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Obesity, sedentary behavior and lifestyle: A lifecycle model of eating and physical activity ☆

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ABSTRACT

We propose a theoretical model to study individual lifestyle choices related to calorie intake and physical activity, depending on personal fitness and body weight. The model builds on the rational eating literature and can generate a variety of behaviors that are consistent with the empirical evidence. In particular, we show that engaging in periods of a sedentary lifestyle can be a rational, utility-maximizing decision—a finding that is not present in the existing literature but is empirically widespread. Additionally, we show the possible existence of multiple equilibria and multiple indifferent lifestyles. The former justifies policy interventions to help individuals exit a self-reinforcing, but unhealthy equilibrium; the latter provides a theoretical basis for remediation plans that compensate for earlier unhealthy behaviors.

1. Introduction

Individuals often engage in behaviors that harm their health, even when they are aware of the long-term consequences (Cawley and Ruhm, 2012). This has been widely documented in the empirical literature on eating and physical activity. For example, in the United States, one third of adults and half of children have poor dietary habits (Rehm et al., 2016; Liu et al., 2020). In 2019 one third of EU population did not eat fruit or vegetables daily, and only 12% of those aged 15 or older met the WHO guideline of five portions per day (Eurostat, 2022). The WHO also recommends at least 150 min of moderate or 75 min of vigorous weekly activity for adults (World Health Organization, 2010, 2020), yet one in four adults and 81% of adolescents are found to be insufficiently active (Guthold et al., 2018, 2020). Consistent with these figures, since 1990, adult obesity has more than doubled, and adolescent obesity has quadrupled. In 2022, 2.5 billion adults were overweight, including 890 million classified as obese. This accounts for about 43% of the global adult population (World Health Organization, 2025).

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Poor diet and insufficient physical activity contribute to the obesity epidemics and constitute a public health concern. Obesity increases morbidity, mortality and healthcare costs, and it reduces productivity due to absenteeism and disability (Cawley, 1999; Okunogbe et al., 2022). Insufficient activity accounts for an estimated 9% of premature deaths globally (Lee et al., 2012). Some stylized facts emerge from the literature. Health shocks can lead to short-term improvements in diet and related behaviors, but these changes are often not sustained over time (Bünnings et al., 2025). Over their lifecycle, some individuals alternate between periods of caloric restriction combined with increased physical activity and periods of weight regain (Atella and Kopinska, 2014; Lounassalo et al., 2021; Mathisen et al., 2023). With age, physical activity tends to decline, particularly during the transition from adolescence to early adulthood, and sedentary behavior becomes more common in older age (Gordon-Larsen et al., 2004).

This paper proposes a rational choice model of obesity that can rationalize these patterns. Our approach is based on the economic literature on risky health behaviors, in which health is treated as one among several valued outcomes and enters the utility function alongside other arguments (Grossman, 1972, 1993; Becker et al., 1991). Within this framework, utility maximization may lead to health outcomes that fall below clinical recommendations or public health objectives, even when individuals are fully informed about the long-term consequences of their actions. This reflects the trade-offs between the immediate utility generated by certain behaviors, such as eating or exercising, and their future consequences. Individuals may accept short-term costs—such as engaging in physical activity or restricting food consumption—when these are outweighed by longer-term benefits. Conversely, individuals may prioritize immediate rewards, such as food consumption, while accepting the associated long-term effects on health and overall utility.

We show that our model can generate a range of optimal behavioral patterns, including sedentary lifestyles, persistent overweight, and the emergence of multiple long-run equilibria. In some cases, individuals converge to a long-run equilibrium through gradual adjustments in behavior, such as a progressive increase in body weight accompanied by a decline in physical activity. In other cases, behavior follows a cyclical pattern, with individuals alternating over time between periods of physical activity and inactivity, or between restrictive dieting and episodes of overeating. These oscillatory patterns arise from the endogenous relationship between body weight and the marginal utility of food consumption and physical activity, as well as from diminishing returns to fitness improvements at higher fitness levels. As a result, it may be optimal for individuals to refrain from exercising when already fit and to resume physical activity only once body weight exceeds a certain threshold.

In the long run, three distinct types of optimal outcomes can emerge. In the first, the individual maintains an optimal body weight, consumes to satiation, and engages in high levels of physical exercise. In the second, the individual is overweight, adopts a restrictive diet, and also overexercises. Although this second outcome is detrimental to health, it can be a rational choice because achieving or maintaining a lower body weight requires time and effort. In the third equilibrium, an individual can become underweight despite consuming food beyond satiation. This can occur, for example, when individuals have high energy expenditure due to a fast metabolism or a strong preference for physical activity, which results in caloric expenditure exceeding their caloric intake and to lower body weight.

We also show that the model allows for different lifecycle patterns of behavior to be optimal. When this is the case, some individuals can fully offset a lack of physical exercise and restrained food consumption in the early stages of life by committing to these behaviors in later stages. This results provides a theoretical rationale for delayed remedial interventions in health behavior, along the lines of Cunha and Heckman (2007)'s pioneering work on remedial interventions in education.[1] It emerges as a consequence of the non-concavities of the model, which can generate multiple optimal trajectories that yield the same lifetime utility. Accordingly, we label these trajectories as Indifferent Lifestyles and propose a No Regret criterion to choose among them, based on ranking alternative lifestyles over a predefined, finite time horizon T. Accordingly, when confronted with two indifferent lifestyles as candidate solutions of the consumer's intertemporal problem, an individual would select the one that provides higher utility over the next T years. To our knowledge, this type of selection criterion is new in the literature.

Our paper contributes to the literature showing that a non-zero prevalence of obesity is consistent with optimal individual decision-making, once the full cost of weight reduction—including time, effort, and forgone utility—is taken into account. Analogously, while physical inactivity is often regarded as problematic from a public health perspective, a sedentary lifestyle may be individually optimal during certain stages of the life cycle. These results contrast with static approaches that overlook the dynamic relationship between present actions and future outcomes, as well as with views attributing obesity primarily to behavioral biases (Calitri et al., 2010), time-inconsistent preferences (Laibson, 1997; Ikeda et al., 2010), or cognitive limitations (Muraven and Baumeister, 2000; Baumeister, 2018). While such explanations may be relevant in specific cases, they often do not account for the persistence of obesity among informed and capable individuals.

Although there is no market failure to correct, as choices are optimal from the individual point of view, our results do not rule out a role for public policy. When there are multiple long-run equilibria, individuals may be trapped in an equilibrium — such as being overweight and inactive — even when they are aware of a preferable alternative. In such cases, targeted interventions may help facilitate transitions towards a more desirable outcome.

More generally, policy maker may have an objective function that differs from that of individuals, for example by placing more weight on long-term health outcomes, the distribution of health, or the social costs associated with risky health behaviors. Policy makers may also account for externalities — such as public health expenditures — and for equity considerations that individuals do

[1] For empirical investigation on remedial behavior and remedial policies in the context of skills formation, see Cunha and Heckman (2007), Cunha et al. (2010). For the role of early health conditions on future outcomes and behavior, see Currie and Almond (2011), Campbell et al. (2014), Conti et al. (2016), Baranov et al. (2020), Hendren and Sprung-Keyser (2020), Carneiro et al. (2021).

not internalize. For a given policy target, our model contributes to understanding how individuals respond to interventions that alter the relative cost of food and access to physical activity, offering a theoretical support for empirical studies on food and beverage taxes (Cawley, 2016; Cawley et al., 2020, 2021), incentives for exercise (Della Vigna and Malmendier, 2006; Charness and Gneezy, 2009; Kókai et al., 2022), and information or educational campaigns (Mazzocchi et al., 2009). Specifically, we consider changes in the relative cost of food consumption and access to physical activity, and we show that these policies can shift not only individual behavior but also the type of long-run equilibrium that emerges. When this is the case, even small changes in policy parameters can lead to large changes in optimal behavior and long-term outcomes.

While the main focus of the existing theoretical and empirical economic literature on obesity is on the intake of calories through eating or drinking, our model emphasizes the role of physical activity and exercise, along the lines of Della Vigna and Malmendier (2006), Charness and Gneezy (2009), Dragone (2009a), Yaniv et al. (2009) and Strulik (2019). Our results also complement those relating obesity to impatience and time preferences (Ikeda et al., 2010; Courtemanche et al., 2015; Stoklosa et al., 2018; Cobb-Clark et al., 2023), market dynamics and technological changes that influence the relative cost of calories and the availability of high-calorie products (Lakdawalla et al., 2005; Lakdawalla and Philipson, 2009; Dragone and Ziebarth, 2017), and factors that depend on social interactions, such as peer effects (Christakis and Fowler, 2007; Cohen-Cole and Fletcher, 2008), social contagion effects (Strulik, 2014) and social norms about physical appearance (Dragone and Savorelli, 2012; Dragone et al., 2016).[2]

Our paper also contributes to the literature by providing a model to be used for empirical analysis. Structural estimation of parameters related to body weight dynamics, preferences, and constraints can help identify how genetic and environmental factors interact, as in the recent works of Cawley et al. (2019) and Biroli et al. (2025), and in estimating the role of health awareness (Arni et al., 2021), the impact of fitness and weight on mortality (McAuley et al., 2016), and the effects of technology-based exercise interventions (Kókai et al., 2025).

