and 1930, cessation at age 60, 50, 40, or 30 gained, respectively, about 3, 6, 9, or 10 years of life expectancy. Jha et al. (2013) arrive at an even higher estimate and suggest that life expectancy is shortened by more than 10 years among current smokers compared with those who have never smoked. Schauer et al. (2015) estimate that the mean age of cessation (of those who quit smoking) is about 40 years. Of course, some individuals never quit. According to the CDC (2012), 8 percent of American men aged 65 and over were smoking in the year 2010. These considerations illustrate that any calibration of a Reference American will be a compromise that tries to capture the essence of these stylized facts.

Obviously, the degree of self-control ω is difficult to quantify, mostly due to measurements problems. To deal with this problem, I consider the sensitivity of results with respect to this parameter. In an attempt to assess ω, I relate the benchmark specification to the estimate provided by Kovacs (2016). This study estimates the temptation parameter for Gul and Pesendorfer (2001) preferences, which can be mapped into an estimate of ω. In order to see this, note that maximizing $U(c,u) - \omega\left[U(c_s,u_s) - U(c,u)\right]$ is the same as maximizing $U(c,u) - \frac{\omega}{1+\omega}U(c_s,u_s)$.

[7] Following (Kan, 2007), Fletcher (2009), and Daly (2015), we consider smoking, and in particular, not quitting smoking, to be explained by limited self-control. An alternative and complementing approach would be to follow the rational addiction literature (Becker and Murphy, 1988) and explain smoking as a habit with reinforcement and tolerance effects. In Strulik (2017), I investigate rational addiction in the context of the health deficit model.

This means that the utility function is structurally identical with temptation preferences as in Gul and Pesendorfer (2001), where $\omega/(1+\omega) \equiv \lambda$ is the temptation parameter. Using consumer expenditure data for the US, Kovacs (2016, Table 5) estimates $\lambda = 0.2$, implying $\omega = 0.25$.

The remaining seven parameters, A, B, β, γ, σ, ψ, and ζ, are calibrated jointly with ω such that: (i) the model predicts the actual accumulation of health deficits over a lifetime (as estimated by Mitnitski et al., 2002), (ii) death occurs at the moment when $\bar{D}$ health deficits have been accumulated at an age of 77.1 years, (iii-iv) health expenditure matches health care expenditure of American men in 2010 at the age of 35 and 70 (MEPS, 2010), (v) the Reference American spends on average \$ 364 per year on the unhealthy good, (vi) the Reference American quits smoking for good at age 45, and (vii) that consumption of the unhealthy good costs about 7 years of life. This leads to the estimates $A = 0.00177$, $B = 3 \cdot 10^{-6}$, $\beta = 0.365$, $\gamma = 0.19$, $\psi = 0.5$, $\zeta = 650$, and $\sigma = 1.035$.[8]

The estimated value of σ is in line with empirical studies suggesting that the intertemporal elasticity of substitution is close to unity (Chetty, 2006). The implied price elasticity of demand for the unhealthy good is -0.48 which is in the middle of the empirical estimates of the demand elasticity for cigarettes compiled in Chaloupka and Warner (2000). As another plausibility check of the calibration, I calculate the value of life (VOL) of the Reference American and compare it with previous estimates. The VOL provides a monetary expression of aggregate utility experienced during life until its end, that is, period utility is converted by the unit value of an "util", $u'(c)$. The VOL at the initial age is obtained by applying the formula $VOL = \int_0^T \mathrm{e}^{-\rho(\tau-t)} U(c(\tau), u(\tau)) \mathrm{d}\tau / [\partial U(c(0), u(0))/\partial c(0)]$. The benchmark calibration predicts a VOL of about \$ 5.9 million at age 20. In terms of order of magnitude, this value corresponds well to Murphy and Topel's (2006, Fig. 3) estimate of a VOL of about \$ 6.5 million for American men at age 20.