The proceeding is structured as follows. Section 2 presents the model and the features of the optimal solution. Section 3 introduces a quadratic utility function to study the explicit solutions of the intertemporal maximization problem, the possible optimality of sedentary behavior and the possible emergence of indifferent lifestyles. Section 4 illustrates the consequences of policy interventions affecting the price of eating and physical exercise. Section 5 concludes.

2. Theoretical framework

2.1. The model

The model follows a structure similar to a Grossman-style framework, with fitness and body weight modeled as components of health that evolve depending on eating and physical exercises choices. In the framework of Grossman (1972), health affects the number of healthy days, and therefore influences utility, labor productivity, and mortality. Our approach is simpler because body weight and fitness only affect the utility function. These effects may capture not only health-related discomfort, but also psychological or social factors, such as physical appearance, stigmatization or social pressure.

Consider an instantaneous utility which depends on current calorie intake c, time allocated to physical activity u, leisure time q, and time spent at work l, as well as on body weight W and individual fitness level F.[3] Specifically, consider the following function:

$$\mathbb{U} = C(c, W) + U(u, W) + Q(q) + L(l) + \mathcal{W}(W) + \mathcal{F}(F) \tag{1}$$

The utility function is assumed to be strictly increasing in leisure time and fitness level ($Q_q, \mathcal{F}_F > 0$), and strictly decreasing in time spent at work ($L_l < 0$).[4] The marginal utility of food consumption (C_c) is positive up to a satiation point and becomes negative beyond it. For individuals who dislike physical exercise, the marginal utility of exercise (U_u) is negative at all levels. However, some individuals derive enjoyment from physical activity, up to a threshold beyond which it becomes a bad. In such cases, the marginal utility of exercise is positive for moderate levels of activity and negative for more intense exercising.

The marginal utility of body weight is $\mathbb{U}_W = C_W + U_W + \mathcal{W}_W$. Hence, body weight affects utility both directly (through the component $\mathcal{W}$), and indirectly, through the utility from food consumption and physical activity (C and U).[5]

The sign of the cross-partial derivatives provides information on how preferences evolve over time. A positive cross-partial ($C_{cW} > 0$) represents taste formation, as past eating behavior raises the marginal utility of current food consumption. Conversely, a negative cross-partial derivative ($C_{cW} < 0$) denotes intertemporal satiation: past net food intake, reflected in current body weight,

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[2] For excellent overviews, see Cawley (2004), Cawley and Ruhm (2012), Cawley (2015), Okunogbe et al. (2022).

[3] Whenever it does not create confusion, time arguments are omitted to simplify the exposition. Partial derivatives of the utility function and of the laws of motion are indicated by subscripts.

[4] Physical fitness consists of several components, including cardio-respiratory fitness (endurance or aerobic capacity), musculoskeletal fitness, flexibility, balance, and speed of movement (U.S. Department of Health and Human Services, 2018). It can be conceptually divided into health-related fitness and performance-related fitness (Roy et al., 2010). In what follows, we consider fitness as a positive component of health. A more fit individual is also healthier, although the reverse does not necessarily hold. We found no empirical evidence that lower fitness is ever preferred. We therefore assume monotonic preferences in F, that is, "more is better". This is equivalent to assuming that the bliss point for fitness corresponds to an unattainable level, so that $\mathcal{F}_F > 0$ always holds, as in the paper.

[5] Healthy body weight can be defined as the level at which $\mathcal{W}_W = 0$. This generally differs from the static optimal body weight, which instead satisfies $\mathbb{U}_W = 0$. Focusing on the latter allows us to emphasize that the individual's objective is the instantaneous utility function, and not just health.

reduces the marginal utility of current consumption (Dockner and Feichtinger, 1993; Dragone, 2009b).[6] Based on the evidence of obesity on fatigability in physical tasks (Mattsson et al., 1997; Cavuoto and Nussbaum, 2014; Mehta, 2015; Mehta and Cavuoto, 2017), the marginal utility of exercising is assumed to decline with body weight ($U_{uW} < 0$). All remaining second-order derivatives are strictly negative, and the utility function is assumed to be strictly concave.

Body weight and fitness level are components of individual health and are considered as the state variables of the problem.[7] Consider the following law of motion for body weight,

$$\dot{W} = g(c, u, W, F) = c - \varepsilon u - \delta_w W F \tag{2}$$

with $\varepsilon \geq 0$ and $\delta_w > 0$. As it is common in the literature, we assume that body weight increases with eating and decreases with body weight and physical activity (see, e.g., Dockner and Feichtinger, 1993; Levy, 2002a; Dragone, 2009b; Strulik, 2014, 2023). Differently from previous contributions, we add an interplay between body weight and fitness in the last term, which captures how body weight decreases as a result of metabolism and current health conditions, i.e. the basal metabolic rate. Specifically, based on Shook et al. (2014a), Shook et al. (2014b) and Arnold et al. (2021), we assume the basal metabolic rate rate is higher, the higher the individual fitness level and body weight. The intuition is that a higher fitness level goes along with a higher proportion of muscles. Hence, for a given body weight, a more fit body consumes more energy. Analogously, for a given fitness level, the basal metabolic rate is higher when body weight is higher.

The fitness level changes over time, depending on physical activity. Based on the evidence of a Plateau Effect in sports training (see, e.g., Counts et al., 2017; Abe et al., 2018; Kataoka et al., 2024; Rosenblat et al., 2024), we assume that exercising contributes more to the fitness level when the individual has a poor fitness level.[8] For concreteness, we consider the following:

$$\dot{F} = f(u, F) = \frac{u}{F} - \delta_F F, \tag{3}$$

Since $f_{uF} < 0$, the marginal contribution of physical exercise to the fitness condition is lower when the fitness condition is higher. The last term of (3) represents the decay of fitness in the absence of physical activity, with $\delta_F > 0$.

At each point in time, the individual faces the following time and budget constraints, respectively,

$$\tau = l + q + u \tag{4}$$

$$M + wl = p_u u + p_c c \tag{5}$$

where τ is the time endowment to be allocated between labor, leisure and physical exercise, M is an exogenous income flow, w denotes the wage rate of labor, p_u is the cost of exercising (such as gym memberships or equipment), and p_c is the price of eating. The time and budget constraints (4) and (5) can be combined to obtain the full income constraint (Becker, 1965)

$$M + w\tau = p_c c + (p_u + w)u + wq. \tag{6}$$

The left-hand side is the full potential income, with the time endowment valued at the wage rate of labor. The right-hand side allocates this income among eating, exercise, and leisure. By assumption, eating takes no time, hence its cost is solely determined by its market price p_c. The cost of exercising includes both its market price and the opportunity cost of time evaluated at the market wage of labor, i.e. $p_u + w$. The cost of leisure is only given by its opportunity cost w.

The individuals' objective is to maximize intertemporal utility, which is given by the sum over time of the instantaneous utility $\mathbb{U}(\cdot)$, discounted by the subjective discount rate r_1 and the survival probability $S(t)$. The latter is assumed to follow an exponential distribution with mortality (hazard) rate r_2 (and, consequently, life expectancy $\frac{1}{r_2}$). Hence, the individual discounts the instantaneous utility $\mathbb{U}(\cdot)$ by the combined rate $r := r_1 + r_2$, and solves the following problem:

$$\max_{c(t),u(t),q(t),l(t)} \int_0^\infty e^{-rt} \left[C(c(t), W(t)) + U(u(t), W(t)) + Q(q(t)) + L(l(t)) + \mathcal{W}(W(t)) + \mathcal{F}(F(t))\right] \mathrm{d}t \tag{7}$$

$$\text{s.t.}\ M + wl(t) = p_u u(t) + p_c c(t) \tag{8}$$

$$\tau = l(t) + q(t) + u(t) \tag{9}$$

$$\dot{F}(t) = f(u(t), F(t)) \tag{10}$$

$$\dot{W}(t) = g(c(t), u(t), W(t), F(t)) \tag{11}$$

$$W(0) = W_0 > 0, \qquad F(0) = F_0 \geq 0 \tag{12}$$

Given the fixed mortality rate contained in the discount rate r, the problem is formulated over an infinite time horizon. This implies that it is optimal for individuals to make time-consistent plans as if they could live indefinitely. This approach is commonly adopted in the economic literature (e.g., Yaari, 1965; Becker and Murphy, 1988; Mas-Colell et al., 1995; Dragone and Raggi, 2021; Dragone and Vanin, 2022, 2025) as it facilitates the analysis of optimal trajectories converging towards steady-state equilibria. However, note that such equilibria will be reached with probability zero because agents will in fact die in finite time with probability one.

[6] Dragone and Ziebarth (2017) discuss the concepts of taste formation and habit formation in relation to the accumulation of a food-specific consumption capital. These ideas are applicable here if body weight is viewed as a proxy for past eating behavior, net of the effects of past physical activity.

[7] Variables names are summarized in Table 1.

[8] Consider, for instance, a runner who can run 10 km in 60 min. Then it is relatively easy to increase training efforts to improve the personal best by one minute. If, however, the runner is able to run 10 km in 30 minutes (which is only a few minutes above the men's world record), it is hardly possible to improve by one minute at all.

Table 1
List of functions and variables.

Functions	$\mathbb{U}(\cdot)$	instantaneous utility function
	$g(t)$	dynamics of body weight
	$f(t)$	dynamics of fitness level
Control variables	$c(t)$	eating
	$u(t)$	exercising time
	$l(t)$	time at work
	$q(t)$	leisure time
State variables	$W(t)$	body weight
	$F(t)$	fitness level
Adjoint variables	$\lambda(t)$	adjoint variable of body weight
	$\mu(t)$	adjoint variable of fitness level

2.2. Types of steady state

The model is solved by applying the Maximum Principle (see Grass et al., 2008). We first consider general formulations of the utility function and the laws of motions of body weight and fitness level, and we study the features of the first-order conditions for optimality. Then we consider specific formulations for the laws of motions, and we show the types of steady states that the model can produce. In Section 3 we consider a quadratic instantaneous utility function and explore these results through numerical simulations.

As a preliminary step, it is useful to isolate the values of q and l from the time and budget constraints (8) and (9). Substituting these expressions into the instantaneous utility function $\mathbb{U}(c,u,q,l,W,F)$ yields a more compact representation of the constrained objective function, denoted by $\mathcal{U}(c,u,W,F)$, which depends only on two control variables—eating (c) and physical exercise (u)—and two state variables—body weight (W) and fitness level (F):

$$\begin{aligned}\mathcal{U}(c,u,W,F) :=& C(c,W) + U(u,W) + \mathcal{F}(F) + \mathcal{W}(W)\\ &+Q\left(\tau + \frac{M - p_c c - \left(p_u + w\right)u}{w}\right) + L\left(\frac{p_c c + p_u u - M}{w}\right)\end{aligned} \tag{13}$$

For a generic point (c,u,W,F), we compute the partial derivatives of the constrained function (13) to establish a reference for classifying the outcomes of the dynamic optimization problem. Specifically, if $\mathcal{U}_c(c,u,W,F) > 0$, we say the individual is eating below satiation (undereating); if $\mathcal{U}_c(c,u,W,F) < 0$, the individual is overeating; and if $\mathcal{U}_c(c,u,W,F) = 0$, the individual is eating up to satiation. Likewise, $\mathcal{U}_u(c,u,W,F) > 0$ indicates underexercising, while $\mathcal{U}_u(c,u,W,F) < 0$ indicates overexercising. For body weight, $\mathcal{U}_W(c,u,W,F) > 0$ denotes underweight, $\mathcal{U}_W(c,u,W,F) < 0$ overweight, and $\mathcal{U}_W(c,u,W,F) = 0$ the optimal weight. In what follows, we use this terminology to classify choices along the optimal trajectory and in steady state. For example, if at some body weight and fitness level the optimal choices satisfy $\mathcal{U}_c > 0$, $\mathcal{U}_W < 0$, and $\mathcal{U}_u < 0$, we describe the individual as undereating, overweight, and overexercising. By assumption, recall that $\mathcal{U}_F(c,u,W,F) > 0$, hence no satiation is allowed for the fitness level.

The Hamiltonian function corresponding to the individual problem with the modified utility function is:

$$\mathcal{H} = \mathcal{U}(c,u,W,F) + \lambda g(c,u,W,F) + \mu f(u,F) \tag{14}$$

where λ and μ denote the adjoint variables of body weight W and fitness level F, respectively. These adjoint variables are the shadow prices of body weight and fitness level, and they describe the marginal impact of one additional unit of the corresponding state variable on lifetime utility. At any time t, the first-order conditions for eating and physical exercise are, for an internal solution,

$$\mathcal{U}_c = -\lambda g_c; \qquad \mathcal{U}_u = -\lambda g_u - \mu f_u \tag{15}$$

hence,

$$\frac{\mathcal{U}_c}{\mathcal{U}_u} = \frac{\lambda g_c}{\lambda g_u + \mu f_u}. \tag{16}$$

The above expression implies that, if an internal solution exists, it is such that the marginal rate of substitution between consumption and physical exercise depends on the shadow prices of body weight and fitness level, as well as by the laws of motion of the state variables. The ratio $\lambda g_c / \left(\lambda g_u + \mu f_u\right)$ is the dynamic analog of the marginal rate of transformation between consumption and physical exercise.[9]

As shown in Appendix A.1, using the law of motions (2) and (3), the following holds in a steady state $(c^{ss}, u^{ss}, W^{ss}, F^{ss})$:

$$\mathcal{U}_W = -\sigma_1 \mathcal{U}_c \tag{17}$$

$$\mathcal{U}_F = -\sigma_2 \mathcal{U}_c - \sigma_3 \mathcal{U}_u \tag{18}$$

[9] For a similar result in the context of the life-cycle literature, see, e.g., Shepard and Zeckhauser (1984), Murphy and Topel (2006), Kuhn et al. (2015).

where $\sigma_1 = \delta_W F^{ss} + r > 0$; $\sigma_2 = \delta_W W^{ss} + \epsilon(2\delta_F + r)F^{ss} > 0$ and $\sigma_3 = \left(2\delta_F + r\right) F^{ss} \geq 0$.

Since $\sigma_1 > 0$, condition (17) implies that the marginal utility of body weight and eating must have opposite sign (see Caputo and Dragone, 2022). Since $\mathcal{U}_F > 0$, the right-hand side of condition (18) must be positive, which requires that either $\mathcal{U}_c$ or $\mathcal{U}_u$, or both, are negative. Hence, the following holds:

Proposition 1 (*Types of Steady State*)**.** *In a steady state, one of the following three cases can occur:*

1. *The individual eats up to satiation, overexercises and has an optimal body weight,*
2. *The individual is on a diet, overexercising and overweight,*
3. *The individual is overeating and underweight*

The first case describes a steady state where the agent reaches the bliss point in terms of eating, physical exercise, and body weight. The second scenario corresponds to an equilibrium in which an overweight individual must exercise more than would be desirable and must restrict caloric intake to avoid further weight gain. This case is the theoretical result consistent with the empirical evidence on obesity. The third case describes a scenario in which an underweight agent must overeat to prevent further weight loss. This underweight condition may result from inefficient nutrient absorption, insufficient caloric intake, a high metabolic rate, or other physiological factors which prevent gaining weight despite overeating.[10]

3. Lifestyles and health outcomes

Contoyannis and Jones (2004) define a lifestyle as *"a set of behaviors which are considered to influence health and generally involve a considerable amount of free choice"*. In our context, individual lifestyles are represented by intertemporal optimal paths of eating and physical exercise that solve the intertemporal problem (7) to (12).

To get insight into the lifestyles compatible with our model, it is convenient to choose a specific utility function. Following the literature on rational addiction (Becker and Murphy, 1988; Dockner and Feichtinger, 1993) and on obesity and addictive consumption (Naik and Moore, 1996; Hauck et al., 2020), we choose a linear-quadratic specification for the instantaneous individual utility function. Specifically, we consider

$$\mathcal{U} = a_c c + a_u u + a_q q + a_l l + a_W W + a_F F + \frac{a_{cc}}{2}c^2 + \frac{a_{uu}}{2}u^2 + \frac{a_{WW}}{2}W^2 + \frac{a_{FF}}{2}F^2 + a_{cW} cW + a_{uW} uW \tag{19}$$

with $a_c, a_q, a_W, a_F > 0$ and $a_l < 0$. To capture the possibility that physical exercise may be either disliked or pleasurable, parameter a_u can take any sign (Dragone, 2009a).