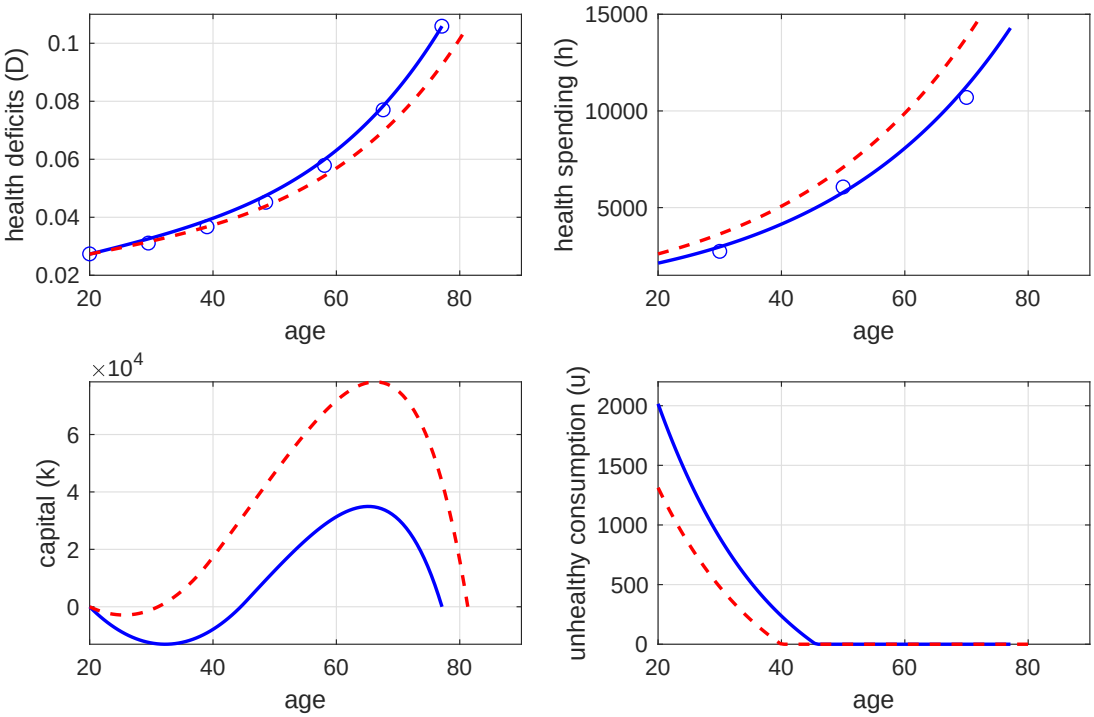
4. Results

4.1. **Limited Self-Control, Health Behavior, and Longevity.** The life cycle health behavior of the Reference American and the implied accumulation of health deficits is shown in Figure 1 by blue (solid) lines. Dots in the health deficit panel indicate the actual health deficits at the

[8]The health data from MEPS (2010) represent total health services including inpatient hospital and physician services, ambulatory physician and nonphysician services, prescribed medicines, home health services, dental services, and various other medical equipment and services that were purchased or rented during the year.

specific ages according to Mitnitski et al. (2002) and dots in the health spending panel indicate actual health expenditure according to MEPS (2010). The upper right panel shows that health expenditure is increasing over age. High health expenditure at old age is financed by savings in middle age, as shown in the lower left panel. The young Reference American goes into debt until age 33 at which point he starts saving and breaks even at age 42. He then accumulates wealth until shortly before retirement at age 65. From then on he depletes his savings in order to finance consumption and high health expenditure in old age. Unhealthy consumption is high when the Reference American is young and then falls steeply with increasing age, as shown in the lower right panel.

FIGURE 1: THE IMPACT OF SELF-CONTROL ON WEALTH AND HEALTH OVER THE LIFE



Blue (solid) lines: limited self-control ($\omega = 0.25$; $T + 20 = 77.1$). Red (dashed lines): perfect self-control ($\omega = 0$; $T + 20 = 81.3$). Dots indicate data from Mitnitski et al. (2002) and MEPS (2010).

According to the model estimate, the Reference American has a self-control value of 0.25. In order to figure out what this number means we rerun the model and set $\omega = 0$, i.e. we endow the Reference American with unlimited self-control and keep everything else from the benchmark calibration. The implied life cycle trajectories are shown by red (dashed) lines in Figure 1. If he had high self-control, the Reference American would reduce smoking at young age and quit

smoking earlier. Moreover, he would save substantially more and start saving more early in life. He would use the extra savings to spend more on health in late age. As a consequence, he would accumulate health deficits more slowly and die significantly later, at age 81.3, instead of age 77.1. This means that the model estimates that imperfect self-control costs the Reference American 4.2 years of his life.

In order to check the robustness of these conclusions, we proceed with a sensitivity analysis. Results are shown in Table 1. Case 1 repeats the benchmark run from Figure 1. The $\Delta h/h$ column shows that the individual would increase lifetime health expenditure by about 16 percent without self-control problems. The $\Delta u/u$ column shows that, with perfect self-control, the individual would reduce unhealthy consumption by about 45 percent. The ΔT columns shows the implied increase of longevity (4.2 years).

Table 1: The Impact of Self Control on Health Behavior and Longevity

case	change	remark	$\Delta u/u$	$\Delta h/h$	ΔT
1	–	benchmark	-45.4	16.4	4.2
2	$\omega = 0.5$	lower self-control	-65.3	33.1	7.9
3	$\omega = 1$	low self-control	-82.6	69.5	14.6
4	$\psi = -0.25$	low elast. of substitution	-33.4	13.0	2.9
5	$B = 10^{-6}$	u less unhealthy	-40.9	22.7	2.0
6	$q = 0.5$	u less expensive	-48.4	16.0	4.4
7	$\tilde{w} = 0.1w$	less temptation	-52.2	14.3	3.9

The table shows the impact of self-control by reducing ω to zero; ΔT is measured in years, $\Delta u/u$ and $\Delta h/h$ are measured in percent.

Case 2 shows that for $\omega = 0.50$ the individual would smoke about 65 percent less, spend about 1/3 more on health and live almost 8 years longer. If self-control declines further and $\omega = 1$, as for case 3, the individual would smoke more than 80 percent less if he had unlimited self-control. This result can be related to the study by Fletcher et al. (2009) on smoking and self-control. Using finite mixture models, Fletcher et al. identify two distinct groups, 'light smokers' and 'heavy smokers' and a strong relationship between their measure of self-control and group allocation of individuals. On average, individuals assigned to the light-smoker–high-self-control group smoke 94 percent less than the individuals in the heavy-smoker–low-self-control group (0.3 versus 5.8 cigarettes per day). If we thus conceptualize a value of $\omega = 1$ (or higher) as low self-control and assume that the Reference American has average self-control, the implied

ω would be closer to 0.5 than 0.25.[9] Altogether this suggests that the average American loses between 4 and 8 years of life due to self-control problems in consumption and health behavior.

We next consider several cases with different types of unhealthy goods. Case 4 sets ψ to -0.25 implying that the elasticity of substitution between unhealthy and health-neutral goods is 0.8 (instead of 2). It also implies a reduction of the price elasticity of demand for the unhealthy good to -0.32 (from -0.48). Naturally, the feature that the unhealthy good is now more complementary to ordinary consumption than cigarettes leads to the prediction of a lower reduction of unhealthy consumption. If the Reference American had perfect self-control, u would decline by 33 percent. As a side effect, health investments increase less steeply by 13 percent, implying that together, 2.9 years of life could be saved by perfect self-control.