We assume (19) is concave and that $a_{cc}, a_{uu}, a_{WW}, a_{FF} < 0$. The last two terms of (19) imply that body weight interacts with both eating and exercising time. Specifically, we assume that past consumption increases the marginal utility of current consumption, $a_{cW} > 0$, a property Dragone and Ziebarth (2017) referred to as taste formation and that, in the context of Becker and Murphy (1988)'s theory of rational addiction, is known as reinforcement. Term $a_{uW} uW$, with $a_{uW} < 0$, describes the realistic possibility that the marginal utility of exercising is a decreasing function of body weight. The linearity and separability of time at work l and of the leisure time q is meant to simplify the analysis, so that price shocks produce changes in consumption and physical exercise only through substitution effects, without income effects being involved (Becker and Murphy, 1988; Dragone and Vanin, 2022, 2025).[11]

After substitution of Eqs. (9) and (8) into (19) we obtain

$$\mathcal{U} = \alpha_c c + \alpha_u u + a_W W + a_F F + \frac{a_{cc}}{2}c^2 + \frac{a_{uu}}{2}u^2 + \frac{a_{WW}}{2}W^2 + \frac{a_{FF}}{2}F^2 + a_{cw} cW + a_{uW} uW + a_0 \tag{20}$$

where

$$\alpha_c := a_c + \frac{a_l - a_q}{w} p_c, \qquad \alpha_u := a_u - a_q + \frac{a_l - a_q}{w} p_u, \qquad \alpha_0 = a_q \tau - \frac{a_l - a_q}{w} M \tag{21}$$

If an internal solution exists, it satisfies:

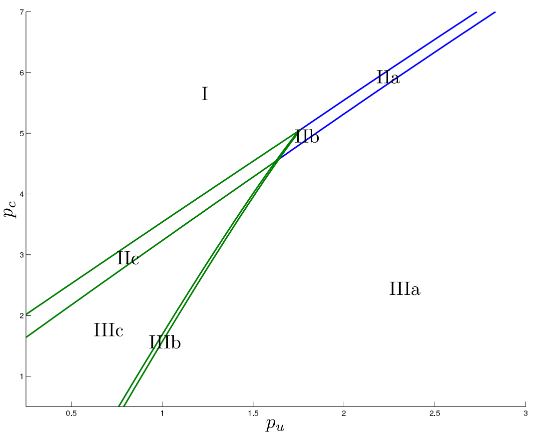
$$c^* = -\frac{1}{a_{cc}}\left(\alpha_c + a_{cW} W + \lambda\right) \tag{22}$$

$$u^* = -\frac{1}{a_{uu}}\left(\alpha_u + a_{uW} W - \epsilon\lambda + \frac{\mu}{F}\right). \tag{23}$$

Optimal consumption c^* increases with the marginal incentives of eating α_c, with body weight W, and with its adjoint variable λ. Optimal physical exercise u^* depends on the marginal incentives of exercising α_u, body weight, the fitness level and their adjoint

[10] Our notions of under/overeating and under/overweight are based on utility-maximizing conditions rather than clinical benchmarks. Since $\mathcal{U}_{cW} > 0$, the satiation level positively depends on body weight, and the utility-maximizing body weight positively depends on food consumption. Consequently, the model's classification of overweight need not coincide with medical definitions based on exogenous thresholds. For example, an overeating individual can be medically overweight yet classified as underweight in the model if their observed body weight — despite being high in absolute terms — remains below the utility-maximizing level given their food consumption. An alternative approach is to use an exogenous, health-maximizing body weight as the reference point, as in, e.g., Levy (2002a), Dragone (2009a), Dragone and Savorelli (2012).

[11] This simplifying assumption contradicts empirical evidence about the existence of a socioeconomic gradient in obesity (see, e.g., Baum II and Ruhm, 2009; Cawley and Ruhm, 2012). This finding suggests that obesity would behave as an inferior good, so that body weight should decrease following a positive (permanent) income shock. Analytically, it can be shown that such outcome is possible. However, the resulting expressions are overly cumbersome to be informative unless further simplifying assumptions are introduced.



Region	Long-run solution	Type of solution
I	W^-	globally optimal
IIa	W^- and W^+	locally optimal
IIb	W^-, W^+ and limit cycle	locally optimal
IIc	W^- and limit cycle	locally optimal
IIIa	W^+	globally optimal
IIIb	W^+ and limit cycle	locally optimal
IIIc	limit cycle	globally optimal

Fig. 1. Bifurcation diagram for different values of p_u and p_c. Underweight steady states emerge in Regions I and II; overweight steady states emerge in Regions IIa, IIb and III. The symbol W^+ denotes an overweight steady state; W^- an underweight steady state. Blue curves denote heteroclinic connections between equilibria (no limit cycle is involved); green curves denote heteroclinic connections between a limit cycle and an equilibrium. The parameters are described in footnote 13.

variables λ and μ. Everything else equal, an increase in body weight W increases eating but reduces physical exercise (recall that $a_{cc}, a_{uu}, a_{uW} < 0$). The former result is due to the reinforcing nature of eating so that past and present consumption are positively correlated (see, in the context of rational addiction models, Becker and Murphy, 1988). The latter occurs because, when body weight is higher, exercising becomes more effortful. Since the fitness level increases the basal metabolic rate, it is optimal to exercise less when the individual becomes fitter, everything else equal and provided increasing the fitness level increases intertemporal utility ($\mu > 0$).

Based on (21), (22) and (23), the following holds

Remark 1 (*Sedentary Behavior*). Optimal physical inactivity is more likely when the marginal utility of exercising a_u and the wage rate w are lower, and when the marginal utility of leisure time a_q, the price of exercising p_u, and body weight W are higher.

This Remark highlights a previously overlooked result: choosing not to exercise can be optimal, at least during certain periods of life. This outcome may be the consequence not only of a high monetary cost and a low taste for exercise, but also of the interaction between the physical cost of exercising and body weight, as well as the opportunity cost of time spent exercising instead of engaging in other leisure activities or work.

3.1. The past matters: history-dependence and multiple equilibria

In this section, we further study the solution of our model through numerical simulations, showing that unique steady states, limit cycles, or multiple long-run equilibria can emerge. When there are multiple equilibria, the solution becomes history-dependent, meaning that the steady state an individual can reach depends on their initial body weight and fitness level. As a result, individuals may find themselves trapped in an undesirable equilibrium, even if they recognize that a different equilibrium would be better. When this occurs, a policy intervention—a "Big Push"—aimed at shifting individuals out of the undesirable equilibrium may be warranted.[12]

The prices of eating and physical exercise are frequently targeted by policy interventions through, e.g. taxes on high-calorie foods and beverages or subsidies for gym memberships. Accordingly, we consider the price space (p_u, p_c) to classify the number and type of steady states that can arise in an optimal solution. In the bifurcation diagram in Fig. 1, underweight steady states (denoted as W^-) occur in Regions I and IIc, while overweight steady states (denoted as W^+) appear in Regions IIa, IIb, and III.[13]

[12] This is conceptually similar to well-known phenomena in dynamic economic models—such as coordination failures in bank runs (Diamond and Dybvig, 1983) or path dependence as in Murphy et al. (1989)—in which forward-looking agents may remain in a stable but dominated equilibrium even when a superior one exists. A comparable issue arises in gradient-descent algorithms: when the objective function is non-concave, the procedure may converge to a nearby local maximum rather than the global maximum.

[13] Parameters: $\alpha_u = 3$, $\alpha_c = 7$, $a_F = 1.5$, $a_W = 0.5$, $\alpha_0 = 0$, $a_{cc} = -5$, $a_{uu} = -0.5$, $a_{WW} = -0.07$, $a_{FF} = 0$, $a_{cw} = 1$, $a_{uw} = -0.01$, $\delta_w = 0.1$, $\delta_F = 0.4$, $\varepsilon = 0.01$, $r_1 = 0.02$ and $r_2 = 0.01$. These values are provided for illustrative purposes only and have not been calibrated or validated using real-world data. Recall from (21) that the linear terms α_u and α_c negatively depend on prices because $a_l < 0$, hence a higher price corresponds to a lower value of the corresponding α.

To interpret Fig. 1, consider the case in which the price of eating p_c is very large (say, $p_c = 6$) and the cost of exercising is small, which amounts to considering Region I. With such a parametric configuration, there exists a unique underweight equilibrium. The equilibrium is globally optimal, which means that it will be reached for any initial condition of body weight and fitness condition. As the price of exercising increases, however, an overweight equilibrium also emerges (Region IIa) and, for even higher cost of exercising (Region IIIa), it remains the only reachable equilibrium. This result is consistent with the notion that increases in the cost of exercising can induce obesity.

Consider now the case of a low price of eating (say, $p_c = 1$) and a low cost of exercising (Region IIIc). In such a case, a limit cycle emerges, that is, an outcome in which a stable oscillatory pattern of eating, exercising, fitness level and body weight emerges.[14] As in the previous case, when the cost of exercising increases an overweight steady state emerges (Region IIIb), until it disappears and only the overweight steady state remains (Region IIIa).

The more complicated cases with an intermediate price of eating will be considered in Section 4 in the context of policy interventions. For now, it suffices to observe that a unique steady state exists when one of the two prices is high and the other one is low (Regions I and IIIa). In the remaining regions, the difference between p_c and p_u is relatively small, which favors the coexistence of multiple steady states and, possibly, limit cycles, i.e. self-sustained oscillations over time around a steady state. The equilibrium ultimately attained depends on the initial conditions. In Region IIa, for instance, convergence to either the underweight or overweight equilibrium is possible. This outcome is reasonable, given that Region IIa lies between Regions I (underweight steady state) and IIIa (overweight steady state). If an individual starts with a large weight and low fitness condition, they will eventually settle into the overweight steady state. This entrapment results mainly from two factors. First, the positive reinforcement parameter α_{cW} implies that a heavier individual derives greater utility from consumption. Second, as indicated by expression (2), a less fit individual burns fat too slowly to counteract weight gain. On the contrary, individuals starting with low body weight and high fitness condition will ultimately reach the underweight steady state.

3.2. Indifferent lifestyles and remedial behavior

In this section we emphasize a so far overlooked result in the literature on obesity: there exists the possibility that multiple lifestyles are optimal. Formally, this occurs when the initial conditions are such that the same steady state can be reached through multiple optimal paths that are indifferent in terms of the associated value function.

Consider, for instance, the time paths in Fig. 2. They share the same initial and terminal conditions of body weight and fitness (panels c and d), they are solutions of the intertemporal problem (7)–(12), and it can be shown that they entail equal values of the maximized intertemporal utility function over the time horizon from zero to infinity. Hence, they are indifferent with respect to the associated value functions. In a sense, they are the dynamic analog of indifference curves in static consumer theory, wherein different combinations of consumption goods yield the same utility levels. Accordingly, we label these trajectories as *Indifferent Lifestyles*.[15]

In the following, we consider a parametric configuration that results in a unique overweight steady state (Region IIIa in Fig. 1). Fig. 2 depicts an example of two indifferent lifestyles.[16] They are indifferent when considering the associated value functions, but they represent different intertemporal behaviors. In the early periods, trajectory B (dashed line) describes higher levels of eating (panel a) and a prolonged period of no physical activity (depicted in red, panel b) compared to trajectory A (solid line). This leads to a higher body weight (panel c) and lower fitness condition (panel d) in the early periods. To compensate for the initial lack of physical activity, prevent excessive weight gain, and obtain a sufficient fitness level, the individual in trajectory B engages in physical activity at an earlier age compared to trajectory A. Physical activity improves the fitness condition and slows down the rate of accumulation of body weight. Ultimately, both trajectories converge to the same body weight and fitness conditions, albeit through different paths over the lifecycle.

This example illustrates two main results. First, periods of sedentary behavior can be optimal during certain phases of an individual's lifetime. Second, the choice to delay physical exercise can be fully remediated later in life, although it may require more effort and an earlier start to catch up to the health condition of an individual who begins exercising at a younger age.

Since multiple, equivalent optimal trajectories exist, one may wonder how an individual would choose among them. We propose a criterion based on an alternative finite horizon T—for example, the expected lifetime $1/r_2$—at the end of which death is assumed to occur with certainty. A possible tie-breaking criterion can be introduced by comparing the finite-horizon utility associated to the indifferent lifestyles from time zero to T.[17]

Formally, define the value of a lifestyle with pre-determined time of death at T as follows:

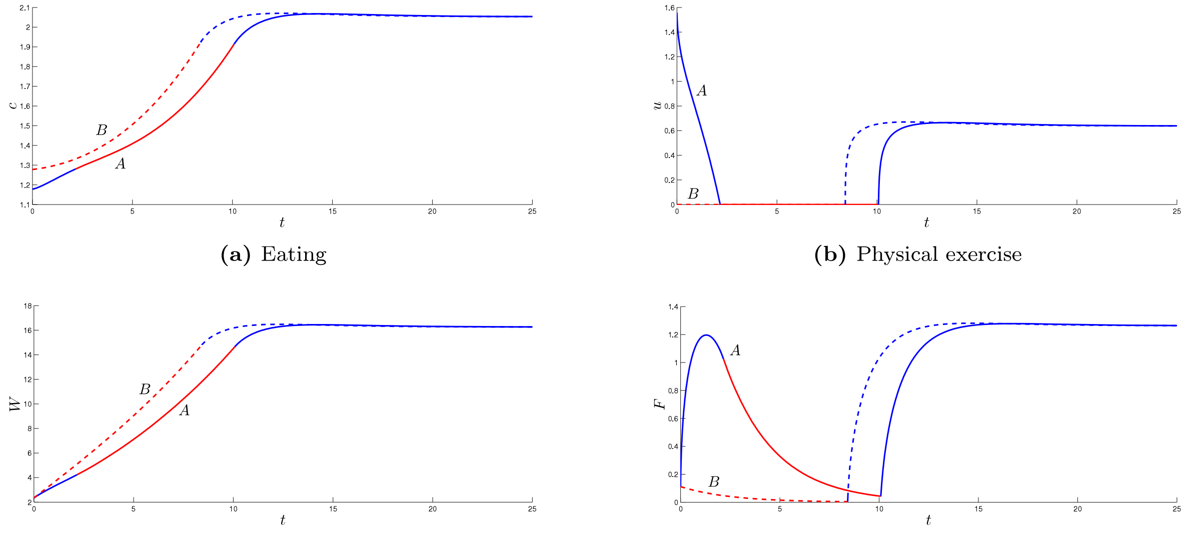
[14] For a similar result in other health-related models, see Dockner and Feichtinger (1993)'s rational eating model and Cawley and Dragone (2024)'s harm reduction model.

[15] The set of initial conditions with these features is known as a Skiba curve (Skiba, 1978). The location of such Skiba points and the comparison of alternative lifestyle trajectories are typically obtained through numerical methods, using the values of the intertemporal utility function along specific time paths, as done in this paper. For an introduction and discussion of Skiba points, see Grass et al. (2008). See also Skiba (1978) and Dechert and Nishimura (1983) for seminal works studying Skiba curves in the context of economic models framed as optimal control problems, particularly the one-sector optimal growth problem with a convex-concave production function.

[16] The phase diagram showing the trajectories of the state variables associated to the two indifferent lifestyles A and B is presented in Fig. 5 in the Appendix.

[17] The assumption of a deterministic time of death is strong, but common in individual lifecycle models in health economics and in labor supply models. Note that the No-regret criterion proposed here holds both when time T is exogenously given, as in Heckman and MaCurdy (1980), and when it is endogenously set, as in, e.g., Grossman (1972) and Dalgaard and Strulik (2014).

Optimal time paths of two indifferent lifestyles



(a) Eating (b) Physical exercise (c) Body weight (d) Fitness level

Fig. 2. Time trajectories of eating, physical exercise, body weight and fitness level associated to the indifferent lifestyles A (solid line) and B (dashed line) described in Fig. 5. The trajectories have the same initial and terminal conditions of body weight and fitness level (panels c and d). Red portions of the trajectories denote periods of no physical exercise, as indicated in panel (b). Parameters as described in footnote 13, with $p_c = 4.5,\ p_u = 3$.

Definition 1 (*Finite-Horizon Utility*)**.** Let $\mathcal{L}(t) = (c^*(t), u^*(t), W(t), F(t))$ denote, for each t, the vector of state and optimal control variables associated to lifestyle L when the time of death is uncertain. The finite-horizon utility associated to lifestyle L from time zero to T is

$$P(L,T) := \int_0^T e^{-r_1 t}\mathbb{U}(\mathcal{L}(t))\mathrm{d}t, \qquad T \in [0,\infty), \tag{24}$$

The finite-horizon utility in (24) represents the intertemporal utility experienced from time zero to T, discounted at the subjective rate of time preference r_1. Since the terminal time is treated as predetermined, it does not incorporate the mortality rate r_2. We can now introduce the following tie-breaking criterion:

Definition 2 (*No-Regret Criterion*)**.** Given two indifferent lifestyles A and B, we say that A is preferred to B over the period t_1 to t_2 if $P(A,T) \geq P(B,T)$ for $T \in [t_1, t_2]$.

Intuitively, this means that if death occurred at T, there would be no regret in having followed lifestyle A rather than B, from time zero to T. While the two lifestyles are indifferent under uncertainty about the time of death, conditional on death occurring at T with certainty, lifestyle A is strictly preferred to B.

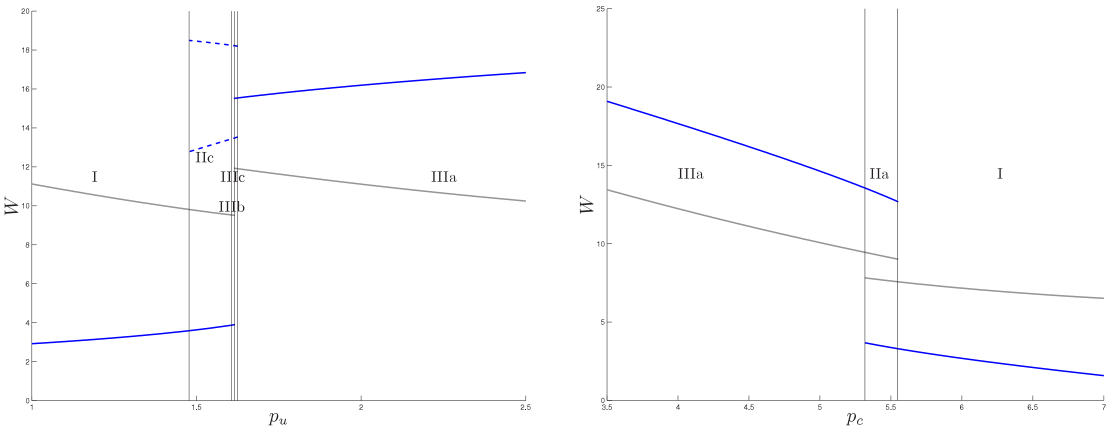
Fig. 6 in the Appendix illustrates the proposed selection criterion by drawing the finite-horizon utility for the indifferent lifestyles A and B described in Fig. 2. The figure shows that an individual is better off with lifestyle A during the first 10 years and better off with B thereafter. Consequently, an individual would prefer lifestyle A if the relevant time horizon T falls within the first 10 years ($T \in [0, 10]$), whereas lifestyle B would be chosen if a longer time horizon is considered ($T \in [10, \infty)$).