Case 5 makes consumption less unhealthy by reducing B by factor 3 to 10^{-6}, implying that 2.5 years of life could be saved by abstaining from unhealthy consumption. This value would be at the lower end of the empirical estimates for cigarettes and at the upper end of the estimates for alcohol. It requires an increase in β to 0.68 and a reduction of A to 0.0015 (lower power of medical technology) because otherwise, the Reference American would consume the unhealthy good too much and/or live too long. With these adjustments the model predicts that a transition to full self-control would save 2.0 years of life by reducing unhealthy consumption by about 40 percent and increasing health expenditure by 23 percent.

Case 7 shows that price effects play only a minor role. If we reduce the price of the unhealthy good by half, the outcome is similar as for the benchmark case, with a 48 percent reduction of unhealthy consumption and a 4.4 year gain in longevity in the case of perfect self-control. Finally, we consider a (drastic) reduction of liquid funds for spontaneous consumption. In order to match expenditure and life expectancy, σ is adjusted to 1.025. If only 10 percent (instead of 100 percent) of wage income were at disposal for consumption, the decline of unhealthy consumption would be 52 (instead of 45) percent and "only" 3.9 years of life would be gained from perfect self-control.

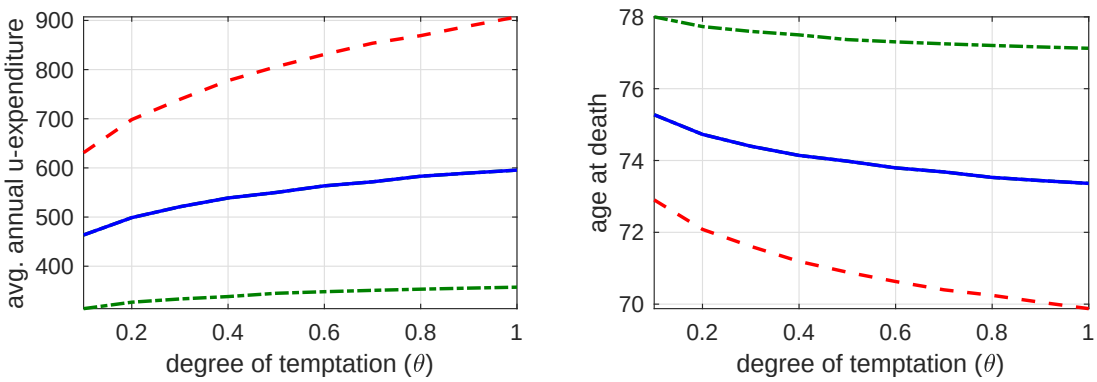
To summarize, the model suggests that about 4 to 8 years of life are lost due to limited self-control. If the price elasticity of the unhealthy good or its unhealthiness is calibrated using

[9]The Fletcher et al. study considers students in grades 7 through 12, which is not the same as our 20 years old benchmark American. The analogy is thus not perfect, in particular, if one acknowledges that self-control is malleable at young ages, see the Conclusion.

values from the lower bound of empirical estimates, the model suggest a lower bound of about 2 years of life lost due to limited self-control.

4.2. **Temptation and the Power of Willpower.** We next use the model for some out of sample predictions. We first confirm a result well-known from the literature, namely that the size of liquid funds matters for behavior, in particular for individuals with low self-control. Figure 2 shows unhealthy consumption and age at death for different degrees of temptation, defined as the share of labor income available for spontaneous purchases ($\tilde{w} = \theta w$). Solid (blue) lines show the outcome for $\omega = 0.5$ (case 1 of Table 1). Going from $\theta = 1$ to 0.1, the Reference American would reduce his average spending on unhealthy consumption by \$ 150 per year and gain about 1.5 additional years of life. A person with less self-control, however, would benefit more from reducing temptation. Dashed (red) lines show outcomes for an otherwise identical person with $\omega = 0.75$. This person is predicted to reduce spending on unhealthy consumption by \$ 250 as θ goes from 1 to 0.1 and would gain about 3 years of life. Naturally, a person with higher self-control ($\omega = 0.25$, represented by dashed-dotted lines) would be relatively unresponsive to reduced temptation and would gain in terms of life extension.

Figure 2: Temptation, Health Behavior, and Longevity



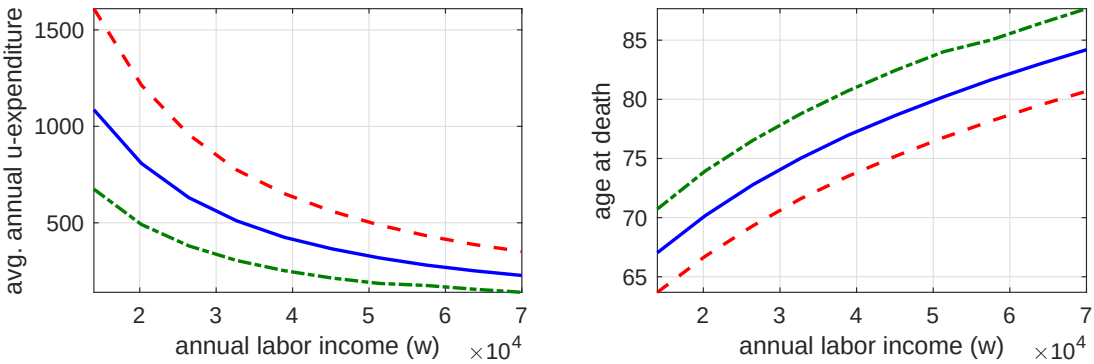
The degree of temptation is the share of labor income disposable for spontaneous consumption. Blue (solid) lines: medium self control ($\omega = 0.5$); red (dashed) lines: lower self-control ($\omega = 0.75$); green (dash-dotted) lines: higher self-control ($\omega = 0.25$).

4.3. **Socioeconomic Status, Self-Control, and Health Behavior.** We next feed different levels of annual labor income into the model. In Figure 3, solid (blue) lines show results for medium self-control ($\omega = 0.5$). The model predicts, in line with the empirical evidence (e.g. Cawley and Ruhm, 2012), that richer persons smoke less. From the perspective of the simple

life cycle model, however, this prediction is perhaps not obvious. Richer persons have a greater budget to spend on everything, including cigarettes, and could thus be expected to smoke more.

For an intuition, a second look at demand for unhealthy goods in equation (16) is helpful. Unhealthy consumption u correlates positively with health neutral consumption c because the goods are not perfect substitutes. Unhealthy consumption, however, also correlates negatively with health expenditure because an optimal allocation of expenditure requires an equalization of the marginal health damage from u and the marginal health gain from h. Because lifetime utility is concave in instantaneous consumption but linear in longevity, richer persons have a greater incentive to spend more on health (see Dalgaard and Strulik, 2014, for a detailed discussion). The marginal return from health spending is thus lower for richer persons who consequently prefer a lower marginal damage from unhealthy consumption. This effect, taken for itself, reduces unhealthy consumption. Whether the c-effect or the h-effect on unhealthy consumption dominates, is undetermined from a theoretical perspective. For our benchmark calibration the health effect dominates and richer persons are predicted to consume less unhealthy goods.

Figure 3: Income, Health Behavior, and Longevity



Blue (solid) lines: medium self control ($\omega = 0.5$); red (dashed) lines: lower self-control ($\omega = 0.75$); green (dash-dotted) lines: higher self-control ($\omega = 0.25$).

For the size of the effect of income on unhealthy consumption the elasticity of substitution is crucial. In the benchmark case of $\psi = 0.5$, the elasticity is 2 and thus quite high. For case 4 from Table 1, assuming $\psi = -0.25$ and thus an elasticity of substitution of 0.8, the result is overturned, and the rich are predicted to consume more unhealthy goods than the poor. A low elasticity of substitution better characterizes alcohol than cigarettes if one acknowledges that bread and wine are better complements than bread and cigarettes. The result may thus

be helpful in order to explain why the rich drink more than the poor, whereas the poor smoke more than the rich.

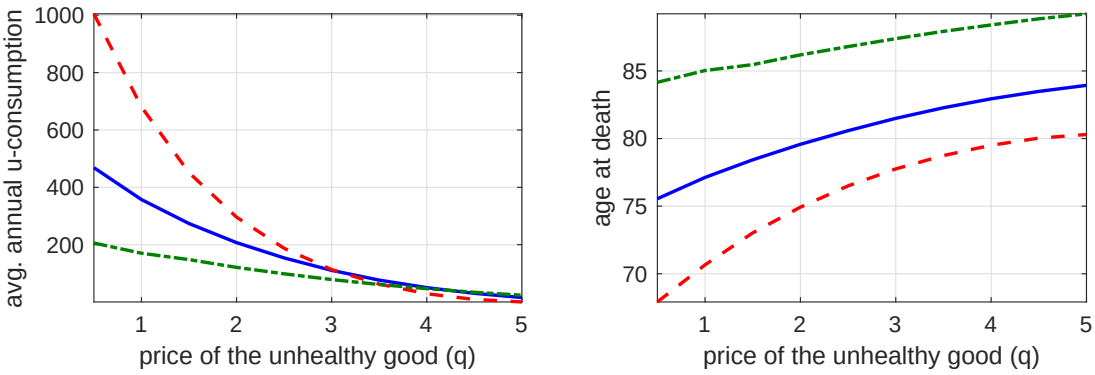
Another interesting observation from Figure 3 is in regards to the impact of self-control. Dashed (red) lines show results for $\omega = 0.75$ and dash-dotted (green) lines show results for $\omega = 0.25$. We see that low self-control is particularly problematic for the poor. The intuition for this result is similar to the one developed above in conjunction with the income effect. Impulsive consumption is subject to decreasing marginal utility (from yet another cigarette now) whereas lifetime utility is linear in life length. This means that impulse consumption is relatively important in the calculus of poor people who have little means to save much for life-extending health expenditure. Rich people, in contrast, experience relatively little additional pleasure from another unit of the unhealthy good. This feature makes them relatively immune against temptation and their behavior is less affected by low willpower.

4.4. **Prices, Income, and Longevity.** In Figure 4, we look at the impact of prices of the unhealthy good on consumption and age at death. We consider the benchmark individual (blue solid lines), and individuals with higher (green dashed-dotted lines) and lower (red dotted lines) labor income. The impact of a rise in price (cigarette taxes) is predicted to be relatively high when the price is relatively low, and for individuals with low income. The different response across income levels is again explained with the notion of declining marginal utility. Unhealthy consumption (or, more generally, impulsive consumption) plays a relatively large role in the life cycles decisions of poor individuals but it is of less importance for rich people. For example, when the income of the Reference American doubles, temptation utility U_s increases by only 10 percent. This means that the life cycle decision of the rich are only slightly affected by impulsive consumption and the pricing of unhealthy goods, on which they in any case spend a relatively low share of their budget.

As shown in the panel on the right-hand side of Figure 4, increasing prices for unhealthy consumption reduce the socioeconomic gradient in health. When prices rise from 0.5 to 5, the longevity gap between low and high income individuals declines from about 15 years to 8 years. The reason for the remaining difference is that the poor continue to suffer from a greater propensity for impulsive consumption, save less, and spend less on health care. The result that the price increase eliminates higher unhealthy consumption of the poor does not necessarily imply that it increases their welfare. Higher expenditure qu exerts a negative influence on welfare. A

policy that reduces temptation θ (e.g. smoking bans) would reduce the health gradient without negative repercussions on welfare.

Figure 4: Prices, Income, and Longevity



Blue (solid) lines: benchmark calibration; red (dashed) lines: half of benchmark income; green (dash-dotted) lines: double benchmark income.