4. Policy interventions and regime changes

The model presented in Sections 2 and 3 assumes that individuals are fully rational and forward-looking, with no role for regret, self-control problems, or systematic biases in decision-making. As a result, individual choices are not suboptimal from the individual's own perspective, and the model does not feature inherent market failures or behavioral deviations that would justify corrective intervention.

This framework, however, does not preclude a role for policy. A policymaker may operate under a different objective function than individuals placing, for example, greater weight on long-term health outcomes or on the distribution of health across the population. The policymaker may also account for externalities, such as public health expenditures, or for equity concerns that are not captured in individual utility.

In what follows, we focus on a descriptive analysis of market-based instruments that have been commonly used to address the obesity epidemic. This approach allows us to examine the behavioral effects of policy tools such as subsidies for physical activity or



(a) Changing the cost p_u of exercising (b) Changing the cost p_c of eating

Fig. 3. Long-run optimal body weight as a function of the cost of exercising (left panel) and eating (right panel). Solid blue lines denote steady-state values, dashed lines the minimum and maximum body weight described by a limit cycle. Grey solid (non vertical) lines depict the optimum of the static constrained problem. The vertical lines indicate bifurcation values for p_u and p_c, respectively, which denote a change of regime. See Fig. 1 for a description of the different types of steady states. Parameters as described in footnote 13.

taxes on energy-dense food without specifying a particular social planner problem or comparing individual and planner allocations. Specifically, we study how changes in the cost of physical activity and in food prices affect body weight.

Steady-state changes as a consequence of changes in the cost of physical activity p_u are depicted in Fig. 3(a), while the effect of changes in the cost of calorie intake are shown in Fig. 3(b). The blue curves represent the set of long-run outcomes (steady states with saddle-point stability or limit cycles) in correspondence of each price, everything else being equal. As a reference, the set of optimal body weights obtained when considering the static constrained utility function, is indicated by the gray (non-vertical) curves. As described in Section 2, long-run outcomes above this curve correspond to an overweight outcome, while those below it indicate being underweight.

Fig. 3(a) shows that body weight monotonically increases with the cost of exercising. Specifically, if the cost is sufficiently low, the individual will become underweight for any initial condition. If, instead, the cost of physical exercise is high enough, the individual will converge to the overweight steady state, irrespective of the initial conditions. These results are intuitive. It is interesting to note, however, that there exists an intermediate range of values of p_u where both an overweight and an underweight steady state coexist. In Fig. 3(a), this range corresponds graphically to the area between the vertical lines, which denote bifurcation values of p_u. Since in this range there exist multiple equilibria, which one will be reached depends on the initial level of body weight and fitness. For example, in Region IIc, for low initial body weight the individual is predicted to reach an underweight condition, while for high initial body weight the long-run outcome is predicted to be oscillating over time, without ultimately converging to any specific steady-state value. As the price increases only the overweight equilibrium survives. When this is the case, the past does not matter, as for a high enough price of physical exercise the overweight equilibrium is reached for any initial fitness and body weight condition.

The above considerations support the notion proposed by Lakdawalla et al. (2005), that one of the causes of the obesity epidemics is the increased cost of physical exercise. They also provide a rationale for government interventions that reduce the cost of exercising through, e.g., incentives to physical activity to reduce body weight in the population, as studied in Yaniv et al. (2009) and Calzolari and Nardotto (2017). We contribute to this literature by showing that policy effects can be either progressive or drastic. The latter occurs when the cost of exercise crosses bifurcation values (graphically, corresponding to the vertical lines in Fig. 3), thereby triggering a regime switch. In this case, small changes in the price of exercise can lead to large shifts in behavior and outcomes, as individuals will jump" to the lifestyles that has become optimal under the new economic conditions.

The effect of the price of eating on body weight features the opposite dynamics. As shown in Fig. 3(b)), for high values of p_c, the individual is underweight. However, as the price of eating decreases, the individual gets more and more body weight, until eventually getting overweight. This is consistent with the observation that in modern society the reduced cost of acquiring calories has played a major role in determining the obesity epidemics (Lakdawalla and Philipson, 2007; Cawley, 2015). In analogy to the previous case, there exists a range of prices in which two steady states coexist: an underweight equilibrium, and an overweight one. They are optimally local, in that the specific body weight that different individuals reach depends on their initial body weight conditions (region IIa in Fig. 1). In the range of prices between the two vertical lines of Fig. 3(b), one would expect a bimodal distribution of body weights. However, if the price of eating becomes even lower, only the overweight steady-state equilibrium survives.

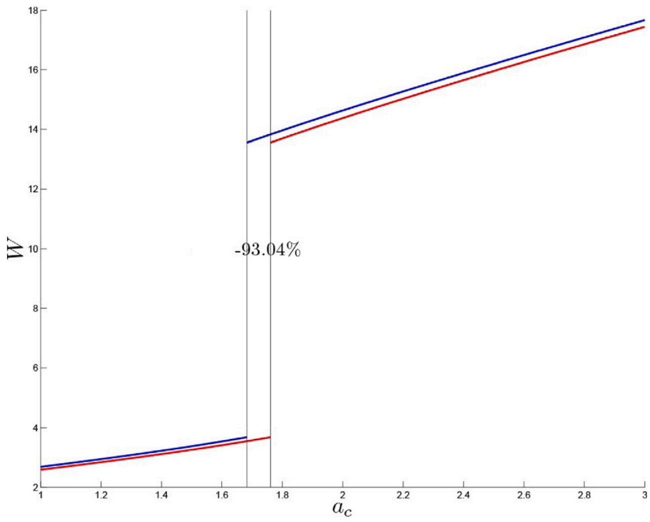


Fig. 4. Taxing food consumption when food taste is heterogeneous. Solid blue lines: steady-state body weights as a function of the individual taste-for-food parameter a_c. Red lines: new steady states after a food tax producing a 5% average body weight reduction. Most of the reduction (93%) comes from individuals switching from the higher to the lower steady state. For this illustration, individuals' taste for food is uniformly distributed and all individuals within the coexistence area are assumed to be at the highest steady state. Parameters as in footnote 13.

The above considerations for a single consumer can be extended to a heterogeneous population. Suppose a policy maker introduces an excise tax to achieve a population-level objective, such as a 5% reduction in long-run body weight. This target reflects the fact that excessive body weight at the population level is a primary concern for policymakers and is commonly targeted in practice.

Because individuals are heterogeneous, they adjust differently to the tax. Moreover, when multiple steady states exist, some individuals may move from a high to a low body-weight equilibrium. These individuals experience the largest body weight and lifestyle change and account for most of the population body weight reduction, despite the fact that the same tax applies to everyone.

Fig. 4 illustrates this result for a heterogeneous population in which the taste parameter a_c is uniformly distributed. The blue line shows steady-state body weights as a function of the taste-for-food parameter. The two vertical lines mark the bifurcation values between which multiple steady states for body weight can coexist. For simplicity, we assume that all individuals in this region are at the higher steady state.[18] As the tax increases, long-run body weight decreases for everyone, but some individuals experience a sharper reduction when the tax induces a switch to the lower equilibrium. Because their adjustment is much larger than that of individuals whose body weight changes only slightly, they account for most (93%) of the 5% population-level reduction.

5. Conclusions

In this paper, we propose a rational choice model of obesity to study lifestyle choices related to eating and physical exercise. Because body weight and the fitness condition change gradually over time, past behaviors influence present utility, which in turn influences future choices. This perspective is consistent with the economic approach to risky health behavior, where health is a component of the utility function and treated as one among many valued outcomes (Grossman, 1972, 1993; Becker et al., 1991). Accordingly, utility maximization may result in health outcomes that fall short of the clinical ideal, or public health targets, even when individuals are fully aware of the future consequences of their choices.

This intertemporal perspective emphasizes that individuals face trade-offs between the immediate utility derived from a given behavior and its potential long-term consequences. This contrasts with static analyses that overlook how current behavior affects future outcomes. It allows for choices that involve short-run costs — such as exercising or limiting food intake — when these yield long-run benefits. Conversely, individuals may chose to obtain immediate rewards, like enjoying food, as long as they accept the associated long-term health and utility costs. Notably, this conclusion is obtained without the need of considering behavioral biases or informational deficits, hence providing a perspective that complements existing approaches attributing obesity to behavioral biases (Calitri et al., 2010), time-inconsistent preferences (Laibson, 1997; Ikeda et al., 2010), or cognitive limitations (Muraven and

[18] These assumptions are made for simplicity, as the qualitative results do not depend on the assumptions about the distribution of a_c or on the allocation of individuals between the two coexisting steady states.