5. Health Effort and Health Consumption

5.1. **Model.** In this section we consider extensions of the basic model in two directions. First, we allow the state of health to enter the utility function, popularized as the "health consumption" approach (Grossman, 2000). This provides a second motive for healthy behavior for the long-run self, aside from the desire for a long life: the experience of high life satisfaction in a good state of health. Health deficits in the utility function can be calibrated on the basis of Finkelstein et al. (2013). This has been done before in Schuenemann et al. (2017b). The main purpose here is to check the robustness of the results on the impact of self-control with respect to this extension.

The second extension is new in the health deficit literature. It considers physical exercise as a further potentially life-prolonging health behavior. This is an important extension in the present context because the empirical literature argues that in particular, low self-control is a main driver of too little physical exercise and the health consequences of it (overweight, obesity, hypertension, diabetes, etc).

In order to integrate the new elements, we rewrite the instantaneous utility function as

$$\tilde{U} = \left(\frac{D_0}{D}\right)^{\alpha} U(c,u) - \delta \left(\frac{D}{D_0}\right)^{\eta} \tau, \tag{17}$$

in which utility from consumption $U(c,u)$ is carried over from (1). The initial state of health D_0 is a normalizing constant such that individuals experience the highest utility from health at

the initial state of best health, when $D = D_0$. From then on, health deteriorates as individuals age and utility declines. How much utility from consumption declines with the accumulation of health deficits is measured by the parameter α, $0 \leq \alpha \leq 1$. The second term in (17) captures the disutility from physical exercise. The variable τ measures the intensity of physical exercise and the parameter δ controls how much the individual dislikes physical exercise in general. The parameter η measures how much the disutitility from physical exercise increases with deteriorating health, assuming that physical exercise gets increasingly painful with the accumulation of health deficits, $\eta \geq 1$.

The purpose of physical exercise is to keep the body in good shape and to delay the accumulation of health deficits. This function can be conveniently integrated into the model by rewriting the equation of motion for health deficits as:

$$D = \mu \left[D - Ah^{\gamma} + Bu - E\tau^{\phi} - a \right], \tag{18}$$

which replaces (4). The parameter E controls the general healthiness of physical exercise and the parameter ϕ controls the (declining) marginal return of physical exercise, $0 < \phi < 1$. The equation of motion for financial wealth is the same as in the basic model (3).

A natural benchmark is to assume that the short-run self cares only about pleasure from consumption and ignores health, implying that the desired level of unhealthy consumption u_s carries over from (2). This means that the pleasure desired by the short-run self, $U(c_s, u_s)$, is the same as in the basic model since the short-run self prefers to exert no effort in physical exercise.

The long-run self solves the problem (1), (3),(17),(18) under the same initial and boundary conditions as in the basic case. The associated current value Hamiltonian is given by

$$\begin{aligned} H = (1+\omega) \left\{ \left(\frac{D_0}{D} \right)^{\alpha} U(c,u) - \delta \left(\frac{D}{D_0} \right)^{\eta} \tau \right\} - \omega U(c_s, u_s) \\ + \lambda_k \left[w + rk - c - qu - ph \right] + \lambda_D \mu \left[D - Ah^{\gamma} + Bu - E\tau^{\phi} - a \right]. \end{aligned} \tag{19}$$

We obtain a new first order condition for optimal physical effort (20):

$$(1+\omega)\delta \left(\frac{D}{D_0} \right)^{\eta} = -\lambda_D \mu E \phi \tau^{\phi - 1}. \tag{20}$$

The term on the right-hand side of (20) shows the marginal gain from physical exercise. According to (18), a unit of physical exercise slows down health deficit accumulation by $\mu E \phi \tau^{\phi-1}$.

Multiplying this effect by λ_D provides the gain in terms of utils (contribution to the objective function). To see this, recall that λ_D is negative since more health damage is bad for lifetime utility. The term $\delta\left(D/D_0\right)^{\eta}$ on the left-hand side of (20) is the utility cost of physical exercise. With perfect self-control, ω would be zero and marginal benefits and costs of physical exercise would equalized. Limited self-control increases the left-hand side of (20) beyond the utility cost of exercise. This means that in order to equilibrate the equation, the marginal return of physical exercise has to be larger as well, which in turn implies that the level of physical exercise τ is lower than it would be under perfect self-control. The intricate way in which low self-control matters for physical exercise is perhaps not obvious: physical exercise reduces instantaneous utility $\tilde{U}$, cf. (17). This makes it harder for the long-run self to resist the desires of the short-run self. Formally, $\omega(\tilde{U}(c_s)-\tilde{U})$ increases. The magnitude of the effect is increasing in ω, i.e. declining in the degree of self-control.

The other first order conditions and co-state equations are similar in the basic model but modified to include the impact of deteriorating health on utility. With auxiliary variable $x \equiv (u+\zeta)/c$ this leads to the following solution:

$$\tau = \left\{ \left(\frac{D_0}{D}\right)^{\alpha+\eta} \frac{p\phi E}{\gamma\delta A h^{\gamma-1}} \beta c^{-\sigma} \left[\beta + (1-\beta)x^{\psi}\right]^{\frac{1-\sigma}{\psi}-1} \right\}^{\frac{1}{1-\phi}} \tag{21}$$

$$\frac{\dot{h}}{h} = \frac{1}{1-\gamma}\left\{ r - \mu - \frac{\mu E \phi \tau^{\phi-1}}{\delta D}\left[\left(\frac{D_0}{D}\right)^{\alpha+\eta} \alpha U(c,u) + \delta\eta\tau\right]\right\}. \tag{22}$$

$$\text{If} \quad \left(q + \frac{pB}{\gamma A h^{\gamma-1}}\right)\frac{\beta}{1-\beta} \geq \left(\frac{c}{\zeta}\right)^{\frac{1}{1-\psi}}, \text{ then } \; u = 0, \; \frac{\dot{c}}{c} = \frac{r-\rho-\alpha(\dot{D}/D)}{\sigma + \frac{(1-\sigma-\psi)(1-\beta)(c/\zeta)^{-\psi}}{\beta+(1-\beta)(c/\zeta)^{-\psi}}}. \tag{23}$$

Otherwise:

$$u = c\left\{\left[\frac{pB}{\gamma A h^{\gamma-1}} + q\right]\frac{\beta}{1-\beta}\right\}^{\frac{1}{\psi-1}} - \zeta \tag{24}$$

$$\frac{\dot{c}}{c} = \frac{1}{\sigma}\left\{ r - \rho - \alpha(\dot{D}/D) - (1-\sigma-\psi)\frac{x^{\psi}}{\beta+(1-\beta)x^{\psi}} \cdot \frac{1}{(1-\psi)\left(1+\frac{q\gamma A h^{\gamma-1}}{pB}\right)}\frac{\dot{h}}{h}\right\}. \tag{25}$$

Equation (21) provides the solution for physical exercise τ. Physical exercise is high for healthy persons (with low D) and when the health gain E is large. It is low when δ is large, i.e. when exercising provides much disutility. Interestingly, physical exercise is also high when

the marginal return of health investments $\gamma A h^{\gamma-1}/p$ is low. This outcome is intuitive because it makes sense to invest more in terms of exercise in order to reduce the accumulation of health deficits when there is little impact of further monetary investments on the state of health. This would imply that richer persons (who presumably spend more on their health) would exercise more. However, exercise is also negatively associated with consumption c, which is presumably higher for richer people. It is thus a priori undetermined whether the rich exercise more than the poor.

The condition for unhealthy consumption is the same as in the basic model. The Euler equations for consumption and health expenditure are augmented by new terms capturing the state of health and the speed of deficit accumulation. The (Edgeworth-) complementarity of health and consumption in utility induces a preference for lower consumption in old age when health is bad. The rate of consumption growth is negatively associated with the rate of health deficit accumulation, see the Euler equations for consumption (23) and (25). For $\phi = 0$, physical exercise plays no role for the accumulation of health deficits and the health Euler equation (22) is reduced to the one of the basic model. The presence of physical exercise leads, ceteris paribus, to a faster decline of the shadow price of health deficits λ_D and the preference for a smoother health expenditure profile over the life cycle. The optimal life cycle trajectories are determined by (3), (18), (21)–(25), the boundary conditions on k and D, and the requirement that $H(T) = 0$ at the time of death.

5.2. **Calibration.** The calibration of health in utility is related to Finkelstein et al. (2013) who estimate that a one-standard deviation increase of chronic diseases is associated with a 11% decline in the marginal utility of consumption (with a 95% confidence band from 2.7% to 16.8%). Finkelstein et al. focus on individuals above 50 and use a small set of severe health deficits whereas the frailty index of Mitnitski et al. (2002) contains also relatively mild health deficits like farsightedness and incontinence. I thus take, for the benchmark case, a smaller impact of health deficits by setting $\alpha = 0.04$. This means that an unexpected increase in health deficits from D_0 by one standard deviation reduces the marginal utility from consumption by 3 percent.[10] In robustness checks we consider greater values of α.

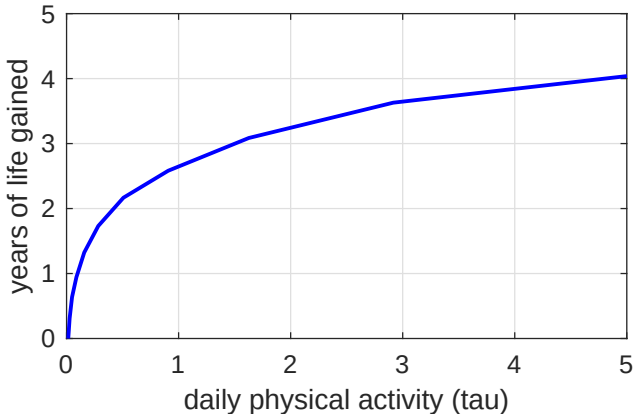
[10]According to Mitnitski et al. (2001) the standard deviation of most health deficits in the frailty index is around $0.4/\tilde{\mu}$, where $\tilde{\mu}$ is the mean of the particular deficit. The mean frailty index from (1) for individuals between 19 and 79 years is about 0.05 with a standard deviation of about 2.2 percent.

The calibration of the health impact of physical exercise is based on Moore et al. (2012). We consider the metric of metabolic equivalents (METs) defined as the energy cost of a given physical activity divided by energy expenditure at rest. This metric allows for the aggregation of different physical activities like walking, playing sports, gardening etc. and to compare them across individuals and across ages. The average American in Moore et al.'s sample spends about 1.14 MET per day (8 MET per week) on physical exercise, an equivalent of about 23 minutes of brisk walking per day. Moore et al. estimate that this exercise increases life-expectancy by about 2.8 years. They also document strongly decreasing returns from physical exercise, i.e. large gains for departure from inactivity and very small gains for excessive exercise.

In order to pin down η, I use information on how physical activity declines with age. Studies from the UK (Townsend et al., 2015) and Canada (Statistics Canada, 2007) suggest that physical exercise declines by about a factor of 2 from age 35 to age 70. Assuming that British and Canadian men are in this regard sufficiently similar to Americans, I try to match their age-gradient of physical activity. Altogether this means that I calibrate δ, η, E, and ϕ such that the Reference American spends $\tau = 1.14$ METs per day on exercise, which allows him to live 3 years longer than he would in total inactivity, and such that we map – with successive out-of-sample predictions – the age-gradient as well as the marginal return of physical exercise for alternative τ, as estimated by Moore et al. (2012). This leads to the estimate $E = 4 \cdot 10^{-3}$, $\phi = 0.10$, $\delta = 0.01$, and $\eta = 2.25$. Figure 5 shows the outcome of the out-of-sample prediction for physical exercise, obtained from feeding alternative values of δ into the model. Comparing it with Figure 1.B in Moore et al. (2012), we see that the calibrated model predicts the estimated association between physical activity and life years gained reasonably well.