Baumeister, 2000; Baumeister, 2018). Although such explanations may apply in particular cases, they fail to explain the persistence of obesity among informed and unbiased individuals.

We show that, in the long-run, three possible types of equilibria can be reached. In the first one, an individual maintains an optimal body weight, eats to satiation, and engages in excessive exercise. In the second one, the individual is overweight, follows a restrictive diet, and overexercises. The reason this seemingly suboptimal outcome is optimal and stable is that reducing or preventing obesity involves time and resources that may outweigh perceived benefits for some, making weight loss a suboptimal choice. As a result, the model implies the possible existence of an optimal non-zero level of obesity in the population. In the third type of long run equilibrium, the individual is underweight and consumes food beyond satiation. This case is possible if, e.g., individuals have a very fast metabolism or have a taste for physical exercise. Accordingly, they overconsume calories, and yet remain underweight.

These three types of equilibria can be reached according to a variety of trajectories of eating behavior, body weight, physical activity, and fitness levels over the lifecycle. In the simplest cases, these trajectories follow monotonic patterns in which a gradual increase in body weight is accompanied by a gradual decline in physical activity over time. In other cases, the trajectories exhibit oscillatory behavior in which, for example, people experience periods of their lives in which they are physically active and fit, followed by periods in which they are inactive. The latter outcome is more likely the more interdependent are eating, physical exercise, fitness condition and body weight. We also show that the model allows for different lifecycle patterns of behavior to be optimal. When this is the case, some individuals can fully offset a lack of physical exercise and restrained food consumption in the early stages of life by committing to these behaviors in later stages. This results provides a theoretical rationale for delayed remedial interventions in health behavior, along the lines of Cunha and Heckman (2007)'s pioneering work on remedial interventions in education. It emerges as a consequence of the non-concavities of the model, which can generate multiple optimal trajectories that yield the same lifetime utility. Accordingly, we label these trajectories as Indifferent Lifestyles and propose a No-regret criterion to choose among them, based on intertemporal utility over a predefined, finite time horizon T. Accordingly, when confronted with indifferent lifestyles as candidate solutions of the consumer's intertemporal problem, an individual would select the one that provides highest utility over the first T years. To our knowledge, this type of selection criterion is new in the literature.

All outcomes presented in this paper are the result of choices made by a fully rational, forward-looking individual. As a result, individual choices are not suboptimal from the individual's own perspective, and the model does not feature inherent market failures or behavioral deviations that would justify corrective intervention. This, however, does not preclude a role for policy. If obesity results from individually optimal behavior, then interventions focused on information provision or behavioral nudges may have limited impact. More effective policies may be those that alter the underlying trade-offs—such as reducing the cost of healthy food, improving access to physical activity, or alleviating time constraints. Moreover, since the model also allows for the coexistence of multiple equilibria, individuals may find themselves trapped in a suboptimal health equilibrium, such as being overweight and unfit, even when they are aware that a healthier state is preferable. In such cases, policy interventions may be needed to help individuals transition out of self-reinforcing, unhealthy equilibria.

More broadly, a policymaker may operate under an objective function that differs from that of individuals—for instance, by placing greater weight on long-term health outcomes or the distribution of health across the population. The policymaker may also consider externalities, such as public health expenditures, and equity concerns that are not reflected in individual utility. Thus, even in the absence of market failures, policy interventions can be justified. Empirical research has already examined some of the channels through which a policy maker can affect individual obesity-related choices. Examples include the role of education in dietary choices and body weight (Devaux et al., 2011), the influence of food prices (Cawley, 2015; Cawley et al., 2021), and the impact of time preferences on obesity (Courtemanche et al., 2015). These factors are not only empirically relevant but also consistent with our model: education can affect the (perceived) marginal utility of food and its implications for body weight, while prices and time preferences influence the full cost of maintaining a given body weight and fitness condition. Accordingly, the model can be useful for the formulation of testable hypotheses for future empirical work. Structural estimation of the parameters of the model related to the dynamics of body weight and fitness, as well as the individual preferences, may be useful to study the interaction between genetics and environment along the lines of Cawley et al. (2019) and Biroli et al. (2025). Other promising venues are the investigation about individual awareness about own health condition (Arni et al., 2021), the role of fitness and body weight on mortality risk (McAuley et al., 2016), and of technology-based exercise programs on health (Kókai et al., 2025).

Notably, the model allows for bifurcation points in the parameter space. At these points, small changes in the parameters that describe the economic environment can lead to abrupt shifts in individual behavior and health outcomes. This contrasts with the idea that small changes in exogenous variables — such as the price of physical exercise — produce small behavioral adjustments. When a policy variable crosses a bifurcation point, instead, even a minor change can trigger a large, discrete shift in behavior and in the long-run health outcome. In a heterogeneous population, this implies that the effects of a policy applied to all individuals can be concentrated on those segments of the population whose lifestyles change most drastically.

For future research, two possible developments appear to be particularly interesting. First, the present paper does not consider income effects. Nonetheless, the existence of a socioeconomic gradient in obesity is well established and remains relevant for evaluating policies that influence individual income, such as subsidies, transfers, or tax credits. Studying how changes in income affect individual choices over time is a natural extension of the analysis presented in this paper. Second, one could extend the model by specifying a social planner problem and formally comparing individual and planner allocations. This would allow for a structured welfare analysis under alternative policy objectives, such as focusing on long-term health, equity, and possibly including the role of externalities.

A limitation of the current paper is that the individual is assumed to face no self-control problem. That is, the solution to the intertemporal optimization problem is presumed to be implemented without deviations as time goes on. This assumption provides a benchmark for optimal behavior but abstracts from the empirical challenges individuals often face in adhering to well-intentioned lifestyle plans. These challenges arise from time-inconsistent preferences (Strotz, 1955; Laibson, 1997), temptation, and the costs of self-control (Gul and Pesendorfer, 2001, 2004; Loewenstein and O'Donoghue, 2004). Controlled experiments have shown that gym attendance can increase in response to modest financial incentives (Della Vigna and Malmendier, 2006; Charness and Gneezy, 2009; Carrera et al., 2020) or behavioral nudges such as weekly reminders (Calzolari and Nardotto, 2017). Whether these effects persist over time and support the formation of lasting healthy habits remains an open question for future research.

CRediT authorship contribution statement

Davide Dragone: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Gustav Feichtinger:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Dieter Grass:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Richard F. Hartl:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Peter M. Kort:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Andrea Seidl:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Stefan Wrzaczek:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT for proof editing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

We have not received any financial support for this particular research.

Neither myself, nor my partner, nor any close relative have covered any paid or unpaid positions as officer, director, or board member of relevant non-profit organizations or profit-making entities.

No other party had the right to review the paper prior to its circulation.

Appendix

A.1. Necessary optimality conditions

Consider the current-value Hamiltonian function

$$\mathcal{H} = \mathcal{U}(c, u, W, F) + \lambda g(c, u, F, W) + \mu f(u, F) \tag{25}$$

The corresponding first-order conditions are (replacing the law of motions after the second equality)

$$\frac{\mathcal{H}}{\partial c} = \mathcal{U}_c + \lambda g_c = \mathcal{U}_c + \lambda \tag{26}$$

$$\frac{\mathcal{H}}{\partial u} = \mathcal{U}_u + \lambda g_u + \mu f_u = \mathcal{U}_u - \lambda\varepsilon + \frac{\mu}{F} \tag{27}$$

The adjoint variables change over time as follows

$$\dot{\lambda} = \lambda\left(r - g_W\right) - \mathcal{U}_W = \lambda\left(r + \delta_W F\right) - \mathcal{U}_W \tag{28}$$

$$\begin{aligned}\dot{\mu} &= \mu\left(r - f_F\right) - \lambda g_F - \mathcal{U}_F \\ &= \mu\left(r + \delta_F + \frac{u}{F^2}\right) + \lambda\delta_W W - \mathcal{U}_F\end{aligned} \tag{29}$$

given the transversality conditions:

$$\lim_{t\to\infty} e^{-rt}\lambda(t) = \lim_{t\to\infty} e^{-rt}\mu(t) = 0.$$

Differentiating (26) and (27), replacing the values of λ and μ that solve the focs, and using (28) and (29) yields

$$\dot{c} = \frac{1}{\mathcal{U}_{cc}}\left[\sigma_1\mathcal{U}_c + \mathcal{U}_W - \mathcal{U}_{cW}\dot{W}\right] \tag{30}$$

$$\dot{u} = \frac{1}{F\mathcal{U}_{uu}}\left[\tilde{\sigma}_2\mathcal{U}_c + \sigma_3\mathcal{U}_u - \sigma_4\mathcal{U}_W + \mathcal{U}_F\right] - \frac{\mathcal{U}_{uW}}{\mathcal{U}_{uu}}\dot{W} \tag{31}$$

where $\sigma_1 = \delta_W F + r > 0$; $\tilde{\sigma}_2 = \delta_W W + \varepsilon F\left(2\delta_F - \delta_W F\right)$, $\sigma_3 = \left(2\delta_F + r\right) F \geq 0$ and $\sigma_4 = \varepsilon F \geq 0$.