We begin by considering the case of $\omega = 0.25$ and recalibrate the remaining parameters as explained in Section 3. The new estimates are $A = 0.0004$, $B = 3 \cdot 10^{-6}$, $\beta = 0.35$, $\gamma = 0.31$, $\psi = 0.5$, $\zeta = 850$, and $\sigma = 0.995$. The extended model assigns a smaller role to medical technology (A was 0.0016 before) because part of the life-saving power of medical technology is now explained by physical exercise. In this sense, the productivity parameter for medical technology A operates like factor productivity or the Solow-Residual in growth accounting. Its size is determined by the part of longevity that is neither explained by physiology nor by behavior.

Figure 5: Out-of-Sample Prediction: Physical Activity and Years of Life Gained



The curve is obtained by feeding in alternative δ's into the calibrated model, $\delta \in (0.001,\ 0.5)$. It maps the curve estimated by Moore et al. (2012, Fig. 1.B).

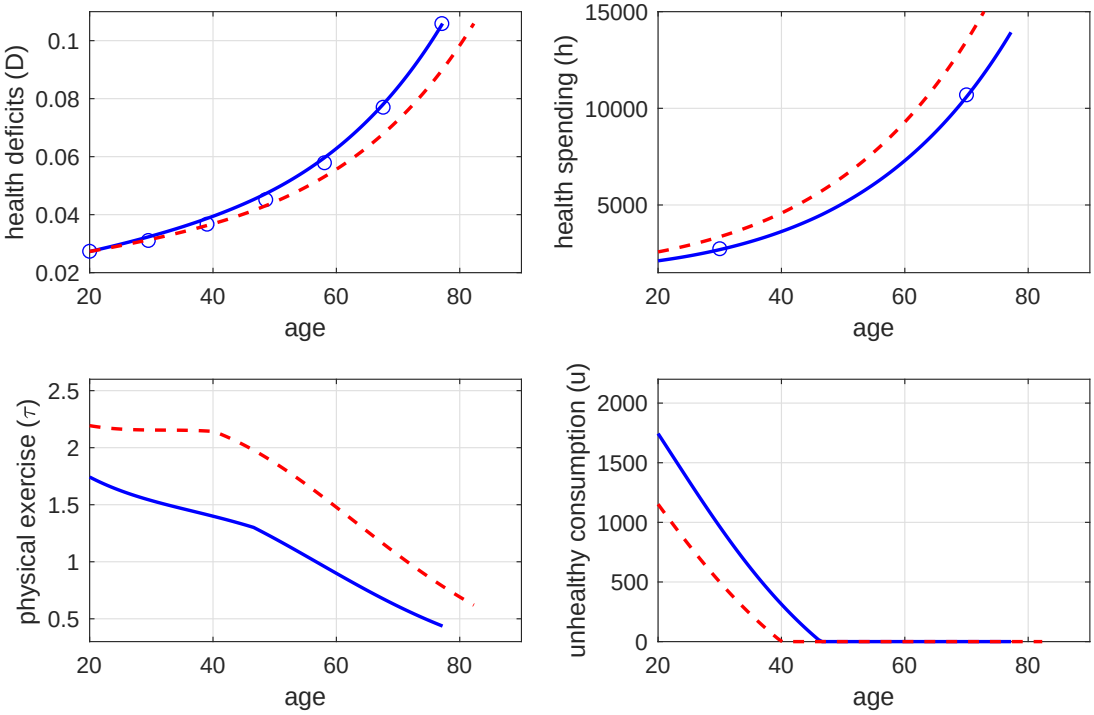
5.3. **Results.** Life time trajectories for the Reference American are shown by solid (blue) lines in Figure 6. The trajectories for health deficit accumulation, health spending, and unhealthy consumption look very similar to the benchmark case, corroborating robustness of these results. The new trajectory obtained for physical exercise is shown in the lower left panel. The model predicts in line with the empirical evidence that physical exercise is falling with age, from 1.7 METs per day at age 20 to 0.5 METs at age 75.[11]

Trajectories for the counterfactual case of perfect self-control are shown by dashed (red) lines in Figure 6. Results are similar to the benchmark model. In the new panel on physical exercise, we see that young adults with perfect self-control would exercise about 30 percent more as the Reference American. In middle age, this gap increases and in old age it narrows again. The behavioral changes predicted for health investments and unhealthy consumption are very similar to the those of the simple model. The individual with perfect control is predicted to live until age 82.2, 5.1 years longer than the Reference American. Case 1 in Table 2 summarizes these observations.

Table 2 provides a sensitivity analysis of the results. As before, individuals with less self-control problems (higher ω) would reduce unhealthy consumption by more and increase health

[11]According to (21), individuals never quit physical exercise completely. A refinement of the model could remedy this outcome by introducing a corner solution. Introducing the possibility of quitting for exercise, however, seems to be less compelling than in the case of unhealthy consumption because one could argue that almost everybody at any age exerts at least somewhat more than resting energy (whereas not smoking is a wide-spread phenomenon). A case differentiation is thus avoided for the sake of simplicity.

Figure 6: Self-Control and Health over the Life Cycle: Extended Case



Blue (solid) lines: limited self-control ($\omega = 0.25$; $T + 20 = 77.1$). Red (dashed lines): perfect self-control ($\omega = 0$; $T + 20 = 82.2$).

investments by more if they had perfect self-control. Additionally we observe a strong impact of self-control on physical exercise. With perfect self-control the benchmark individual would exercise 43 percent more. This effect more than doubles when ω increases to 0.5 and quadruples for $\omega = 0.75$. The study of Crescioni et al. (2011) investigates physical exercise for a sample of Americans of low- and high self-control and finds it about 70 percent higher in the high self-control group. This value is about in between the predictions of case 1 and 2 in Table 2.