In steady state, $\dot{c} = \dot{u} = \dot{W} = \dot{F} = 0$, which holds when

$$\mathcal{U}_W = -\sigma_1\mathcal{U}_c \tag{32}$$

$$\mathcal{U}_F = -\sigma_2\mathcal{U}_c - \sigma_3\mathcal{U}_u \tag{33}$$

where $\sigma_2 = \tilde{\sigma}_2 + \sigma_1\sigma_4 = \delta_W W^{ss} + \varepsilon(2\delta_F + r)F^{ss}$. Using the specific functional forms proposed in the main text, the Hamiltonian becomes

$$\begin{aligned}\mathcal{H} &= \alpha_c c + \alpha_u u + a_W W + a_F F + \frac{a_{cc}}{2}c^2 + \frac{a_{uu}}{2}u^2 + \frac{a_{WW}}{2}W^2 + \frac{a_{FF}}{2}F^2 + a_{cw}cW + a_{uW}uW + \alpha_0 \\ &\quad + \lambda\left(c - \varepsilon u - \delta_w FW\right) + \mu\left(\frac{u}{F} - \delta_F F\right). \end{aligned} \tag{34}$$

By taking the first derivative we obtain the following first-order conditions for the control variables:

$$\frac{\mathcal{H}}{\partial c} = \alpha_c + a_{cc}c + a_{cw}W + \lambda \tag{35}$$

$$\frac{\mathcal{H}}{\partial u} = \alpha_u + a_{uu}u + a_{uW}W + \mu\frac{1}{F} - \varepsilon\lambda, \tag{36}$$

which, for interior solutions, reduces to

$$c^* = -\frac{1}{a_{cc}}\left(\alpha_c + a_{cw}W + \lambda\right) \tag{37}$$

$$u^* = -\frac{1}{a_{uu}}\left(\alpha_u + a_{uW}W + \mu\frac{1}{F} - \varepsilon\lambda\right). \tag{38}$$

The dynamics of the costate variables are

$$\dot{\lambda} = \left(r + \delta_w F\right)\lambda - a_W - a_{WW}W - a_{cw}c - a_{uW}u \tag{39}$$

$$\dot{\mu} = \left(r + \frac{u}{F^2} + \delta_F\right)\mu - a_F - a_{FF}F + \lambda\delta_w W \tag{40}$$

A.2. Proof of Remark 1

Using the transversality conditions (29) and solving backward the adjoint Eqs. (39)–(40) gives the following expressions for the adjoint variables:

$$\lambda(t) = \int_t^\infty e^{-\left(r+\delta_w F\right)s}\left(a_W + a_{WW}W + a_{uW}u + a_{cw}c\right)\mathrm{ds} \tag{41}$$

$$\mu(t) = \int_t^\infty e^{-\left(r+\delta_F+\frac{u}{F^2}\right)s}\left(a_F + a_{FF}F - \lambda\delta_w W\right)\mathrm{ds}, \tag{42}$$

From (38) it follows that $u(t) = 0$ is optimal if

$$-\frac{1}{a_{uu}}\left(\alpha_u + a_{uW}W + \mu\frac{1}{F} - \varepsilon\lambda\right) \le 0. \tag{43}$$

Let us assume for simplicity that equality only holds at one t (and not on an interval). Then the above expression becomes

$$-\frac{1}{a_{uu}}\left(\alpha_u + a_{uW}W + \mu\frac{1}{F} - \varepsilon\lambda\right) < 0. \tag{44}$$

As $a_{uu} < 0$ and $a_{uW} < 0$ the following expression is a necessary condition:

$$\alpha_u + a_{uW}W < -\mu\frac{1}{F} + \varepsilon\lambda, \tag{45}$$

which means that the static incentives for exercising (left hand side) are lower than the dynamic consequences on the fitness condition and exercising, as measured by the corresponding adjoint variables μ and λ (right hand side).

To prove the assertion of Remark 1, consider three cases:

(a) $\mu < 0$. This requires $\lambda > 0$ (see 42), which in turn needs a positive a_{cw} and/or a_W, i.e., high body weight is appreciated as it causes a high direct utility and a high marginal utility with respect to consumption.

(b) $\mu > 0$ but W high enough.

- $\lambda > 0$: means a positive a_{cw}, as in case (a).
- $\lambda < 0$. Consider the contrary, i.e., $a_{cw} < 0$ (so no addition). Then $\lambda < 0$ for sure, which implies a low c by the first order condition. This further implies a low W, which contradicts ((45)). Thus, again $a_{cw} > 0$ and/or $a_W > 0$.

(c) $\alpha_u < 0$: if the exercising causes a (strong enough) disutility the lhs can become smaller than the rhs.

A.3. Additional figures

See Figs. 5 and 6.

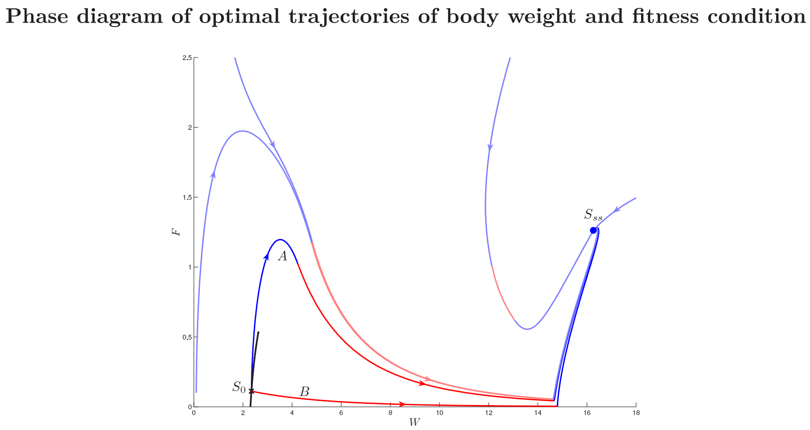


Fig. 5. Phase diagram in the body-weight/fitness-condition space for $p_c = 4.5$, $p_u = 3$ and the parameters described in footnote 13. All optimal trajectories converge to the unique overweight steady state S. Trajectories A and B correspond to indifferent lifestyles with equal initial and terminal conditions and equal value function. Red portions of the trajectories denote periods of no physical exercise ($u = 0$); blue portions denote periods where some physical activity ($u > 0$) is optimal. The Skiba curve is in black.

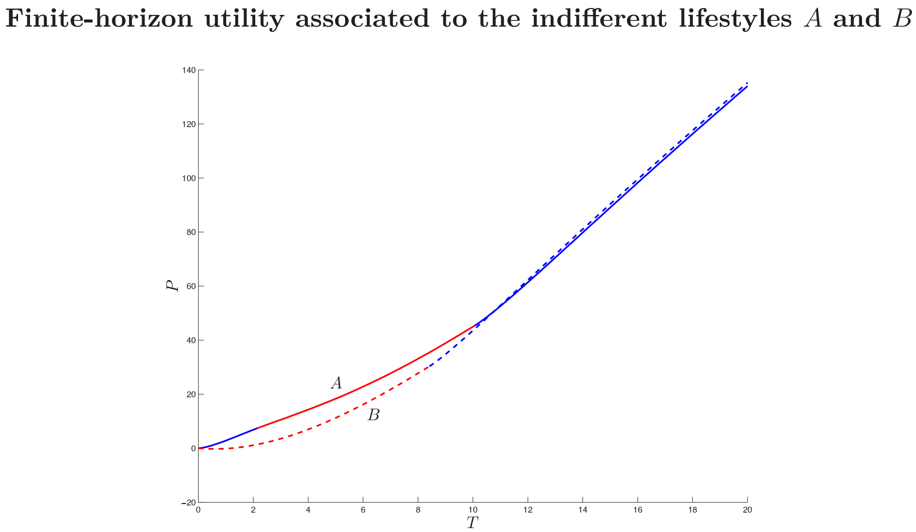


Fig. 6. Time paths of finite-horizon utility, as defined in Eq. (24), corresponding to the indifferent lifestyles A and B depicted in Fig. 5. Lifestyle A dominates B when the agent is younger, and the reverse holds at older age. Since the two paths describe indifferent lifestyles (and the survival rate does not depend on body weight or on the fitness condition), the associated values of intertemporal utility coincide at infinity. Path A: solid line; path B: dashed line. Red portions of the trajectories denote periods of no physical exercise. Parameters as described in footnote 13, with $p_c = 4.5$, $p_u = 3$.

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