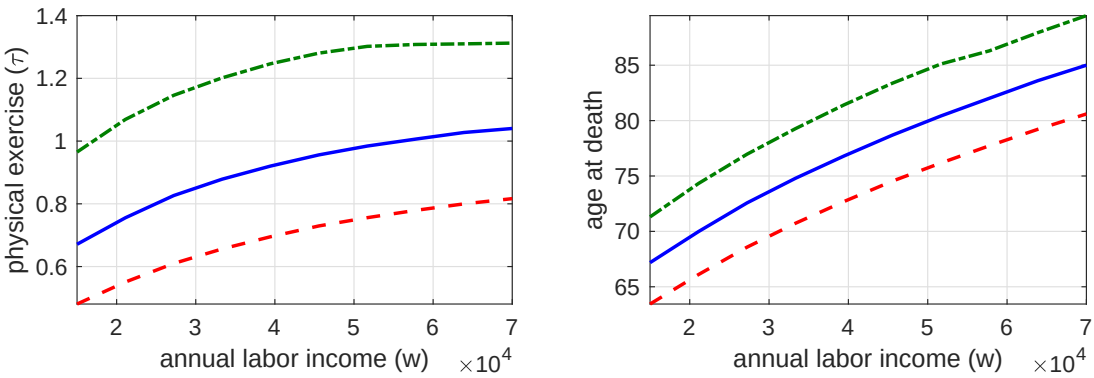
Table 2: Self-Control, Health Behavior and Longevity: Extended Model

case	change	remark	$\Delta u/u$	$\Delta h/h$	$\Delta\tau/\tau$	ΔT
1		benchmark ($\omega = 0.25$)	-47.8	18.2	43.4	5.1
2	$\omega = 0.5$	lower self control	-67.9	38.4	98.7	9.5
3	$\omega = 0.75$	higher self-control	-78.6	61.4	170.0	13.5
4	$\alpha = 0.1$	strong impact of health	-48.9	17.4	42.8	5.2
5	$\alpha = 0.2$	stronger impact of health	-54.3	15.9	33.4	4.8
6	$\omega = 0.5, \alpha = 0.1$	combination 2 and 4	-69.0	36.2	94.6	9.8
7	$\omega = 0.5, \alpha = 0.2$	combination 2 and 5	-72.5	30.4	64.7	8.9

The table shows the impact of self-control by reducing ω to zero; ΔT is measured in years and $\Delta u/u$, $\Delta h/h$, and $\Delta\tau$ are measured in percent.

We next investigate the impact of health in the utility function by assuming a much larger impact of health on marginal utility. This leads only to small changes in the predicted behavior and health outcomes. Results are shown for benchmark ω in case 4 and 5 and for $\omega = 0.5$ in case 6 and 7. The overall conclusion is that depending on model specification, the Reference American is likely to gain between 5 and 10 extra years of life if he had perfect self-control.

Figure 7: Income, Physical Exercise, and Longevity



Blue (solid) lines: benchmark calibration; red (dashed) lines: lower self-control ($\omega = 0.5$); green (dash-dotted) lines: higher self-control ($\omega = 0.12$).

Finally, we look at out-of-sample predictions by feeding different income levels at different degrees of self-control into the calibrated model. Figure 7 reports the predicted impact on physical exercise and age at death (the pattern for unhealthy consumption looks similar to the one in Figure 3). Solid (blue) lines show results for $\omega = 0.5$. Dashed (red) and dash-dotted (green) lines show results for an otherwise identical individual with lower, or respectively, higher self-control. The model predictions are in line with the empirical evidence of a positive socio-economic gradient of physical exercise (Cawley and Ruhm, 2012). In contrast to the case of unhealthy consumption (Figure 3), the impact of self-control on physical exercise does not vanish with increasing income.

6. Conclusion

This paper has proposed a dual-self life cycle model of endogenous health behavior and endogenous health outcomes in order to assess the role of limited self-control on longevity. After calibrating the model for a Reference American with limited self-control we considered the counterfactual experiment and removed the self-control problem and the life cycle problem again.

These computational experiments suggest a gain in lifetime by 4 to 9 years, achieved by less unhealthy consumption, more health investments, and more physical exercise.

The model is a first attempt to discuss self-control problems, health deficit accumulation, and longevity in a quantifiable economic life cycle theory. Naturally, there is scope for further developments. For example, there is a natural link to the addiction literature (built on Becker and Murphy, 1988) since impulsive desires could be the reason why people become addicted. Thus, investigating the role of limited self-control for addiction in a context where addictive consumption affects health and longevity (as in Strulik, 2017) could be a promising research project.

The present study focuses on lifetime outcomes for adults. In this context, self-control is perhaps best treated as a character trait. At shorter time intervals of hours or days, however, it has been suggested that self-control is more like an endogenous resource which can be depleted and re-filled (Baumeister et al., 2007). The integration of short-run behavior capturing effort and fatigue in decision making (Dragone, 2009) could be another useful generalization of the theory.

In an intergenerational context, one could study the inheritance of low self-control through low socioeconomic status (Moffitt et al., 2011). The character trait of self-control is likely to be malleable in (early) childhood like other non-cognitive skills (Diamond et al., 2007; Heckman, 2007) and childhood self-control is a good predictor for adult self-control (Mishel et al, 1989). By treating self-control as exogenous at adult age the present paper has highlighted the potentially large gains in health behavior, longevity, and welfare that can be achieved from policies that support the learning of self-control early in life.

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